THE EFFECT OF CATTLE WINTER FEEDING SYSTEMS ON SOIL NUTRIENTS, FORAGE GROWTH, ANIMAL PERFORMANCE, AND ECONOMICS

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ABSTRACT

Overwintering of cows is a major cost in a cow-calf production system on the prairies. Winter feeding hay and straw directly on pasture is a potentially more efficient and economical system compared to conventional drylot feeding in a yard. The objectives of the research described in this thesis were to compare winter feeding cattle directly on pasture to traditional drylot over-wintering of cattle and the associated mechanized spreading of manure on pasture. This trial compared the effects of winter feeding systems on pasture nutrient distribution, nutrient recovery in soil and forage, pasture forage response, cattle performance, and economics.

The experiment was conducted at Lanigan, SK, on an old russian wildrye grass pasture. Pasture nutrient levels and distribution were measured before and after winter feeding, as well as forage yield, and cattle weight and condition. Nutrient capture and cycling was assessed along with the economics of the different systems. In the pasture fed systems, cattle were fed by either bale processing or bale grazing methods over the winter of 2003-2004. Cattle concentration was 2080 cow-days ha^{-1}, with the cattle in the field for 130 d. In the intensive system used for comparison, cattle were fed in a drylot and 67 tonnes ha^{-1} of raw manure or 22 tonnes ha^{-1} of compost was mechanically spread on the pasture in the fall of 2003.

Soil inorganic nitrogen (N) levels (0-15 cm) measured in the spring where the cattle were winter fed on pasture were 3 to 4 times the unfertilized, unmanured control treatment, with a mean gain of 117 kg N ha^{-1}. Soil inorganic N was not significantly elevated where manure or compost had been spread by machine. Soil extractable potassium (K) was doubled on the winter feeding sites, with a mean gain of 1209 kg K ha^{-1}. Soil extractable K did not increase where manure or compost had been spread mechanically. Soil distribution patterns of both nutrients were highly uneven following pasture feeding, with levels of inorganic soil N ranging from 12 to 626 kg ha^{-1} and extractable soil K ranging from 718 to 6326 kg ha^{-1}. Additional nutrients in surface residue from uneaten feed, bedding, and manure were also heavy and variable following pasture feeding. Greater retention of N and K from urine added directly to the soil in the

field in the bale grazing and bale processing systems compared to the drylot system is believed to be responsible for high soil available N and K levels compared to manure hauled from the drylot into the field.

Soil extractable phosphorus (P) levels (0-15 cm) were measured in the fall of 2005. The compost treatment had the largest increase at 2.6 times the control, an additional 46 kg ha^{-1}. Mean soil P levels did not increase significantly where the cattle were wintered.

Over 18 months and 3 harvests, forage dry matter yields where the cattle were fed on pasture were 3 to 5 times the control where the cattle were fed on the pasture, and 1.4 to 1.7 times the control where raw manure or compost was mechanically spread. Also, protein content of the forage was increased to a greater extent in the in-field feeding compared to hauled raw manure or compost, reflecting a greater conservation of N.

The gain of N in the forage over 18 months on the winter feeding sites was 200 kg ha^{-1} of N, almost double what was measured in soil inorganic forms. Fourteen kg ha^{-1} of P was also recovered. This represented 34% of original feed N and 22% of original feed P that was imported into the field. Recovery of nutrients applied in the raw manure and compost sites was much lower, with only 7% recovery of N and 4% recovery of P in the forage. This was calculated to be 1% of original feed N and 3% of original feed P.

The system by which the cattle were overwintered had little influence on cattle weight and condition. All systems performed favorably in maintaining body weight and condition over the winter. Some slight advantages in cattle weight gain and condition were found on the winter feeding systems compared to the in-yard drylot that appeared to be related to slightly increased feed intake.

Economic calculations favored winter feeding directly on the pasture by 25% over the drylot systems when the feed value of additional pasture growth over 18 months was included and by 56% when the value of additional soil nutrients was factored in. Feed costs were similar between the systems but pasture feeding had savings in machinery use, fuel consumption and manure handling costs, and gains in pasture productivity.

Systems that winter fed cattle directly on pasture provided gains in nutrient cycling efficiencies, pasture growth, and economic savings compared to drylot feeding systems, while maintaining similar cattle growth and condition.

LIST OF ABBREVIATIONS

BG	Bale grazing
BP	Bale processing
FYM	Farmyard manure
RWR	Russian wildrye
N	Nitrogen
P	Phosphorus
K	Potassium
S	Sulphur
Mg	Magnesium
Ca	Calcium
NO_3-N	Nitrate nitrogen
NH_4-N	Ammonium nitrogen
LSD	Least significant difference
DM	Dry matter

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1.0 INTRODUCTION

Cow-calf producers in the northern Great Plains are moving away from over wintering cows in pens in the yard with manure hauled out to the field to in-field wintering systems in which the cattle are fed directly on pasture and the manure (urine and dung) is deposited directly in the field. Anecdotal claims of reduction in expenses for equipment and fuel, improved nutrient retention, increased pasture growth, and an overall cost saving have come forward. However, to date there has been little research on wintering systems to document these effects and support or disprove the claims being made. Nutrient fate and distribution, pasture response, cattle condition, and economic impacts require rigorous scientific investigation. As cattle ranchers face low cattle prices and rising input costs for machinery, fuel, and fertilizer, identification of winter feeding systems that have lower costs and increased returns are important.

The large amounts of nutrients contained in livestock feed itself and the importance of its conservation and recycling into plant production by feeding to animals and capturing nutrients through urine, dung and uneaten feed has been recognized for many years, before the advent of commercial fertilizer nutrients (Kansas State, 1915). The availability of cheap commercial fertilizers and mechanized equipment in western nations that began in the mid 20th century made it possible for livestock production to move into confined drylot systems, with the nutrients excreted viewed as a waste product (Vanderholm, 1979). In third world countries where the conditions of limited availability of commercial fertilizer and mechanized equipment remain, livestock farmers have continued feeding animals directly on crop and forage production areas, with claims of increased nutrient return, greater plant production and reduced overall costs compared to confined drylot systems. One study in Africa looking at these claims reported substantial gains in crop growth by letting animals deposit their manure directly on cropland instead of spreading collected manure mechanically from drylot pens

(Powell et al., 1998). This direct method of animal manure deposition has been suggested by Sommer and Hutchings (1995) and White et al. (2001) as a method that North American livestock farmers could adapt as a buffer against rising costs of commercial fertilizer and machinery. One trial on the Canadian prairies looking at the winter feeding in-field practice of bale grazing (Griffin, 1997) has reported substantial nutrient accumulations on the pasture and greatly increased pasture growth.

A comprehensive, multi-faceted investigation of winterfeeding systems, including soil nutrients, plant growth, cattle condition, and economic impacts was identified as a research need. To address this need, a project was established in central Saskatchewan to compare soil and forage response in cattle wintering systems that feed cattle directly on pasture to wintering systems that conventionally feed cows in a drylot and spread raw or composted manure mechanically. Effects on cattle performance were assessed and an economic analysis of the different systems was conducted.

The objectives of the research described in this thesis are to compare in detail traditional drylot over wintering of cattle and the associated spreading of manure on pasture with equipment, to winter feeding cattle directly on pasture and letting the cattle spread the manure themselves. Specifically the study covers:

1) literature review (Chapter 2)
2) experimental site and set-up (Chapter 3)
3) soil nutrient levels and patterns of accumulation (Chapter 4)
4) forage response (Chapter 5)
5) cattle performance (Chapter 6)
6) economics (Chapter 7)

2.0 LITERATURE REVIEW

2.1 Retention and Distribution of Feed Nutrients by Cattle

2.1.1 Nitrogen

Plant nitrogen (N), which is almost totally in the form of protein, is highly digestible by the cow, with normally over 80% of the N initially absorbed into the animal system (Satter et al., 2002). The N in more difficult to digest material is expelled as dung. The absorbed N that is not used to make meat or milk protein is turned into urea and is mostly excreted in the urine, with a small amount rerouted into the digestive system to feed gut microbes, which are also eventually excreted in the dung. Total retention of N in the beef animal is small. Bierman et al. (1999), reported that of the total N fed to steers in a feedlot environment in Nebraska, only 9 to 10 % was retained in the animals. Similar results were reported by Erickson and Klopfenstein (2001). Most of the N is expelled as urine, as Bierman et al. (1999) reported that 66 to 78% of the excreted N was expelled in the urine and 22 to 34% was expelled in the dung. In dairy cows, only 9% of N was retained (Fisher et al., 2000), but total retention was improved when additional amounts recovered in milk production are considered. Upwards of 90% of the N in the urine is in the form of urea, while the fecal N is present mainly as protein and other organic N forms (Ball and Ryden, 1984).

The large amounts of N that are expelled from the cow provide a significant pool of nutrients that are returned to the pasture in grazing systems. However, conventional drylot feeding of cattle over winter can result in very high losses of N. In Nebraska, Bierman et al. (1999) reported that of the total amount of N excreted from the animal; only 9 to 19% was removed in the manure when the pens were cleaned out. Ten to 15% remained in the soil below the level of the manure deposition, while 5 to 19% was lost as runoff. The remaining 57 to 67% of N excreted was assumed to be lost through volatilization of ammonia. Volatilization loss of N occurs when the N excreted in the form of urea [$(NH_2)_2CO$] is converted to ammonia gas (NH_3) by the urease enzyme (Muck and Steenhuis, 1981). Urease is produced by microorganisms present in the feces (Voorburg and Kroodsma, 1992), and thus the activity of the enzyme in converting urea to ammonia is partially dependent on the mixing of the urine and feces after excretion. Temperature is important in controlling volatilization, as urease activity is low below 10°C but increases exponentially with increasing temperature up to 30°C (Muck and Steenhuis, 1981; Rotz, 2004). As a result, low temperatures limit volatilization losses until spring. Once urea is converted to ammonia the volatilization loss of urine N is rapid, especially on hot, windy days. Paul et al. (1998) measured losses of up to 38% of total urine N plus dung N in the first 24 hrs after excretion in laboratory conditions, while Stewart (1970) found that up to 90% of the N applied was lost to volatilization in 30°C temperatures when urine was applied repeatedly to bare dry soil, compared to 25% when the soil was kept moist.

Farm yard cattle manure (FYM) has been reported to normally have low total N content. Moolecki et al. (2004) and Salazar et al. (2005) both measured N concentrations under 1.5%, of which only 5 to 14% existed as plant available ammonium N. Nitrate N concentrations are typically very low. Other manures such as dairy and hog slurry typically have half of their N component in the volatilizable ammonium form (Beckwith et al., 2002; Salazar et al., 2005). Most of the N that exists in solid FYM is tied up in organic matter that was expelled by the animal in the feces, which along with straw bedding, results in a high ratio of C to N (Mooleki et al., 2004).The high C:N ratio makes FYM very dependent on microbial breakdown of organic matter, with the resultant loss of carbon as CO_2 required to make the N plant available (Qian and Schoenau, 2002). Because of this low availability of readily available N, in Great Britain FYM has been excluded from spreading restrictions designed to limit nitrate losses from slurry and poultry manure (Webb et al., 2001).

N losses from winter feeding cattle on pasture under cold climatic conditions typical of high latitudes have not received much investigation. Summer grazing has received considerably more attention, with the major loss mechanisms appearing to be volatilization, denitrification and leaching. Urine N appears to be the major component from which losses occur (Ball and Ryden, 1984). In a study in subtropical Australia, Vallis et al. (1982) found that ammonia volatilization from urine patches depended on the season, with a higher rate in hot summer conditions and a lower rate in the dry of winter. Ball and Keeney (1981) in New Zealand measured N capture in soil and plants and also found seasonal variation, but in their case the highest losses were under hot and dry conditions and the lowest losses were when conditions were cool and moist. Stout et al. (1997) in the eastern USA found that leaching of nitrate can be another significant source of N loss, with spring deposited urine having about half the loss rates of fall deposits due to uptake by the growing crop. Literature values are summarized in Table 2.1.

Table 2.1 Summary of literature values for losses of urine nitrogen from summer pasture grazing.

Report	**Location**	**Volatilization loss**	**Leaching loss**	**Soil capture**	**Plant capture**
		----------------------------	%	--------------------------	
Ball et al. (1979)	New Zealand	15-18	n.d.	n.d.	22-37
Ball and Keeney (1981)	New Zealand	n.d.†	n.d.	47-69	11-55
Vallis et al. (1982)	Australia	14-28	n.d.	n.d.	n.d.
Stout et al. (1997)	United States	n.d.	18-31	n.d.	n.d.
Williams et al. (1999)	Scotland	n.d.	n.d.	n.d.	37-51

† Not determined

The vegetative or residue condition of the pasture, specifically the amount of bare ground and the resulting tendency to encourage dry and hot soil conditions through lack of shade, may have the largest impact on pasture N loss though volatilization. The findings of Stewart (1970), where up to 90% of the N applied was lost to volatilization occurred when urine was applied repeatedly to bare, hot, dry soil, indicates that losses of N by volatilization would be much higher in pastures with poor ground cover.

Pasture winter feeding area conditions in the northern prairies in which cold winters are followed by cool early springs with moist soil covered by vegetation residue and leftover bedding/feed may be conductive to low volatilization losses. Likewise nitrate leaching may be limited due to low annual moisture combined with early plant growth and N uptake. Runoff and denitrification losses may possibly increase, due to spring flooding from snowmelt and runoff into waterways and ditches. However, Dixon et al. (1981) in a Idaho study found that runoff losses from overwintering cattle on pasture were minimal at a 10 cow ha^{-1} stocking rate. Overall there may be considerably better conditions for N accumulation in the soil of the winter pasture versus that of the manure/bedding pack in a corral. Lenehan et al. (2005) and Griffin (1997) both found large increases in soil N where cattle were winter fed on pasture.

2.1.2 Phosphorus

The element phosphorus (P) has many functions in cattle, including energy transfer and cell membrane structure (Satter et al., 2002). Large amounts are stored in the bones and teeth, which act as a reservoir to some extent against deficiencies. Microbes in the rumen of the cow produce the phytase enzyme, so P bound in the phytate contained in feed is available to cattle (Morse et al., 1992). However, like for N, P retention rates are still quite low, ranging from 15%-16% (Erickson et al., 2000) to 15-26% Cole (1999). Normally almost all of the P is excreted in the dung, with less than 2% in the urine (Wu et al., 2001). If P is overfed in the diet, retention rates are reported to go down (Wu et al., 2001).

When the livestock are fed in the drylot, some P can be lost to runoff, as dust blown downwind (Todd et al., 2004), or accumulated in the pen soil below the manure removal depth, but since P is relatively immobile and does not volatilize like N, retention in the pen manure tends to be high. Related to this, FYM tends to have much higher concentrations of P relative to N than the ratio in the original feed despite slightly higher retention rates of P in the animal. As reported by NRC (2000), the N:P ratio in alfalfa hay and barley straw is around 10:1, while FYM in Saskatchewan has a ratio around 3:1 (Mooleki et al., 2004).

2.1.3 Potassium

Beef cattle require approximately 0.6% potassium (K) in their feed on a dry matter basis (NRC, 2000). Potassium is the major cation in intracellular fluid and has an important role in a number of bodily functions. Retention rates range from 9 to 18 % as reported by Cole (1999). Potassium excretion is almost all in the urine, with Gustafson et al. (2003) measuring a K distribution of 91% in the urine and 9% in the dung. Plant availability of manure K is high as almost all of it is immediately available. Mooleki et al. (2004) found 1.6% K in FYM, similar to N levels. In plants, K has also been noted to be leached rapidly from plant residue material (Lupwayi et al., 2006), as K is present as a free ion in plants and thus not dependent on decomposition for release as is nitrogen.

Once in the environment K does not volatilize but moves slowly through soil (Schomberg et al., 2000), although in prairie soils it is generally considered an immobile cation. Soil K is found in four different forms, which vary from very plant available to unavailable (Kirkman et al., 1994), with amounts in each form variable depending on many different factors.

2.2 Utilization of Dung and Urine Nutrients in Pasture Systems

2.2.1 General

Despite the fact that cattle on pasture return 60 to 90% of the nutrients they consume back to the soil (Haynes and Williams, 1993), over time pastures can become deficient in one or more essential nutrients (Dormaar and Willms, 1998). Related to this, pastures tend to be very responsive when nutrients are added (McCaughey and Simons, 1998; Lardner et al., 2000; Chen et al., 2004), and recovery of all nutrients can be enhanced when those that are deficient are added as fertilizer or manure. Recovery of the added nutrients by the forage varies widely, with N recovery varying from 12 to 112% in studies done by McCaughey and Simons (1998) and Chen et al. (2004) in Manitoba. Lardner et al. (2000) in Saskatchewan found that a large application of broadcast or liquid fertilizer alone or combined with mechanical treatments increased pasture yield and quality, but only in the short term.

The availability of moisture for pasture growth is an important factor in the efficiency of nutrient utilization, with higher annual rainfall areas having increased optimum application rates. Higher rainfall can increase nutrient recovery (McCaughey and Simons, 1998; Chen et al., 2004). However, Harapiak et al. (1992) found that timing of rainfall could also be very important, overriding seasonal amounts in some years. Another important factor is maximum daily temperature as Nuttal et al. (1991) found a negative relationship between pasture yield and maximum daily temperature in a study at Pathlow, Saskatchewan, and suggested that higher temperatures can reduce pasture yield if not combined with higher moisture.

Other factors affecting pasture response to nutrient amendments in general include pasture residue or trash cover and ground compaction. High levels of residue reduce the percentage of bare ground, lower soil temperature by acting as an insulating layer, and increases soil moisture, all of which can substantially increase capture of excreted N (Stewart, 1970). Greater cover also decreases grasshopper population numbers and the resulting damage to the forage (Craig et al., 1999; Onsager, 2000). Ground compaction in pastures can be a problem in reducing forage yield in following years. Cattle have a high ground pressure, measured as 250 kPa when walking (Scholefield and Hall, 1986). This is 10 times the ground pressure of a man. Cattle can therefore cause significant compaction of the soil, especially when conditions are wet. Stephenson and Veigel (1987) found that soil compaction from overwintering cows in Idaho was significant and took more than one season for the pasture to recover.

2.2.2 Manure on pasture

The application of FYM on pastures may have several advantages over application on cultivated ground. Advantages noted by Bittman et al. (1999) include the pasture being able to use large quantities of nutrients, manure application being possible several times in the year and the reduction of leaching and runoff potential due to continuous ground cover. One major drawback is that incorporation of manure is considerably more difficult so traditionally manure has been spread on the surface and left uncovered, which may encourage N loss due to volatilization. However Jolley and Raguse (1981) found that there were no differences in forage yield when FYM was incorporated or broadcast and Mooleki et al. (2004) found that delaying soil incorporation of FYM on cropland by 24 hrs had little to no effect on crop yield or recovery of manure N compared to immediate incorporation. Compared with dairy and hog slurry, FYM is typically very low in plant available mineral N and has a large proportion of N locked up in organic matter (Beckwith et al., 2002; Salazar et al., 2005). This has the effect of reducing volatilization losses after spreading. Salazar et al. (2005) measured ammonia losses of only 11% of total N in FYM over 3 d after spreading, compared to 35-37% loss from spread dairy slurry. Losses from water runoff also appear to be minimized when FYM is broadcast on pasture. Edwards et al. (2000) found that losses of N and P from FYM applied on pasture were low, while Lim et al. (1998) reported that relatively short border strips of pasture without applied manure were very effective at filtering out nutrients.

Reported dry matter yield increases from applying FYM to forages have been significant, although much lower than commercial inorganic fertilizer, averaging around a third of the increase for an equivalent rate of nutrient added. Holt and Zentner (1985) found that applications of 20 tonne ha^{-1} manure every year over a 4 year period increased crested wheatgrass yield by 39% and bromegrass yield by 54% over the control plots, while N recovery from the applied manure averaged only around 10 percent of the total.

There has been little work done on nutrient fate and distribution of nutrients when cattle are overwintered on pastures in the northern prairies. Lenehan et al. (2005) found additional accumulations of 79 kg ha^{-1} N, 181 kg ha^{-1} P, and 3318 kg ha^{-1} K where cattle had been winter fed using round bale feeders while Griffin (1997) recorded an extra 89 to 119 kg ha^{-1} of N as soil nitrate (NO_3) where cattle had been bale grazed. Dixon et al. (1981) in Idaho found that losses of nutrients in runoff water were minimal at a 10 cow ha^{-1} stocking rate, but increased at the 40 cow ha^{-1} stocking rate.

In comparison to in-field overwintering and feeding, more studies have been done on the distribution and coverage of manure when pasturing cattle in the summer. High accumulations of N, P, and K were measured near shade, water sources, and supplemental feeders by Mathews et al. (1994) in Florida. Franzluebbers (2000) reported 147 kg ha^{-1} inorganic soil N close to water sources or shade, decreasing to 56 kg ha^{-1} farther away in the pasture, while Schomberg et al. (2000), also in Florida, found up to 8 times as much P and 15 times as much K close to shade and water as away from it. Gerrish et al. (1995) noted large concentrations of dung where the cattle stood for shade as well as where they watered, and devised fencing and watering systems that greatly increased the uniformity of distribution, although wide variations in dung concentration levels still remained. While dung is the most visible sign of nutrient deposition by cattle grazing on pasture, it covers a much smaller area than urine. Afzal and Adams (1992) estimated that over a grazing season of 120 d, cattle at a stocking rate of 3 animals ha^{-1} would cover 1.5% of the pasture area with dung and 17% with urine. This is especially important as nutrient levels left by cattle in urine patches have been reported to be very high, with deposition varying from 300 to 1000 kg ha^{-1} of N (Ball and Ryden, 1984). Afzal and Adams (1992) in a trial conducted in Wales found that ammonium N in urine patches rapidly converted to nitrate N and built up in the 30 to 40 mm soil depth, with some leaching as deep as 452 mm. Nitrogen levels under dung patties were only one tenth that of urine patches and had little effect on soil N levels below the top 20 mm of soil.

Compared to spreading FYM manure on pasture, even less work has been done on forage yield after wintering cattle on pasture. In one study in the Peace River region of Alberta, Griffin (1997) measured forage yield in feeding areas that were double after one year and quadruple after two years. In one trial that directly compared equipment spread manure to animal spread manure, Powell et al. (1998) found plant biomass to be doubled after cows and sheep were kept in temporary pens overnight on prospective cropland after grazing during the day. This increase was 3 times that found when the equivalent amount of manure was spread from conventional drylots. The increase in efficiency was credited to the capture of urine nutrients in the animal spread manure system.

2.3 Winter cattle feeding systems

2.3.1 Methods of feeding

The first cattle brought to the Canadian prairies in the late 1800's were kept out on the open range all summer and winter, only being corraled briefly for sorting and processing. This approach changed with the harsh winter of 1906-07, when unusually severe weather caused the death of thousands of range cattle (CCA, 2005). Since then the traditional winter feeding method in the northern prairies has been to house the cattle in small sheltered pens, named “drylot” after the lack of vegetation inside compared to a pasture. Here they consume feed that has been harvested and stored over the growing season. In the summer cows and calves again go out to pasture to graze, and the accumulated manure is hauled out to the field and spread in the summer or fall, often after several years. The methods of winter feeding vary widely in feed handling, labour, and equipment (SAF, 2000). Common methods include putting whole large round bales into bale feeders in the pens, or processed and fed out using a feed wagon.

Feeding out in the field or “in-field” feeding over the winter is a relatively recent phenomenon, but one that is rapidly increasing, driven largely by the perception of greater economy and the avoidance of having to haul manure out of the corrals. Improvements in electric fencing equipment, pasture watering systems, and a renewed interest in snow as a watering source has helped make this possible. Common methods include hauling large round bales out to the pasture or field, then grinding and spreading the hay with a bale processor, or unrolling the bales with a bale unroller. Another method is where the bales are set out in the field before feeding and then fed gradually using electric wire to limit consumption (Kallenbach, 2000).

2.3.2 Animal performance and feed efficiency

Although there has been recent widespread adoption of winter feeding cattle directly on fields, there is a lack of information comparing this in-field feeding to feeding in a drylot using the same feeding techniques. There are a few recent trials using alternative feeding methods. McCartney et al. (2004) reported that animals swath grazed in the field consumed more energy than those fed in the drylot, but gained less weight, although body condition score and reproductive efficiency remained the same. The authors suggested that cows grazing swaths required 18 to 21% more energy. Willms et al. (1993) in southern Alberta found that cows kept on rough fescue pastures all winter without artificial shelter and with snow for water had lower average daily gain than cows kept in drylot, but gave birth to calves with the same weight and the same subsequent gain.

2.3.3 Manure handling

When cattle are fed in a pen over the winter, the manure will need to be hauled out eventually to prevent build-up in the pen floor. Manure used to be regarded as a valuable fertilizer during the first half of the century, but as large supplies of chemical fertilizers became available, it became increasingly regarded as a waste product (Vanderholm, 1979). Farmyard manure is typically scraped up from the pen floor during the summer by a tractor equipped with a front end loader or blade. Added effort is made to collect only the manure and not the soil underlying the pen, where many nutrients can remain. In mid summer or in the fall the manure is then loaded up and spread by machine as economically as possible, which often means overloading of nutrients on the land closest to the pens (Henry, 2003).

One variation in the handling of FYM is composting the material prior to spreading it in the field. In the composting process the raw manure is pushed into piles or rows where the decomposition of organic matter drives off some of the carbon in the organic matter as carbon dioxide, freeing up some of the N stored in the organic matter and reducing the volume of the manure by up to 72 percent (Larney et al., 2000). Other advantages include the reduction or elimination of weed seed viability (Larney and Blackshaw, 2003), and the ability to dispose of dead animals in the pile for fast and safe decomposition (Stanford et al., 2000). One disadvantage is that for the composting process to work optimally, the manure should be turned and aerated periodically, which is best done with specialized equipment. There is also considerable loss of N, with Eghball et al. (1997) reporting N losses of 19 to 42%, almost all from volatilization of ammonia.

2.3.4 Economics

According to Kaliel and Kotowich (2002), the costs of traditional pen based winter feeding in the northern prairies is the largest single expense in a cow-calf operation, amounting to 60 to 65% of the total cost of production. Studies have shown there are economic gains to switching to winter pasture feeding. Willms et al., (1993) calculated a winter feeding cost from October to March of $50-61 for grazing on pasture versus $110-125 per cow for feeding in a drylot. McCartney et al. (2004) estimated that swath grazing on a field in the winter for 100 days cost between $70 and $57 less per cow then drylot, and took between 21 and 38% less labour.

None of the cost calculations for pen based versus pasture based winter feeding systems included the value of the manure nutrients or the growth differences in the pasture from applying these nutrients. Peterson and Gerrish (2005) estimated that the loss of 13% of manure nutrients was equivalent to US$910 of commercial fertilizer for a 100 cow herd per year, although this figure seems small as pastures can recycle a large portion of the nutrients applied. Although McCaughey and Simons (1998) reported good response from N fertilization of bromegrass in Manitoba, they still found it difficult to justify N fertilization of low value forages with commercial fertilizer given high N fertilizer prices. This was also noted by Kopp et al. (2003) who found that fertilization of grass pastures with commercial fertilizer carried a significant financial risk as it was only cost effective when moisture was not limiting. Increases in the price of inorganic fertilizer has been suggested to be the most important cause of decreasing forage yields (Jefferson and Selles, personal communication, 2007) due to a decrease in fertilizer use. African farmers have used direct deposition of animal manure to maximize nutrient capture from animals and minimize equipment use due to the high cost to them of commercial inorganic fertilizers, fuel, and mechanized equipment (Powell et al., 1998). Canadian producers have found themselves in a similar situation recently due to increases in the price of commercial fertilizer due to high demand in the cropping industry related to higher prices from alternative fuel production and increases in the cost of natural gas. As well, with continual increases in the prices of fuel and mechanized machinery, alternative overwintering systems have received increased interest. It is possible that winter feeding systems that involve direct deposition of animal manure would benefit Canadian farmers in the same way they have benefited farmers in Africa.

3.0 EXPERIMENTAL DESIGN AND SETUP

3.1 Study Site Description

The experiment started in the fall of 2003 and was conducted at the Termuende Research Ranch located in east central Saskatchewan, near the town of Lanigan. The cattle wintering sites and the spread manure, compost, and check plots for this project were set out on an old established pasture of russian wildrye grass [*Psathryrostachys juncea* (Fisch.) Nevski] (RWR) on the SW quarter of section 27-33-21-W2. Records (Appendix A) indicated that the field had not been fertilized in 2002 or 2003. In 2001, 56 kg ha^{-1} N as 46-0-0 had been applied and 67.2 tonnes ha^{-1} of cattle manure was applied in 2000. The drylot cattle wintering pens and the cattle handling area was located at the Termuende Research Ranch site, 1 km away on the NE quarter of section 22-33-21-W2.

The soil of this field is a Black Chernozem formed in loamy glacial till, and is classified as a mixture of orthic and carbonated Oxbow association soils on mid and lower slopes and calcareous Oxbow soils on upper slopes and knolls, with saline Oxbow soils on some lower slopes, and poorly drained soils in depressions. The surface texture is a loam, and the surface formation is hummocky with gentle to moderate slopes (Saskatchewan Soil Survey, 1992). It is classified as a good agricultural soil of capability class 2 with moderate amounts of organic matter in the A horizon. The major restriction is a slight moisture deficit brought on by the subhumid climate and moderate water holding capacity. Usually these soils are low in available P but high in available K.

During the site preparation in late October of 2003 two soil profiles were examined. One was near the center of the trial area, on high ground, and one was in a depression located immediately beside the trial area. The soil profile on the high ground had a 0-15 cm Ah horizon (black), a 15-36 cm Bm horizon (brownish), a 36-61 cm Cca horizon (whitish and high calcium), and 61 cm and below a C horizon (light brown). There was a sharp boundary between the B and the Cca horizons. The soil texture is a silty clay all the way through the profile. In the depression, the surface horizon was a 0-15 cm Ahe with a 15-25 cm Bt (platy structure) below, followed by a 25-45 cm dark clay band, a 45-60 cm band of clay and sand mixed, a 60-80 cm dark clay layer, a 80-100 cm layer of gravelly sand, and then pure sand 100 cm and below. There was no evidence of calcium carbonate anywhere in the depression profiles. The soil in the depression bore characteristics of an eluviated Chernozem or a humic luvic Gleysol, with mottling indicative of poor drainage.

3.2 Experimental Design

3.2.1 Layout

The winter feeding sites were established in the fall of 2003 as two 220 m X 90 m (2 ha) areas located diagonally opposite each other with a winter watering system located in the center. This strategy was intended to minimize problems in keeping the cattle groups separated while allowing all animals access to water. Each feeding area was then separated into two replicates. The plot sites were laid out to minimize the effect of topographical variation associated with the hummocky landscape, especially two long depressions that ran on either side of the test area. Site design was conducted with the aid of infra-red aerial photos, field inspection on the ground and exploratory soil sampling and observation of profile characteristics.

Once the feeding areas were established (Figure 3.1), solar powered electric fencing was used to keep the cattle groups in the required areas. Solid fencing was used around the watering system at the separation point between the two plots, where pressure on the fence was the greatest.

Portable wind shelters were used to provide protection for the cattle from the elements. The wind shelters were 5 m long X 3 m high, made from 10 cm X 2.5 cm boards on a steel frame.

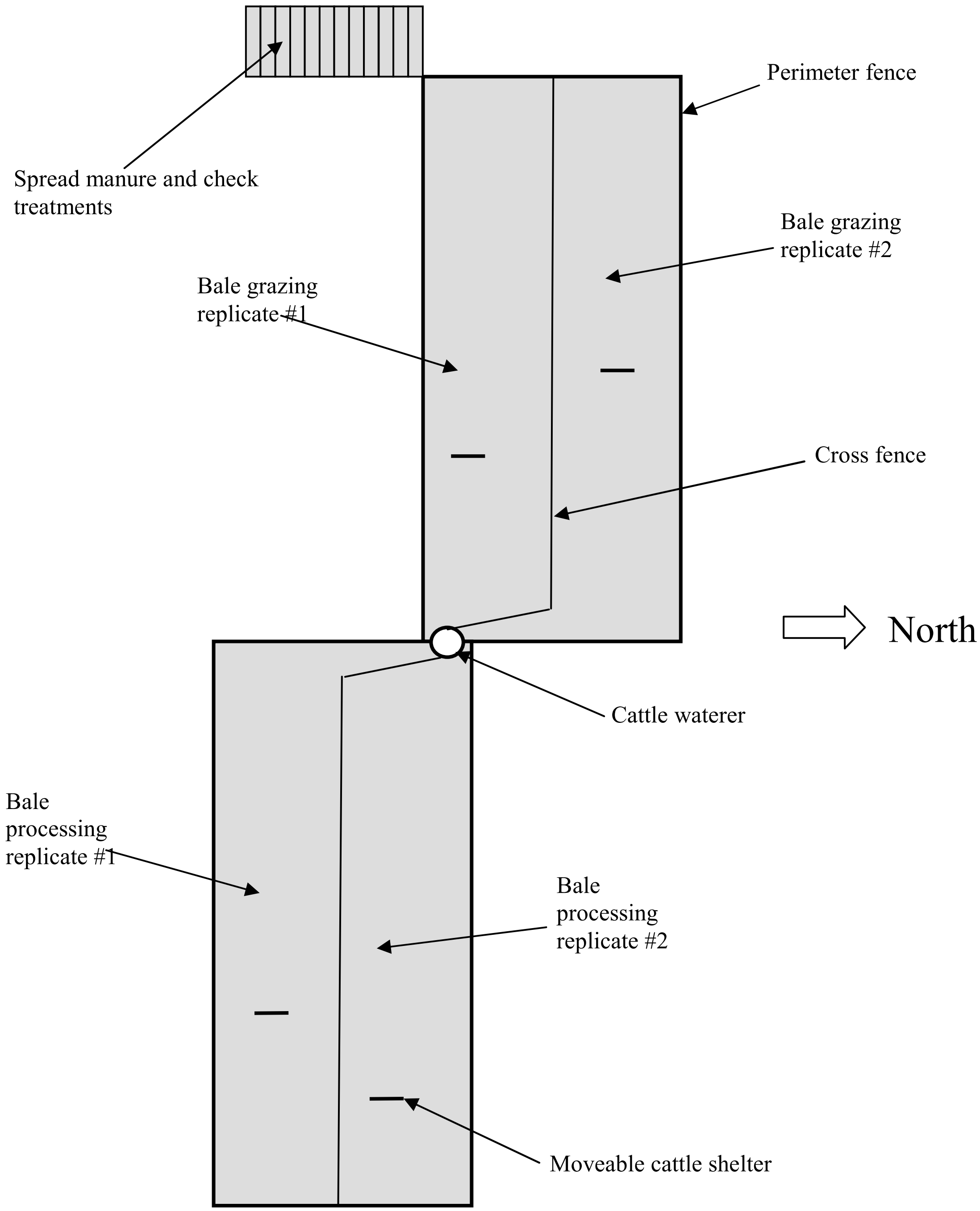

Figure 3.1 The plot layout of the spread manure and the cattle wintering areas on the pasture of russian wildrye, SW quarter of section 27-33-21-W2 (drawn to scale).

The watering system (Appendix B) was installed using a line trenched below the frost from a well located 400m away. It was a relatively new system designed by Kelln Solar using geothermal water heating.

The mechanically applied manure treatments were established beside one corner of the wintering site in a uniform level region of the field. They consisted of three treatments: unmanured and unfertilized check (control), raw manure, and composted manure. Treatment strips were 30 m long X 5 m wide and arranged side by side in a replicated randomized complete block design with four replicates per treatment (Figure 3.2).

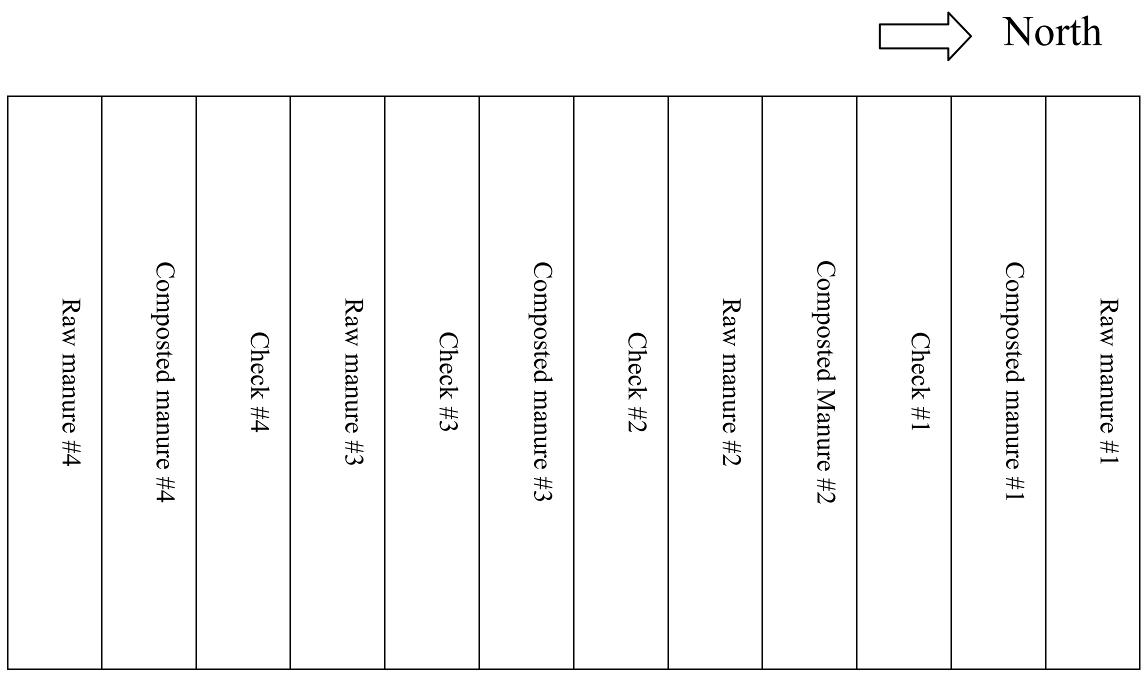

Figure 3.2 A detailed layout of the raw manure, composted manure, and check (unmanured, unfertilized) treatments applied on pasture.

3.2.2 Manure spreading and drylot winter feeding

On October 8th, 2003 a New Holland 679 box-type solid manure spreader was loaded with raw manure from a drylot area where cattle had been fed the previous winter. The spreader was calibrated by making test runs using treatment application at the engine rpm and ground speed to be used and catching the spread manure using a tarpaulin. Settings were then adjusted so that wet manure was then spread at an overall rate of 67.2 tonnes ha^{-1}. The manure was then applied on all four replicates. At the study site it was noted that the spreader did a reasonable job of evenly spreading lengthwise but produced uneven spreading across the plot (Figure 3.3). Consistently, the depth of manure in the center of the spread was lowest; rising to two well defined peaks averaging 2.5 cm in depth either side of center and tapering off again towards the edges.

Figure 3.3 The spread pattern of the raw manure, showing light deposition in the center of the plot flanked by two strips of heavy concentration.

After the raw manure was spread, the spreader was then emptied, cleaned, and loaded with cattle manure from the corrals which had been composted in rows for 24 months. The manure spreader was recalibrated to spread compost at a rate of 22.4 tonnes ha^{-1}, which was estimated at the time to have roughly the equivalent N content of the raw manure. This was then spread on all four replicates. The compost was also spread in a similar pattern to the raw manure. Problems were encountered with bunching caused by lumps of weed material that had been growing on the compost piles.

Four composite samples containing the mixed material from ten sub-samples each were taken for nutrient analysis from both the loads of manure and of compost. The amount of sub-samples taken exceeded the amount deemed necessary by Davis et al. (2002) when sampling solid beef manure and compost for total N and P for results within 10% error at a 95% confidence level. They were analyzed for total N and P using H_2SO_4 digestion (Thomas et al., 1967) and available N and P using water extraction (Table 3.1).

Table 3.1 Nutrient analysis of raw manure and composted manure applied to the pasture site, wet weight basis.

Treatment	Total N	Total P	Total K	Available N	Available P
	kg $tonne^{-1}$				
Raw manure	5.1 b†	1.7 b	4.2 b	.026 a	.042 a
Composted manure	12.4 a	3.5 a	9.3 a	.094 a	.048 a
LSD $_{(0.10)}$	1.61	.32	1.42	.107	.018
	%				
Raw manure	.51	.17	.42	.0026	.0042
Composted manure	1.24	.35	.93	.0094	.0048
	kg ha^{-1}				
Raw manure	343.2	114.4	285.7	1.8	2.8
Composted manure	277.8	78.4	207.6	2.1	1.1

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

The manure samples were kept in a freezer at -20 °C to prevent mineralization and other biological activity until lab analysis. A standard H_2SO_4 analysis (Thomas et al., 1967) was done to determine total N and total P. Initially 0.250 g subsamples of manure (wet) were weighed and put in 75 mL digestion tubes. Two digestion tubes were left blank to check for contamination and two had 0.03 g of glycine added to check for the percent recovery of N. Five mL of sulphuric acid was then added to each digestion tube and the contents shaken with the vortex. The mixed samples were heated on a block digester set at 360 degrees °C for 30 min. After cooling for approximately 20 min 0.5 mL of 30% H_2O_2 (hydrogen peroxide)was added to each tube and they were reshaken on the vortex. The samples were then heated again on the block digester for a further 30 m before cooling and another 0.5 mL of H_2O_2 was added, whereupon the samples were returned to the heating block. This process was repeated an additional five times until the solution turned clear, whereupon the tubes were heated for an additional 60 min to remove all H_2O_2. The samples were then cooled for 20 min after which they were brought up to 75 mL volume with deionized water and shaken on the vortex. Sub samples were then transferred to 50 mL vials and stored in the cooler. Analysis of the total N and P content of the processed samples was then done with a Technion Autoanalyzer II. Analysis of total K was measured using inductively coupled plasma emission spectroscopy (Perkin Elmer Optima 3000 DV).

A water extraction technique was done to determine water soluble N and P. Five g of manure (wet) was added to 15 mL of deionized water and shaken for an hour on a rotary shaker. The resulting suspension was filtered and analyzed for ammonium N and P using a Technion Autoanalyzer II.

Starting November 3rd 2003 thirty-two cross bred cows (*Bos taurus* L.) were fed in drylot pens in the Termuende farmyard. A tub ground ration of mixed straw and greenfeed was fed once a day in bunk feeders with a Farm-Aid mix wagon, with the feeding rate adjusted so that the bunks were approximately at 10% fill in the morning. This ration was fed until February 3rd, whereupon it was changed to an alfalfa/grass hay, straw, and barley grain mix.

Samples were taken from all feedstuffs for further analysis. Ten samples were randomly taken from each source of feed and mixed together. Analysis was done for moisture, protein, and total digestible nutrients at Envirotest labs in Saskatoon.

3.2.3 Pasture winter feeding

Sixty-four cows were allocated to the pasture winter feeding sites on November 22nd, 2003 after being weighed and condition scored. The cows were divided into two groups of 32 for each feeding treatment and then further subdivided into 16 cows per replicate. Based on the assumption that each cow would produce 32 kg d^{-1} of manure (SAF 1997) and that the cows would winter on the trial site for 130 d, the wintering area of 4 ha was calculated to receive 67.2 tonnes ha^{-1} of manure, the same rate as the mechanically applied raw manure. Cattle concentration on the site would be 2080 cow-days ha^{-1}.The cows were weighed every 30 d to assess body weight change and were also condition scored again at the end of the 130 d.

On one of the treatment areas the cows were fed by the bale processing method and on the other by the bale grazing method. In each feeding method the ration was based on 3% of body weight or 18.2 kg d^{-1}, which consisted of 7.3 kg of oat straw and 10.9 kg mixed grass/legume hay. Average hay bale weight was 608 kg on the bale processing treatment and 649 kg on the bale grazing, while straw bale weight was 408 kg for both treatments.

Feed samples were taken by coring round bales with a power drill driven corer. Ten samples were taken for each feedstuff and bulked together. Analysis was conducted at Envirotest labs for moisture, protein, and total digestible nutrients. For the bale processing method a tractor and a Highline 6800 bale processor was used to windrow one hay and one straw bale every 3 to 4 d, with the feeding being side by side in different areas of the paddock each time in a line pattern (Figure 3.4). During the first part of the feeding period the feeding lines extended the length of the paddocks, while in the latter part of the winter the feeding was done across the width of the paddock (Figure 3.5). The widthwise feeding started at the waterer end of the paddock and worked backwards, however it only covered an estimated 2/3 to 3/4 of the paddock area by the end of the trial.

Figure 3.4. View of feeding with the bale processor in mid winter, showing the windrow of hay and straw put out by the bale processor when feeding across the pasture.

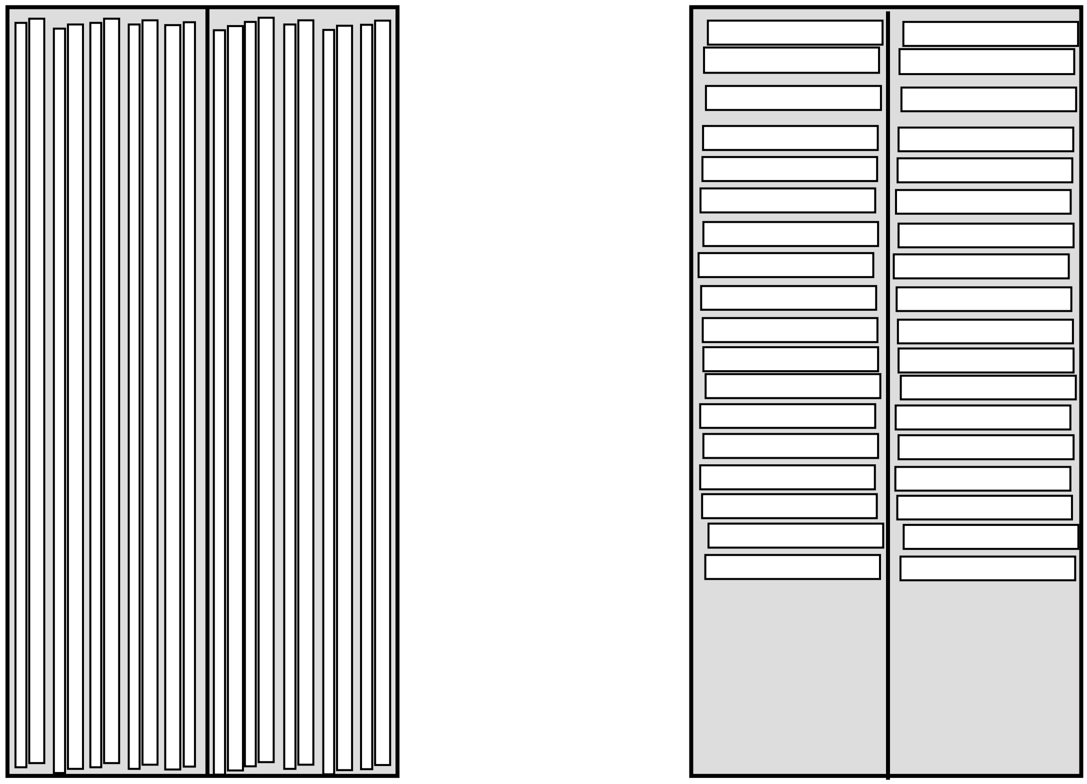

Figure 3.5 Simplified diagram of bale processing feeding patterns showing how the bale processor laid the feed out in lengthwise lines early winter (left) and crosswise lines late winter (right). The waterer was in the top right corner of the paddock.

In the bale grazing method all straw and hay bales were set out on the site during the fall, in 18 rows of 8 bales each (Figure 3.6), alternating hay and straw bales with on-center spacing 10 m apart across the width of the paddocks and 12 m down the length. Access was then controlled with electric wire so the 16 cows in each replicate could access one hay and one straw bale every 3 to 4 d, slowly progressing their way down the field away from the waterer throughout the winter (Figure 3.7). In both feeding methods the amount of feed was adjusted according to winter weather conditions, with supplemental feed supplied as needed during adverse weather conditions. Block salt and 1:1 trace mineral was supplied free choice (Appendix C) to all cows throughout the trial.

Figure 3.6 Bale grazing winter feeding site in early winter, showing actual size and spacing of the hay and straw feed bales.

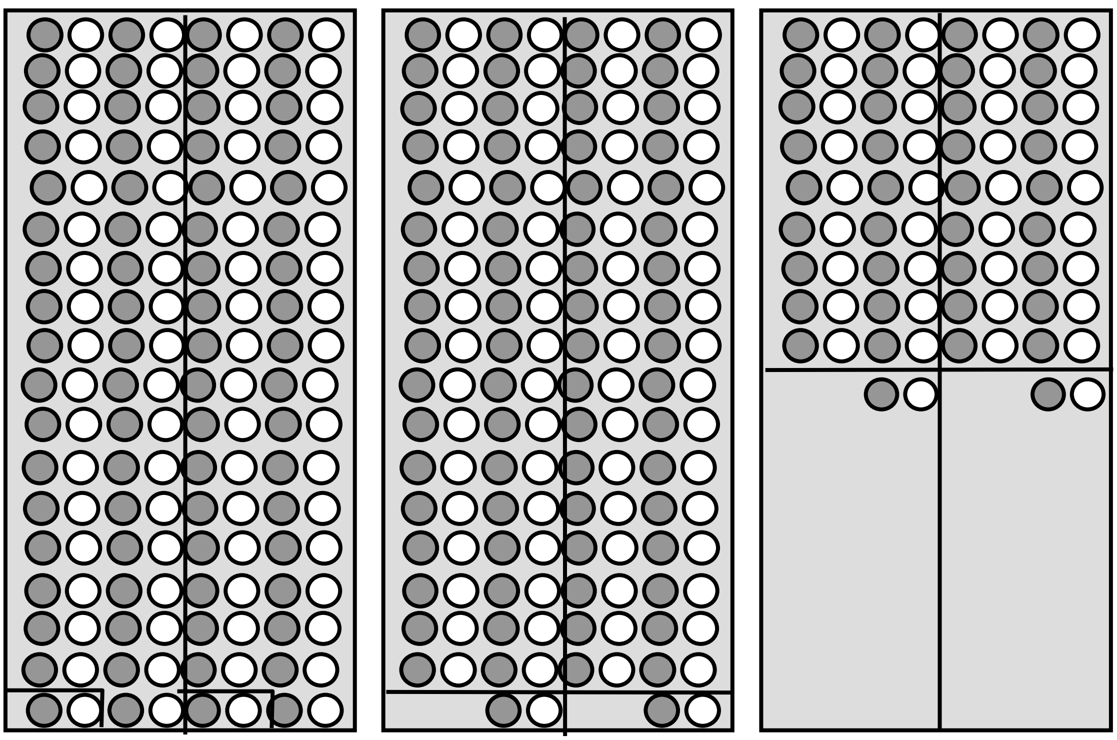

Figure 3.7 Diagram of bale grazing feeding patterns showing feed bale and electric fence locations in the pasture on day one (left), day five (center), and halfway through the 130 day feeding period (right). Dark circles represent hay bales, white circles represent straw bales. The water location is in the lower left hand corner.

On March 31st, 2004 the cows from the pasture winter feeding treatments were removed from the study site, weighed and condition scored (see Section 6.11 for details). The cows in the drylot treatments were weighed and condition scored at the same time.

3.3 Precipitation and Temperature

Environmental conditions in the fall of 2003 were dry, with little precipitation occurring in October (Appendix D). The winter of 2003/2004 was marked with a colder than average period during January, with a mean minimum temperature of minus 26.4°C. The growing season in 2004 was unseasonably cold for the entire period. Moisture conditions were average in May but were followed by drier than normal conditions in June and July and a wet August. During the spring and early summer of 2005 temperatures were also somewhat below average. Here a dry April was followed by average moisture conditions in May and June. Rainfall and temperature were measured during the summers of 2003 and 2004 from a weather station operated by PFRA located on the site. During the summer of 2005 as well as the fall, winter and spring of all years rainfall and temperature were collected from a weather station operated by Agriculture Canada on section 35 which was within 2 km. Long term averages were collected online from Environment Canada using data from 1971 to 2000 at the Guernsey weather station (Latitude 51° 46.800´ N, Longitude 105° 16.800´ W).

4.0 SOIL AND RESIDUE NUTRIENTS

4.1 Materials and Methods

4.1.1 Background sampling and analysis

All the plots were soil sampled in early October 2003 to obtain background nutrient levels prior to manure application or cattle overwintering. The cattle wintering areas were sampled in a grid pattern starting 10 m from the edge of the outside perimeter with samples at 25 m intervals. This resulted in 36 points for each wintering treatment area (Figure 4.1) that were marked out with 7 cm squares of coreplast. At each point a 15 cm soil sample was taken using a dutch auger with a 2.5 cm bit.

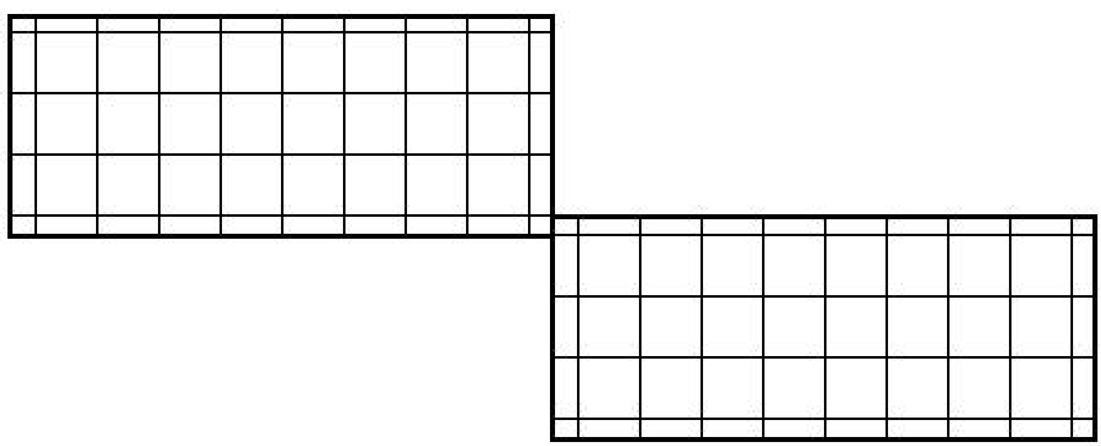

Figure 4.1 The soil sample grid pattern that was used in both pasture winter feeding areas for assessing the background level of soil nutrients.

Soil samples from each treatment of the mechanically spread manure areas were also taken to a 15 cm depth using the same dutch auger with samples taken in a zig-zag pattern down the center of each replicate plot. Four samples were taken per replicate plot and composited. Samples were stored at 4°C until they were air dried. The samples were then ground to pass through a 2 mm sieve, after which they were stored at room temperature in vials.

For nitrate-N and ammonium-N analysis, 5 g of soil was measured into 250 mL extraction bottles. Fifty mL of 2M KCl solution was then added and the bottles were shaken for 1 hr at 142 rpm. The suspension was then filtered through VWR 454 filter paper into 50 mL vials and placed in a cooler. Colorimetric analysis of nitrate and ammonium was done using a Technicon Autoanalyzer II (Keeney and Nelson, 1982).

Available P and K were extracted using a modified Kelowna solution (Qian et al., 1994). Four grams of soil were weighed and placed in a 250 mL extraction bottle where 40 mL of modified Kelowna solution was added and the mixture agitated for 5 min on a shaker. The suspension was then filtered through VWR 454 filter paper and stored in vials in the cooler. Colorimetric automated analysis for P was done using the Technion Autoanalyzer II, but problems with pH of the solutions led to errors in colorimetric determination. Therefore the soil extractable P values were considered to be not reliable for fall 2003 and spring 2004 sampling dates. The problem was rectified and samples were taken in the fall of 2005.

Electrical conductivity (EC) and pH were measured by weighing 20 g of soil into a 250 mL bottle, adding 40 mL of distilled water, then shaking the bottle for 20 m. After standing for 2 hrs the solution was filtered through Whatman #1 filter paper and following this pH and EC readings were taken.

4.1.2 Post overwintering sampling and analysis

The following spring, May 2004, all the plots were soil sampled a second time. For better resolution in the winter feeding areas 4 intensive grids of 12 X 20 m with 45 sample points per grid at 2.5 X 3 m spacing were marked out, one in each replicate area (Figure 4.2).

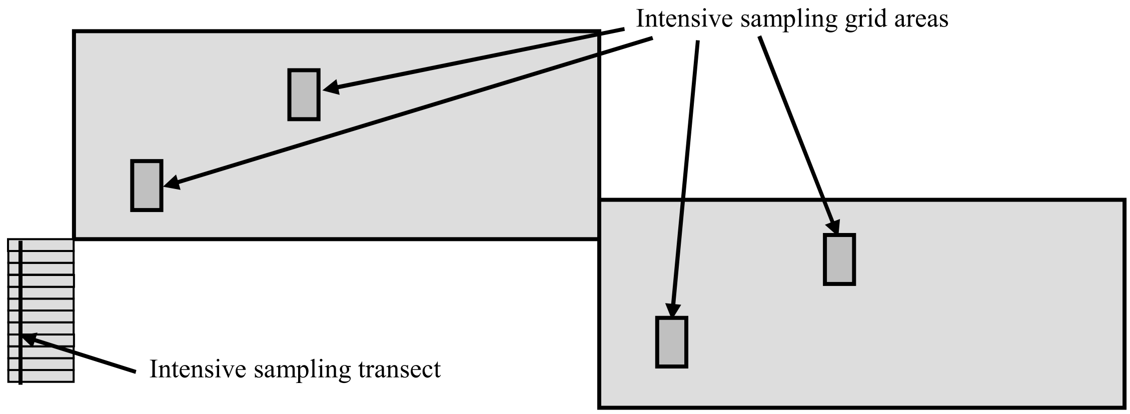

Figure 4.2 Location of the 45 point spring sampling grid areas on the winter feeding pasture sites and the location of the soil sampling transect on the spread manure strips.

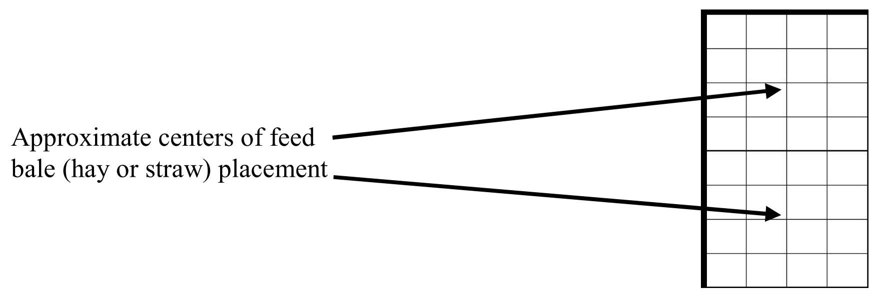

Figure 4.3 Detailed view of the soil sampling grid (12 X 20 m area) on the cattle pasture wintering sites (bale grazing) showing sampling points and locations of bales.

The location of the sampling grids was selected on the bale grazing site so as to include the feeding area of 1 bale of hay and 1 bale of straw (Figure 4.3). The same strategy was then used in the bale processing site. Care was taken to stagger the grid location on the replicates, to place the grids at an equivalent distance from the water source for each feeding treatment, and to also put them in midslope topographical positions.

Soil samples were taken in late May of 2004 by driving 10 cm diameter PVC plastic tubes to a 15 cm depth and removing the intact soil core beneath the surface residue. Samples were stored at 4°C, air dried, and then screened by hand through a 2 mm sieve. Analysis for nutrients was done using the same methods as described for the background samples, as described in Section 4.1.1.

Due to the very high K concentrations encountered 6 samples representing a full range of the K results from the west bale grazing grid were sent to Envirotest labs, Saskatoon SK, and retested (Appendix E).

Surface residue, including manure, uneaten feed, and bedding, was extracted from the soil sampling tubes and bagged separately. Surface residue samples were stored in plastic bags at 4°C until they were spread out and air dried. To avoid loss of volatile N, field moist samples were used in the analysis, with concentrations reported on a dry weight basis by determining the moisture content. Analysis of total N and total P was determined using the H_2SO_4 digestion and analysis used for the manure samples, as described in Section 3.2.2.

Soil samples were taken from the mechanically spread manure areas in late May. Sampling was done in a transect across the plots (Figure 4.2), with five samples taken per replicate plot. Samples were taken along each replicate plot at the 1.0 m, 1.75 m, 2.5 m, 3.25 m, and 4.0 m points, corresponding to the low, high, low, high, and low deposition areas identified for the manure spreader pattern. Sampling was done using a dutch auger with a 2.5 cm bit to a depth of 15 cm, with any remaining residue of raw manure or compost removed beforehand. Processing and analysis was conducted as described for samples from the cattle wintering areas.

The results of all the soil and residue sample point values were used to create field concentration maps using Surfer 8.0 software (Golden Soft. Inc. Golden Col.).

4.1.3 Statistical analysis

For calculation of means and least significant differences (LSD at $p \leq 0.10$) the results of the replicate treatments or transects were analyzed with SAS software (SAS inst. Inc. 1985) using the General Linear Model procedure.

4.2 Results and Discussion

4.2.1 Background soil nutrient levels and distribution

Soil N levels were low on all sites in the fall of 2003 prior to manure application or cattle wintering, with little variation in values (Table 4.1). Similar results have been found in soil tests of other established forage fields that have received little recent fertilization (Lardner et al., 2000).

Table 4.1 Soil inorganic nitrogen (nitrate plus ammonium) levels in the fall of 2003 at the 0-15 cm depth, prior to treatment application.

Site	Mean	Min	Max
	-------------------	kg NO_3-N + NH_4-N ha^{-1}	------------------------
Bale processing	35.2 b†	11.3	52.1
Bale grazing	33.9 b	8.7	65.5
Spread composted	47.4 a	33.0	60.5
Spread raw	36.4 b	32.6	43.0
Check	41.0 ab	33.6	47.1
LSD $_{(0.10)}$	9.4		

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Distribution patterns made using the grid sample points on the future cattle wintering areas and extrapolated with Surfer software showed relatively small variation in inorganic N (Figure 4.4).

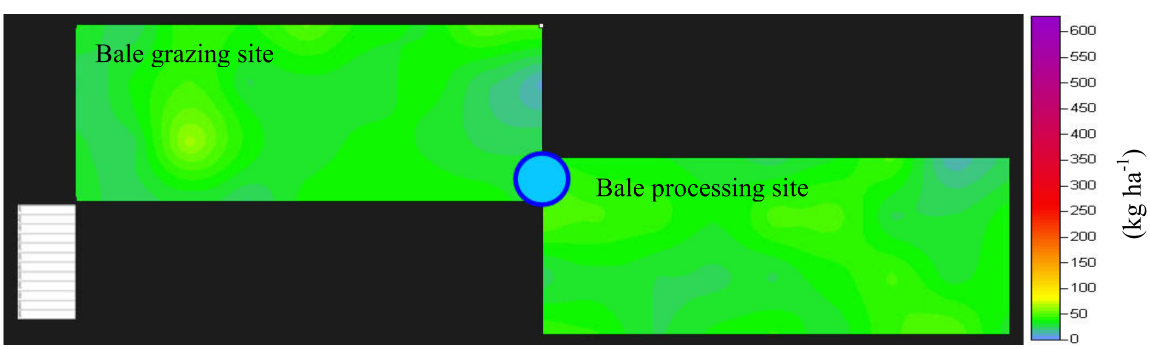

Figure 4.4 Soil inorganic nitrogen (nitrate plus ammonium) field concentration patterns in the fall of 2003 at the 0-15 cm depth.

Soil extractable K levels were high on all sites in the fall prior to manure application or cattle wintering (Table 4.2). While these levels are substantially higher than the Saskatchewan average of 508 kg ha^{-1} for available soil K (PPI, 2005) they are similar to levels seen on other pastures at the Termuende Research Ranch (Lardner, 2002).

Table 4.2 Soil extractable potassium levels in the fall of 2003 at the 0-15 cm depth, prior to treatment application.

Site	Mean	Min	Max
	--------------------------	kg K ha^{-1}	--------------------------
Bale processing	1616 a†	978	2737
Bale grazing	1548 a	841	2488
Spread composted	1400 a	1108	1577
Spread raw	1494 a	1040	2308
Check	1274 a	1060	1440
LSD $_{(0.10)}$	392		

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Potassium showed some variation in nutrient concentration across the study areas (Figure 4.5).

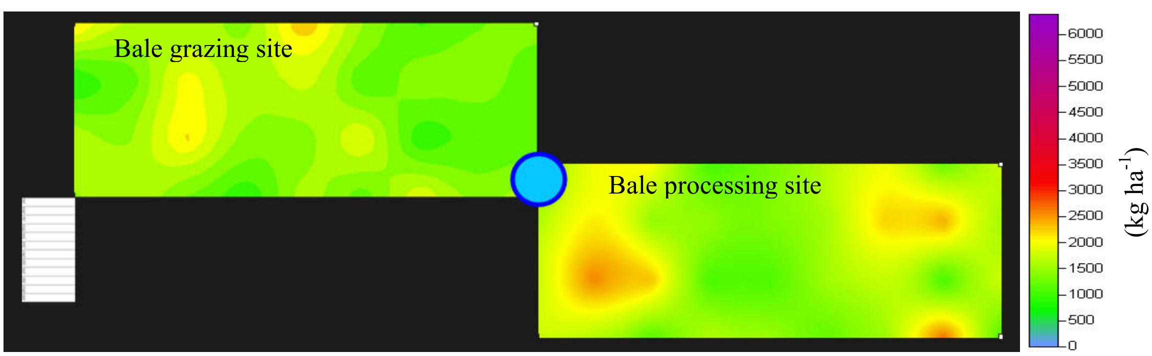

Figure 4.5 Soil extractable potassium concentration patterns across the site in the fall of 2003 at the 0-15 cm depth.

Soil P levels were also tested in the fall but the results were not used due to possible laboratory analysis problems. However background soil tests done for previous pasture trials at Termuende showed very low levels of soil level P, ranging from 3 to 12 kg ha^{-1} in the top 0-30 cm (Lardner, 2002, 2003).

Soil pH averaged 7.4 for all treatments and showed little variation between treatment sites.

4.2.2 Soil nutrient levels and distribution after treatments

4.2.2.1 Inorganic nitrogen

Inorganic N amounts in the mineral soil (0-15 cm) in May of 2004 revealed levels of 3 to 4 times the control treatment where the cattle were wintered, with no significant increases where the manure or compost was spread (Table 4.3).

Table 4.3 Soil inorganic nitrogen levels, spring 2004 in the 0-15 cm depth.

Treatment	Soil levels Mean	Min	Max	Mean
	kg NO_3-N + NH_4-N ha^{-1}			%
Bale processing	186.7 a†	14.8	626.0	375
Bale grazing	146.4 b	12.4	542.2	295
Spread composted	57.0 c	36.8	58.2	115
Spread raw	44.9 c	9.8	59.8	90
Check	49.7 c	15.4	58.0	100
LSD $_{(0.10)}$	36.0			
	kg NO_3-N ha^{-1}			%
Bale processing	141.4 a	8.0	558.4	390
Bale grazing	81.2 b	5.2	365.2	224
Spread composted	38.3 c	18.0	46.8	105
Spread raw	35.2 c	18.0	46.8	97
Check	36.3 c	3.0	49.0	100
LSD $_{(0.10)}$	36.1			
	kg NH_4-N ha^{-1}			%
Bale processing	65.1 a	4.6	438.4	482
Bale grazing	45.4 b	4.2	322.2	336
Spread composted	18.7 c	5.8	17.2	139
Spread raw	9.8 c	3.0	13.8	73
Check	13.5 c	9.6	18.4	100
LSD $_{(0.10)}$	11.8			

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

A mean gain of 117 kg ha^{-1} of inorganic soil N in the winter pasture feeding treatments was observed compared to the check, with a greater amount found on the bale processing site than on the bale grazing. This represents about 20% of the 579 kg ha^{-1} N imported onto the field as feed and bedding for the animals in the hay and straw (Appendix F). The net gain in soil inorganic N found after winterfeeding on pasture was similar to the 79 kg N ha^{-1} reported by Lenehan (2005), who also only tested to the 0-15 cm depth. It was also similar to the 89 to 119 ha^{-1} reported by Griffin (1997), where a deeper 0-30 cm sampling depth was used but only nitrate N was measured. The total amount of soil inorganic N gain per cow over the winter feeding period was calculated as 7.3 kg N with an amount per day of 56.1 g.

The 117 kg ha^{-1} gain in soil N measured in the 0-15 cm depth is 36% of the amount estimated to be released by the animals in urine (Appendix F). This amount is somewhat smaller than the 47 to 69% recovery reported for summer pasture applied urine N in New Zealand by Ball and Keeney (1981). Soil sampling the pasture only to a 15 cm depth may have excluded any inorganic N that had leached deeper. Sampling to greater depths for N has proven useful in trials on summer pasture (Ball and Keeney, 1981; Afzal and Adams, 1992), although these trials are located in New Zealand and Wales which have considerably greater rainfall and leaching potential. There is also potential for inorganic N to be immobilized in the heavy residue present on the surface of the winter feeding sites and not be included in 2M KCl extractable inorganic N from the soil samples.

There was considerable variation in inorganic N levels in the winterfeeding areas, ranging from less than 20 kg ha^{-1} N to over 600 kg ha^{-1} N. This range was considerably greater than that reported by Mathews et al. (1994) and Franzluebbers (2000) who did similar grid sampling with summer pasture grazing in Florida and Georgia, respectively. Approximately two thirds of the soil N in this trial was in the nitrate form and one third in the form of ammonium. Stewart (1970) found that nitrate levels only increased after repeated urine additions when the soil surface in summer conditions remained moist, as a result of rapid nitrification of ammonium to nitrate. It appears that some nitrification to produce nitrate from ammonium also occurred in the pasture soil in this study in the early spring prior to sampling. The high variability in soil nutrient levels after cattle were fed on the field as well as the significant percentage of N in the ammonium form suggests that a large number of cores, and testing for ammonium as well as nitrate would be required to provide an accurate assessment of the available N status. This was also noted by Afzal and Adams (1992) in pasture grazing systems.

Soil N levels were not affected after spreading raw manure or compost on pasture even though the amendments contained 278 and 343 kg ha^{-1} of total N, respectively. This is explained by only 1.8 to 2.1 kg ha^{-1} of the N being in the plant available NH_4 form at the time of application, with no N present as plant available nitrate. The remaining N in the raw manure and compost was tied up in organic matter and release of N from the organic form can be very slow for cattle manure in either the raw or composted form (Qian and Schoenau, 2002). Holt and Zentner (1985) in Saskatchewan found that only 11% of the N in spread manure was utilized after two years, compared to 48% of the N in commercial inorganic fertilizer. Helgason et al. (2007) reported that even when incorporated into the soil, less than 5% of organic N from compost was mineralized in 425 d, and the N response of the crop was directly proportional to the inorganic N content of the compost at the time of application. Similarly, with incorporated raw manure Mooleki et al. (2004) found that over four years only 7-10% of the total N was utilized by the crop. This appears to be the reason why mechanical applications of raw manure or compost in forage trials need to be repeated annually over long periods of time (Holt and Zentner, 1985; Olson and Papworth, 2006) or resort to adding inorganic N to the manure treatment (Beckwith et al., 2002) to supply sufficient N to maximize forage growth.

The patterns of soil inorganic N (Figure 4.6), reveal a close relationship to the placement of the bales in the bale grazing system, while nutrient distribution in the bale processing area is more even. The spread manure and compost areas by comparison showed little to no distinct patterns in soil inorganic N.

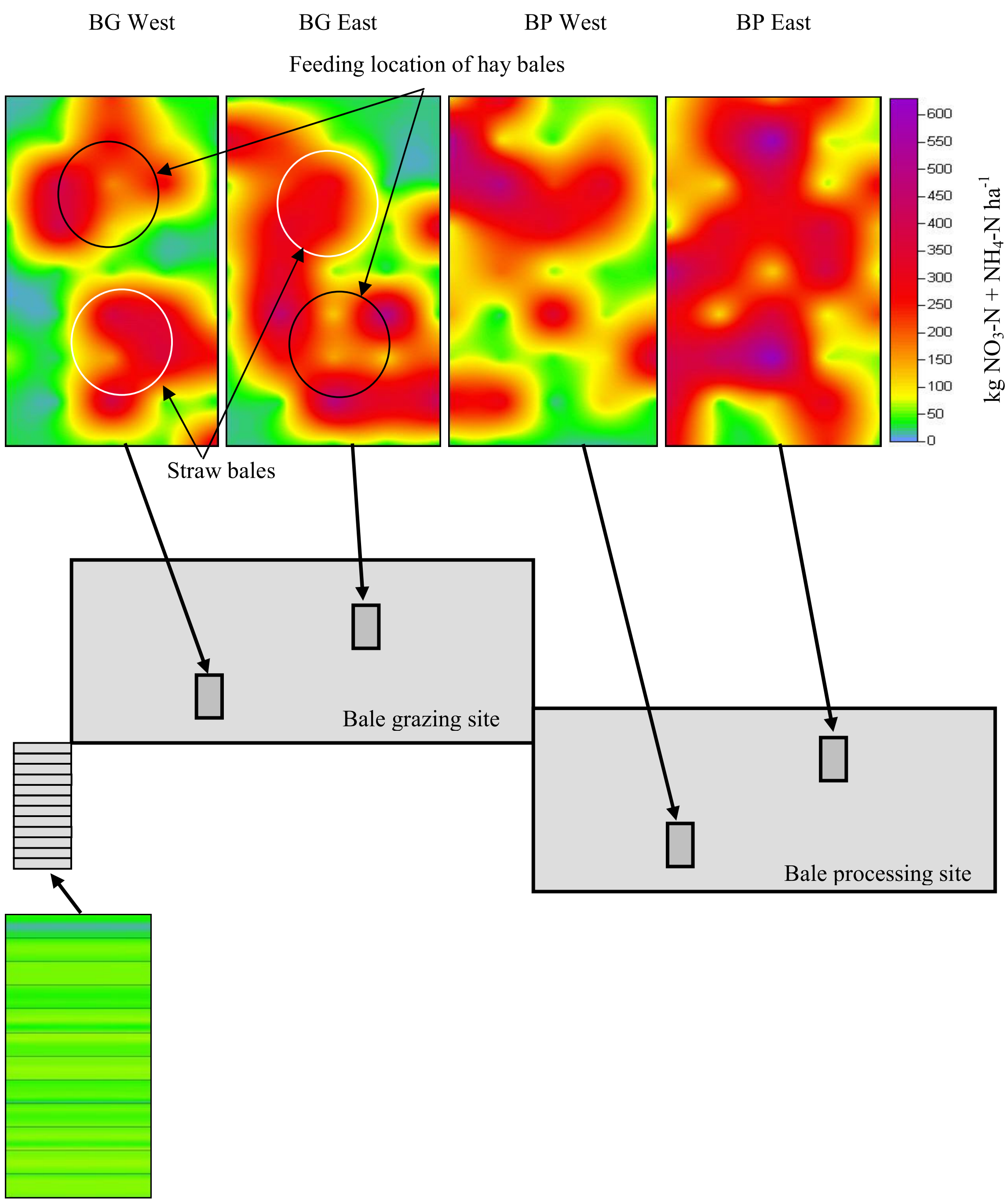

Figure 4.6 Soil inorganic nitrogen (nitrate plus ammonium) in the 0-15 cm depth in four sample areas taken where cattle were winter fed (top) and in the replicated strips where there was manure, compost, or check treatments.

As almost all the inorganic N excreted by cattle is contained in the urine (Ball and Ryden, 1984; Bierman et al., 1999), the soil inorganic N patterns likely follow those of urine distribution. The first sample area in the bale grazing, BG West, shows clear circular concentrations of soil inorganic N where the two bales were fed and a lack of nutrients around the borders, suggesting the cattle spent most of their time around the bales. There is a definite separation in nutrient concentration between the two bales, which can be explained as these bales were fed as parts of two separate hay/straw bale pairs, separated by temporary electric fence. This prevented cattle activity between them until feeding was done and the electric fence was moved. The second sample area in the bale grazing, BG East, was made up of a hay bale and a straw bale that were fed together. High inorganic N levels between the two bales suggest that cattle movement between them was considerable. Nitrogen deposition was similar in the areas where hay and straw was placed; suggesting that feed type did not greatly influence N deposition from urine.

The apparent relationship between cattle activity and soil inorganic N levels is consistent with that found by Mathews et al. (1994) and Franzluebbers (2000) in which high levels of soil inorganic N on summer pasture were found near shade, water sources, and supplemental feeders where the cattle concentrated and spent more time. It would appear to be important in winter feeding on pasture situations to undertake strategies to ensure animals deposit their urine as evenly as possible throughout the field, such as rotating bale placement, bedding areas, and making sure the cattle are not allowed to spend time in non-pasture areas such as shelterbelts or corrals with waterers.

In the bale processing system the round bales were broken up and spread in long windrows, first the length of the field and then across it's width. This overlapping feed and bedding application resulted in a more even distribution of nutrients in the pasture with less recognizable patterns as compared to the bale grazing.

The spread raw manure and compost areas had no obvious patterns in inorganic N, which was consistent with the lack of change in soil inorganic N levels compared with the check.

4.2.2.2 Extractable Potassium

Soil extractable K levels followed the same trend as soil inorganic N, with much higher amounts where the cattle were fed over winter and no significant differences where manure or compost was spread (Table 4.4).

Table 4.4 Soil extractable potassium levels in the spring of 2004 at the 0-15 cm depth.

Treatment	Soil levels			
	Mean	Min	Max	Mean
	------------------------- kg K ha^{-1}	-------------------------		%
Bale processing	2613 a†	932	4850	203
Bale grazing	2381 a	718	6326	185
Spread composted	1363 b	677	2000	106
Spread raw	1449 b	723	2680	113
Check	1288 b	791	2260	100
LSD $_{(0.10)}$	558			

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

The effect of winterfeeding on pasture was an average increase in soil K levels of over 1000 kg ha^{-1}, even larger than the gains in soil N. Large increases in soil K have also been reported by Lenehan (2005) around round bale winter feeding sites in Kansas. While high rates of cattle manure additions are frequently reported to result in large increases in available soil K in other studies (Qian et al., 2005; Olson and Papworth, 2006), it took applications of 2 to 3 kg K ha^{-1} in manure over long periods of time to increase soil levels by 1 kg K ha^{-1}. Considering that 448 kg ha^{-1} of K was estimated to be available in the urine (Appendix F, column H, consumption minus retention minus dung), a single winter of feeding cattle directly on pasture appears to be between 4 to 6 times more effective at increasing soil K levels than multi year trials applying cattle manure mechanically. While there was additional K estimated to be present in the refused feed, bedding, and in the excreted solid manure on the winter feeding, it only amounted to an extra 200 kg ha^{-1}, not enough to make a substantial difference even if it had all leached into the soil.

Greater than expected increases in soil extractable K have also been found when summer pasture grazing (Wolton, 1955). The cause of this increase has been proposed as the effect on the soil of high levels of ammonium ions in urine deposits. High concentrations of ammonium has been found to displace K from cation exchange sites on minerals and interlayer positions on clays, increasing levels of extractable K (Joffe and Levine, 1944). Winter feeding on pasture appears to be acting in the same way in the soil as summer pasture grazing, liberating small percentages of normally unavailable soil K which results in large increases in extractable soil K.

High amounts of extractable soil K can lead to excess amounts being taken up by pasture plants, producing high concentrations in plant materials that can affect grazing animals (Grunes and Welch, 1989). The subsequent elevated levels of K can suppress magnesium and calcium levels in the blood, causing problems such as grass tetany or milk fever. Different species of pasture plants have varying abilities to take up and accumulate soil K, with the highest potential for animal problems in lush spring growth when the tetany ratio K/(Mg+Ca) is above 2.2 (Cherney et al., 2002). A counterbalancing factor may be the high amounts of magnesium and calcium brought onto the winter feeding sites in the hay, 77 kg ha^{-1} and 243 kg ha^{-1}, respectively (Appendix G), which could increase plant levels of Mg+Ca and reduce the tetany ratio. Still, with the high levels of available soil K found in this trial on the winter feeding sites it appears that care may need to be taken when grazing these areas, especially in the early spring.

The complete lack of a significant increase in soil extractable K in the spread manure and compost treatments likely reflects reduced contribution from urine and feed compared to in field feeding. There was 286 kg ha^{-1} of K in the raw manure and 208 kg ha^{-1} in the compost (Table 3.1). Potassium is readily leached from surface residue (Lupwayi et al., 2006) and repeated applications of cattle manure on forages at high rates caused elevations in soil K levels up to 3713 kg ha^{-1} after a number of years (Qian et al., 2005; Olson and Papworth, 2006). However the one other trial found in the literature that used a single years application of cattle manure (Zhang et al., 2006) also did not find any significant increase in soil levels of K. In this trial, leaching on the site over the fall, winter and spring may have not been sufficient to move enough nutrient from the surface applied manure and compost to significantly affect K levels in the mineral soil beneath the thatch.

The distribution patterns of the extractable K on the winter feeding sites (Figure 4.7) were similar to patterns found with inorganic soil N, appearing closely linked to feed and bedding placement. One difference however, is on the bale grazing site, with the highest zones of concentration being where the straw bales were fed, in contrast to soil N being distributed evenly between straw and hay areas. As K is primarily excreted in the urine in cattle (Gustafson et al., 2003), it should follow similar patterns in distribution as the inorganic N deposited from cattle urine. However unlike N, significant amounts of K are held in straw residue, which remained on the field in high amounts. The findings that soil K patterns appear to mainly be related to the distribution of cattle urine supports the conclusion of Wolton (1955) who suggested that soil extractable K levels are enhanced by a reaction of cattle urine with the normally unavailable K contained in soil minerals.

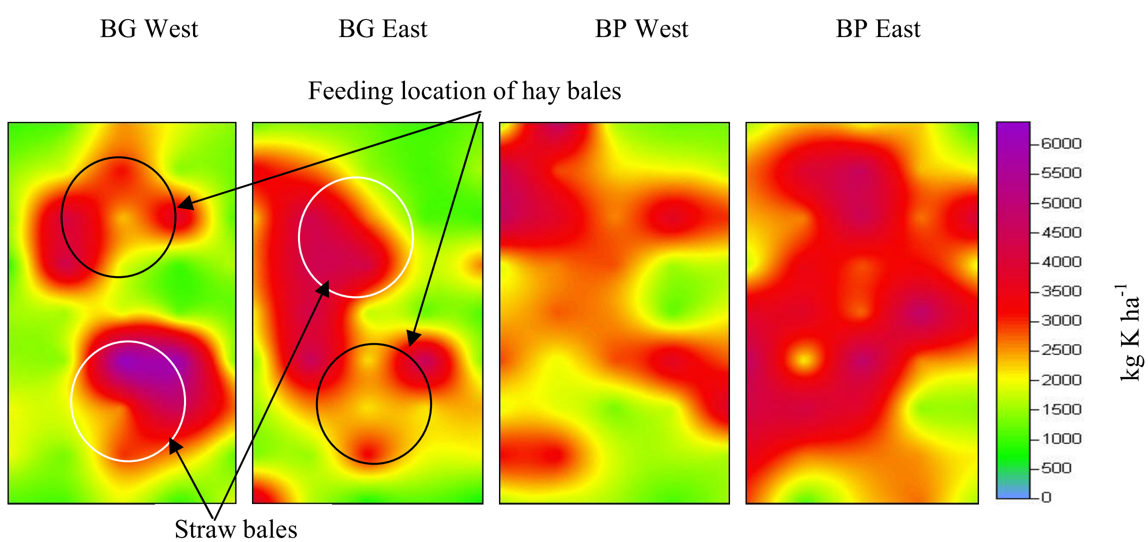

Figure 4.7 Soil extractable potassium in the 0-15 cm depth in four soil sampling areas taken from where cattle were winter fed.

4.2.2.3 Phosphorus

Soil P levels were sampled in the spring of 2004 but were considered unreliable due to laboratory problems in 2004 with the P detection method. The soils were resampled in September of 2005 at the same sampling points (Table 4.4). In contrast to the other soil nutrients tested, the largest increases in soil P being where manure was spread by equipment, and the lowest increases being on the winter feeding sites.

Table 4.5 Soil phosphorus levels in the fall of 2005, 0-15 cm depth.

Treatment	Soil levels			
	Mean	Min	Max	Mean
	-------------------------- kg P ha^{-1}	--------------------------	--------------------------	------- % ------
Bale processing	46.5 bc†	14.6	225.0	169
Bale grazing	51.7 ab	19.4	240.2	188
Spread composted	73.1 a	42.4	98.5	265
Spread raw	56.5 ab	31.3	86.5	205
Check	27.6 c	22.6	36.3	100
$LSD_{(0.10)}$	22.6			

† Within columns, means followed by the same letter are not significantly different according to $LSD_{(0.10)}$

The greater increase of soil P in the spread manure treatments could be explained by the larger amounts of P applied, 78 kg ha^{-1} in the compost and 114 kg ha^{-1} in the raw (Table 3.1), compared to 44 kg ha^{-1} (Appendix F) excreted by the animals on the winterfeeding sites. Eighteen months of P removal through forage clippings before these samples were taken would also have to be taken into account, although P is excreted by the animal almost totally in the dung (Wu et al., 2001) in a stable form not immediately available to plants (Watkin, 1957).

The larger amount of variation in soil P levels found on the winter feeding sites is similar to that found by Lenehan et al. (2005), who found increases in soil P between 16 and 181 kg ha^{-1} depending on how close soil sampling was to where bales were winter fed on pasture.

Soil P distribution maps on the winter feeding treatments (Figure 4.8) are distinguished by large areas of low and even P levels with a few zones of higher concentration. Overall there is less spatial variation than shown for N and K on the nutrient maps.

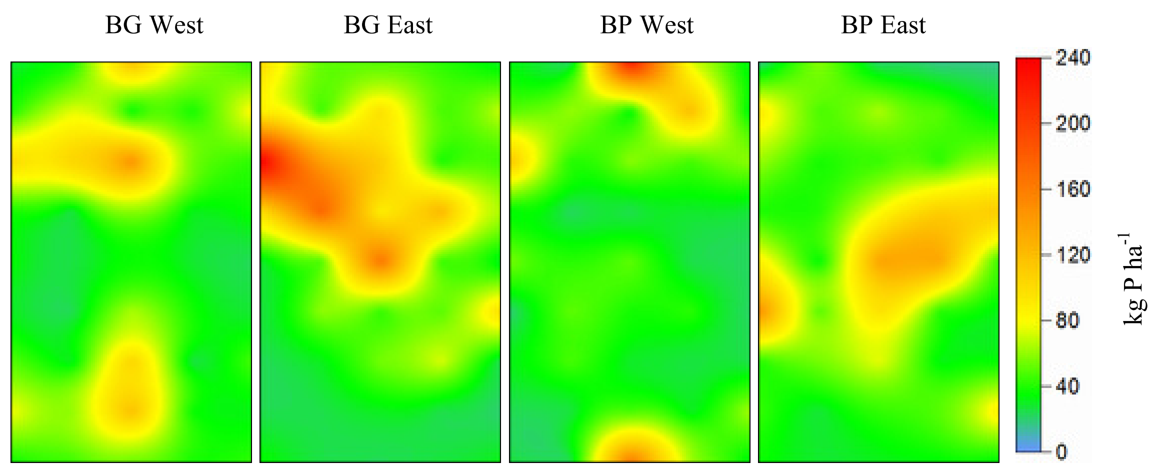

Figure 4.8. Soil phosphorus distribution patterns in the 0-15 cm depth in 2005.

The large areas of low and uniform P concentration can be explained by the comparatively small amount of P calculated to be released onto the winter feeding sites, combined with two years of nutrient removal by forage growth. The smaller zones with high P levels are generally where there was heavy dung and bedding deposition (Figure 4.9) which contained significant amounts of P (Figure 4.11). This surface residue not only could have supplied large amounts of P to the soil, but suppressed plant growth (Figures 4.9, 4.10) which limited P removal in the forage growth in these areas.

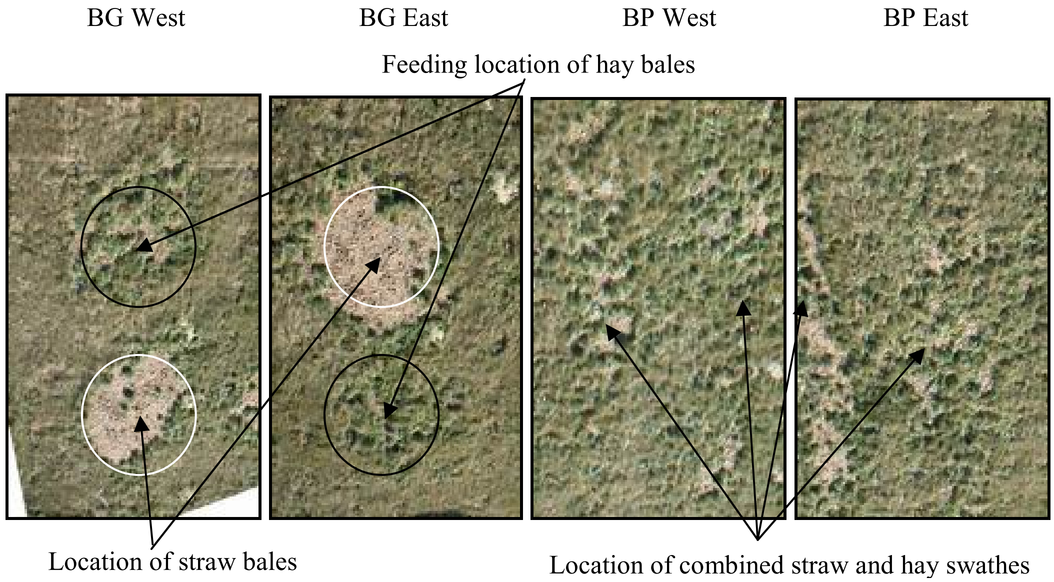

Figure 4.9 Aerial photos of forage regrowth in the sampled areas of the pasture feeding treatments, fall of 2004.

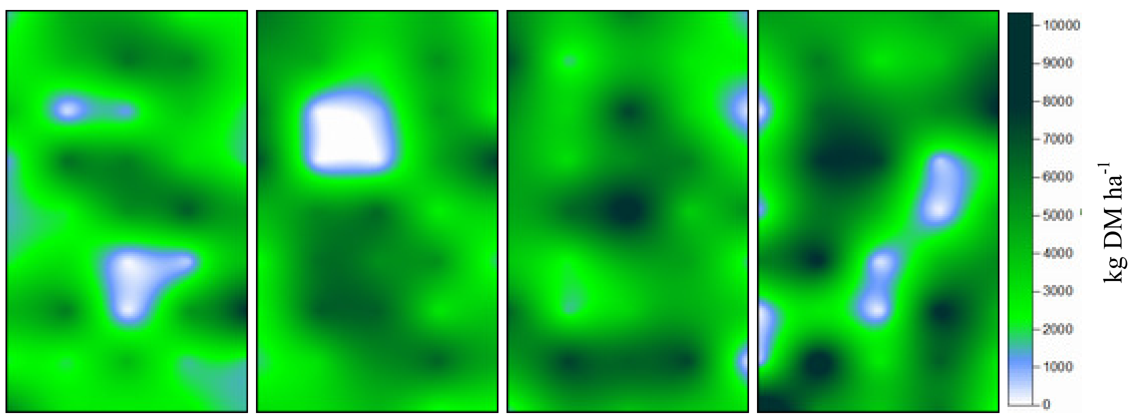

Figure 4.10 Total harvested forage as dry matter in the sampled areas of the pasture feeding sites in 2004.

4.2.3 Surface residue amounts, nutrient levels, and distribution

There was substantial surface residue in the spring after pasture feeding (Table 4.6), with mats of uneaten straw up to 20 cm thick in places, and areas of uneaten hay mixed with manure up to 5 cm thick. Considerably less material appeared to be present in the spread raw manure treatment and no surface accumulation could be seen where compost had been applied, except for the occasional mound where the spreader misfed.

Table 4.6 Surface amounts of dry matter in tonnes ha^{-1}.

Treatment	Residue levels		
	Mean	Min	Max
	---------------------------- kg DM ha^{-1}	----------------------------	
Bale processing	19.4 a†	2.7	82.9
Bale grazing	16.0 a	0.2	131.5
LSD $_{(.10)}$	11.9		

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Variation in dry matter was extremely high on both the bale processing and the bale grazing treatments. As expected, distribution patterns of surface residue (Figure 4.11) generally followed where feed and bedding was placed, in circles where bales were placed on the bale grazing treatment and in north-south lines where the bale processor laid down material on the bale processing treatment. Leftover straw was highly visible and leftover hay much less so.

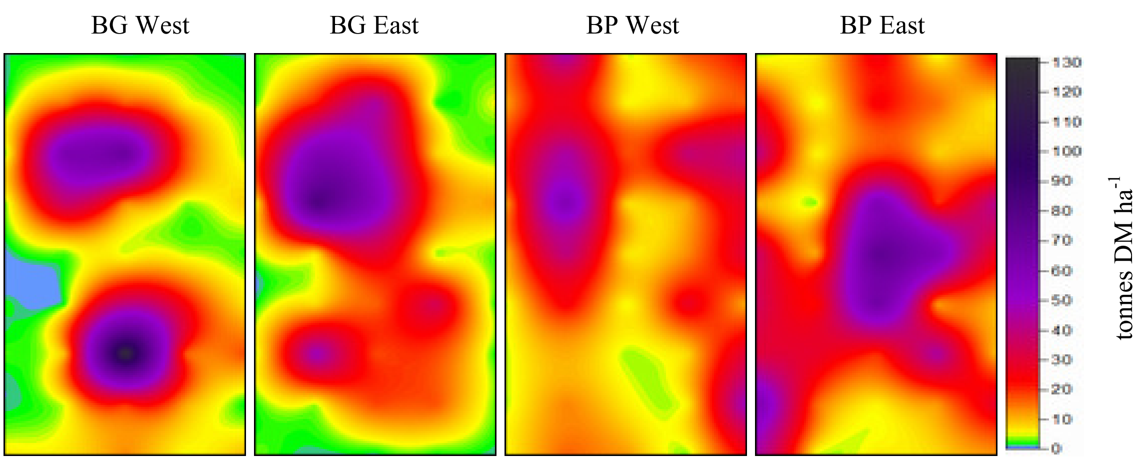

Figure 4.11 Surface residue distribution by weight of dry matter.

The amounts of N in the residue left after feeding on the field (Table 4.7) were substantial with a mean of both winter feeding treatments of 188 kg N ha^{-1}. Variation across the treatment areas was high, with values as high as 1200 kg N ha^{-1} in localized zones.

Table 4.7 Nitrogen levels in winter feeding area surface residue in the spring of 2004 and applied in manure/compost in the fall of 2003.

Treatment	Residue and Manure/Compost Levels		
	Mean	Min	Max
	----------------------------	kg N ha^{-1}	----------------------------
Bale processing	196.5 a†	22.3	994.3
Bale grazing	180.3 a	1.8	1196.2
LSD $_{(.10)}$	106.2		
Spread composted	277.2	N/A	N/A
Spread raw	344.7	N/A	N/A

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

When comparing the rate of raw manure to compost the total N content as spread was 24% higher in the raw manure than the compost, indicating that the compost rate used should have been increased from 22.4 to 27.8 tonnes ha^{-1} so that an equivalent rate of total N was spread in the compost compared to the raw manure.

The patterns of surface residue N after winter feeding (Figure 4.12) were similar to surface residue dry matter weight, which was noteworthy considering that the N content of the hay hauled onto the field was double that of the straw and the manure was concentrated in the areas where the hay was fed. It is possible that the greater thickness of straw promoted capture of N contained in the urine, while in the areas where hay was fed the urine N passed through into the soil. Specific microsite evaluation would be required to support this theory.

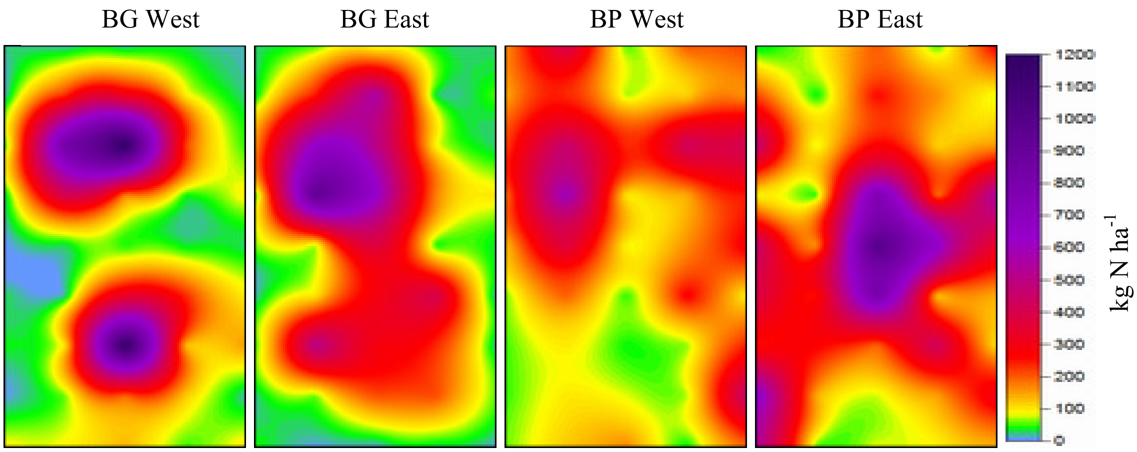

Figure 4.12 Surface residue nitrogen distribution.

The amounts of P in the pasture feeding surface residue (Table 4.8) were much lower than N, averaging about 35 kg P ha^{-1}. Some loss of P may have occurred from leaching into the mineral soil as the estimated total contribution of P was 54.1 kg ha^{-1} (Appendix F). Bromfield and Jones (1972) reported that although it was difficult for moisture to leach out all P from plant material, a large percentage may leach out rapidly. Similar to N, P levels varied considerably, from less than 1 kg P ha^{-1} to close to 300 kg P ha^{-1}. The ratio of total N to P in the surface residue material was 5.3 to one.

Table 4.8 Phosphorus in winter feeding area surface residue in the spring of 2004 and applied in manure/compost in the fall of 2003.

Treatment	Residue levels		
	Mean	**Min**	**Max**
	-------------------------- kg P ha^{-1} --------------------------		
Bale processing	27.8 a†	1.1	194.4
Bale grazing	42.9 a	0.2	287.3
LSD $_{(.10)}$	35.7		
Spread composted	78.5	N/A	N/A
Spread raw	111.5	N/A	N/A

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Phosphorus in the spread raw manure was much higher than that contained in the residue on the pasture feeding sites. The total amount of P spread as raw manure was

42% higher than spread as compost, also indicating that an increase in compost spreading rates would have been required to keep P levels the same as the raw manure.

Residue P distribution patterns (Figure 4.13) were similar to that of the surface residue N. Phosphorus is primarily a nutrient excreted in the dung (Wu et al., 2001), tends to concentrate in the top layers of soil (Royer et al., 2003) and leaches fairly readily from plant material (Bromfield and Jones, 1972). It is not surprising therefore that soil patterns of P were similar to the patterns in the surface residue.

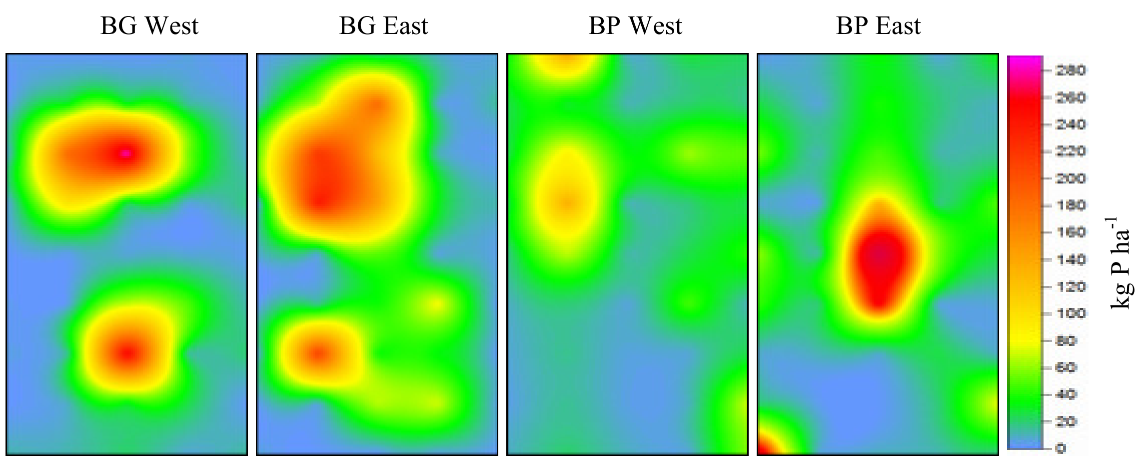

Figure 4.13 Surface residue phosphorus distribution.

4.2.4 Nutrient capture in the pasture feeding treatments

The nutrient balance and capture associated with the pasture feeding process was assessed (Appendix F), using measurements of the amount of nutrients brought on to the field in the feed and bedding and the percent of feed and bedding consumed by the cows. Literature values were used to estimate nutrient retention in the animals and the percent of nutrient excretion in the urine versus the dung. These results were then compared with those from soil sampling and surface residue measurements. For simplicity the results for bale processing and bale grazing feeding techniques were averaged together and reported.

The total amount of material imported to the field in the form of feed and bedding was 38.3 tonnes ha^{-1} with moisture content as fed, or 32.3 tonnes ha^{-1} as dry matter. The total N added was 579 kg ha^{-1}, double the content of the raw manure hauled onto the site in the intensive treatment. Actual animal consumption of N was measured as 501 kg ha^{-1}. With a N retention rate of 10% based on work by Bierman et al. (1999) and Fisher et al. (2000), 451 kg ha^{-1} would then have been excreted by the animals, of which 28% (Bierman et al., 1999) was estimated to be present in the dung and 72% in the urine. This equates to 325 kg ha^{-1} of inorganic N to be added to the soil through the urine as urea.

The quantity of inorganic N actually recovered in the soil was 117 kg N ha^{-1}, which represents a capture of 36% of urine N, somewhat lower than the 47 to 69% reported by Ball and Keeney (1981) in summer pasture grazing in New Zealand. As previously mentioned, only the 0-15 cm sampling depth was used and it is possible that some N had moved below the depth of sampling. Ball and Keeney (1981) based their N recovery on soil N measurements to the 180 cm depth while Afzal and Adams (1992) found substantial nitrate N accumulation from urine application all the way down to the 100 cm depth. It should be noted, however, that both Ball and Keeney (1981) and Afzal and Adams (1992) conducted trials in climates with considerably higher rainfall than found in Saskatchewan. There is also the possibility of urine nutrient retention in the surface residue. Despite the uncertainty over the magnitude of N capture, the high levels of inorganic soil N from winter feeding appears to be the result of the large amount of N hauled onto the field in form of feed and bedding and the conversion of much of this N by the cattle into the inorganic N form that is subsequently excreted as urine.

The N in the dung plus the uneaten feed and bedding totaled 204 kg N ha. The amount measured in the field through sampling and analysis of the surface residue was 192 kg ha^{-1}, 94% of the estimation, and over double the capture efficiency of the urine N. This large amount of N contained mainly in the organic form is consistent with the findings of Mooleki et al. (2004) who found that N in cattle dung and bedding was mainly tied up in the high C:N ratio organic matter. In this form, N is much less prone to loss than the urea form of N expelled in cattle urine.

Potassium added to the field in feed and bedding (723 kg ha^{-1}) was greater than N, due to high K concentrations in the straw. The amount consumed was calculated as 573 kg K ha^{-1}. Using an estimate of 14% retention of K in the animals (Cole, 1999) the amount excreted was 493 kg ha^{-1}. With 91% of excreted K present in the urine

(Gustafson et al., 2003), the maximum amount of K available to be directly added to the soil would be 448 kg K ha^{-1}. However, the gain in soil K found in the soil tests was much greater, averaging 915 kg K ha^{-1}. Additional K in the uneaten feed and bedding was estimated as an additional 194 kg ha^{-1}. Since the gain in extractable K found in the soil after winter feeding was much higher than what could have possibly been added to the soil in the feed, six soil samples from the west bale grazing site, ranging from the lowest to the highest in reported soil K content, were taken to be retested by an independent soil testing laboratory (Appendix E). Results were very similar to the soil testing done at the U of S laboratory, indicating that there were no problems in analysis. Considerable gains in soil K concentrations after winterfeeding cattle has also been found by Lenehan et al. (2005), who reported an increase of 3318 kg K ha^{-1} near where bales were fed after one winter of feeding on pasture. Wolton (1955) who found greater than expected increases in extractable soil K after summer pasture grazing, has proposed that this is an effect on the soil of high levels of ammonium ions in urine deposits releasing normally unavailable soil K. This has been found to occur in laboratory conditions by Joffe and Levine (1944), due to the influence of ammonium on displacing K^+ from surface and interlayer sites on clay minerals.

The total amount of P imported to the field in the feed and bedding was much lower than N or K, averaging 64 kg P ha^{-1}. This was only 50% of that hauled onto the field in the raw manure treatment. The amount consumed by the cattle was 54 kg P ha^{-1}. Phosphorus retention in the animal is higher compared to N and K retention, but still is only about 19% (Erickson et al., 2000; Cole, 1999), leaving 44 kg ha^{-1} to be excreted by the animal. In comparison to N and K, almost all P is in the dung, with 98% of the nutrient excreted there (Wu et al., 2001). Little P is excreted in the urine, only estimated to be 1 kg P ha^{-1} in this trial. The total amount then estimated to remain in the uneaten feed, bedding, and dung was 53 kg P ha^{-1}, of which 33 kg P ha^{-1} was actually measured, giving a capture of 63% in the surface residue. Although increases in soil P from leaching of the surface residue were not measured at the same time, soil measurements taken two years later in the fall of 2005, after 14 kg ha^{-1} of P removal through forage growth (Table 5.7), still showed gains of 22 kg P ha^{-1}. Lenehan et al. (2005) found large increases of soil P close to where bales were fed when winter feeding. Bromfield and

Jones (1972) also reported that the majority of P was quickly leached from plant material. Therefore the retention of the remaining 21 kg ha^{-1} of P in the soil in the spring of 2003 is highly likely.

4.2.5 Cattle spread manure versus machine spread manure

A goal of this trial was to have application rates of raw manure and compost spread by machine equivalent to that deposited by the cattle, so that the relative efficiency of nutrient capture between intensive and extensive systems could be directly compared. Assumptions were made in the trial setup calculations, one being that the weight of dung listed in the literature as excreted by a beef cow per day (SAF, 1997) could be used in direct comparison with the same weight of machine spread manure hauled from a drylot in which those cows were fed.

However, after the current trial was conducted, closer examination of the literature and the data showed that the weight of dung excreted by cows and the weight of stockpiled raw manure hauled from a corral have substantial differences in moisture content. The only other trial found that compares the effects of machine spread to cattle spread manure (Powell et al., 1998) used equivalent dry matter amounts in both treatments. While the moisture content in the excreted cattle manure was not measured in this trial, literature figures are available and fairly consistent. Moisture in fresh manure from a cow is around 89% according to Nennich et al. (2005) and Gustafson et al. (2003), and the SAF (1997) manure excretion trial calculations indicated that the percentage used was the same. The moisture content measured in the spread raw manure of 51% together with an 89% level in the directly excreted manure spread in the winter feeding areas results in 33 tonnes ha^{-1} of manure dry matter spread on the raw manure sites and 7.4 tonnes ha^{-1} spread by the cattle.

However, it also must be recognized that the machine spread manure weight includes bedding and uneaten feed while the excreted manure calculated for the pasture feeding sites does not, and the amount of bedding and uneaten feed in drylot pen manure can be substantial. Larney et al. (2006) stated that feedlot pen material removed in western Canada contains, on a dry weight basis, a ratio of 1 part bedding to 5 parts of manure. In this trial the pasture feeding systems were managed without bunks or feeders, and a larger amount of feed and bedding, especially straw, was left on the ground than in an intensive drylot based system. The amount of uneaten feed and bedding on the pasture feeding areas was measured, with a dry weight average of 5.1 tonnes ha^{-1} of straw and 1.2 tonnes ha^{-1} of hay, or almost as much dry matter as was calculated to be applied by the cattle in their manure. Therefore it appears that under half, (14 tonnes ha^{-1}) of the amount of dry matter was applied on the winter feeding sites as was applied by machine, (33 tonnes ha^{-1}), on the raw manure sites.

Nitrogen amounts in the surface residue in the winter feeding sites was also around half of that measured in the spread raw manure. Phosphorus measurements of the feed and bedding brought onto the field, minus animal retention totaled 54 kg P ha^{-1}, also half of the 102 kg P ha^{-1} found in the spread raw manure. Both the N and P calculations do not depend on assumptions of moisture content in the excreted cattle manure.

It therefore appears that on a dry matter basis this trial compared spreading double the rate of raw stockpiled manure and bedding from an intensive system to that applied in the extensive pasture feeding system. This provides an explanation for the comparatively low amounts of surface residue, surface residue N, and particularly the amounts of P in the winter feeding sites.

4.2.6 Phosphorous application rates and N:P ratios

Phosphorus application rates are becoming an important consideration in manure disposal due to the buildup of P in conventional manure application scenarios (Whalen and Chang, 2001, Qian et al., 2004; Olson and Papworth, 2006). The problem is related to the ratio of total N to total P in manure and compost. While different forage species can contain widely different N:P ratios, those grown under good growing conditions with balanced N:P fertility have ratios around 10:1 for legumes and 7:1 for grasses (Pederson et al., 2002). However after losses of volatile N, stockpiled cattle manure and compost have N to P ratios of 3.5:1 or less (Mooleki et al., 2004; Larney et al., 2006), a much lower N content relationship than what is needed by the plants. This has lead to recommendations that cattle manure should only be applied to meet crop P requirements, with commercial fertilizer N added to increase the N:P ratio to optimum levels (Whalen and Chang, 2001; Qian et al., 2004; Schoenau and Davis, 2006). The N:P ratio of the manure and compost in this trial was similar to other studies, at N:P ratios of 3:1 and 3.5:1, respectively. At the time of spreading available N was very low in both cases, and what organic matter breakdown occurred over the winter resulted in limited movement of plant available inorganic N into the soil.

In the pasture feeding systems, the dried plant material (straw and hay) had N: P ratios ranging from 7:1 in the straw to 10:1 in the grass-legume hay, similar to that reported by Pederson et al. (2002). The combined average N:P ratio was 9:1, with 579 kg N ha^{-1} and 64 kg P ha^{-1} added in feed and bedding. This amount of P was about half of what was applied in the spread manure. Due to double the retention rate of P in the animals compared to N (Bierman et al., 1999; Fisher et al., 2000; Erickson et al., 2000; Cole, 1999) the N:P ratio would actually increase after animal ingestion to 10:1 with 529 kg ha^{-1} of N applied to the field after feeding compared to 54 kg ha^{-1} of P. Most of the N excreted by the animal was in the plant available inorganic form, and although losses appear to be substantial there were still significant gains in inorganic N levels in the soil. Combining the soil available inorganic N and the organic residue N, measurements in the field show retention of 309 kg N ha^{-1} and 33 kg P ha^{-1}, giving a similar ratio of 9.3 to one. This does not take into account the P increases in the soil. If the total amount of feed P hauled onto the field minus animal retention is assumed to be retained in the soil-plant system then the N:P ratio drops to 6:1, still double that of the applied raw manure, with over a third of the N in the plant available form. Greater retention of feed N in pasture based feeding methods appears to have a benefit in addressing the concern about overloading of P, as the resultant N:P ratio in the soil is wider, allowing for plant N:P requirements to be more closely matched.

4.2.7 Conclusions

A substantial increase in soil inorganic N was observed in the extensive system where cattle were wintered directly on the pasture. The mean gain from a cattle concentration of 2080 cow-days ha^{-1} on the winter feeding systems was 117 kg N ha^{-1} when compared to the check where no manure was applied. Spreading raw manure at 67.2 tonnes ha^{-1} or compost at 22.4 tonnes ha^{-1} did not result in any significant increase in soil inorganic N. The extra soil N in the winter feeding sites appears to be from the capture of urine N that was lost in the intensive system. The percent of N added as feed and bedding that was captured in the soil was somewhat lower than that found in trials involving grazed pasture in the summer, but the total amounts of kg N ha^{-1} added were much greater due to the large quantity of nutrients hauled on to the field. While amounts recovered are similar to other studies where cattle were fed hay on pasture, N recovery may have been greater if soil sampling had been done to a depth greater than 15 cm.

Soil extractable K levels also increased on the winter feeding sites, with a mean gain of 1209 kg K ha^{-1} compared to the check. There were no differences in soil K where raw manure or compost was spread. It appears from the results in this trial that feeding cattle on pasture may be liberating normally non available soil K. Although this may be counterbalanced by large amounts of Ca and Mg imported in the feed and bedding, high levels of available soil K can cause issues with cattle health. Supplementation with Ca and Mg may be advisable when grazing winter feeding sites, especially early spring growth.

Sampled after two years, the results for soil P were different than for the other nutrients, with the highest levels of P where raw manure and compost was spread and the lowest where animals were fed on pasture. This appears to be a function of approximately twice as much P applied in the machine spread manure treatments.

The patterns of N, K and P distribution were similar to those found in pasture grazing situations, although more concentrated in localized areas. It is important that cattle activity be distributed as evenly as possible across the feeding site, with the bale processor method of feeding allowing more even deposition of feed, bedding, and perhaps dung and urine than the bale grazing method. Given that nutrient distribution is closely related to cattle activity it is also important that cattle are not allowed to spend time in non-pasture areas.

The large range of variation in soil levels of N and K showed that representative composite samples would be difficult to obtain without taking a large number of cores. Accurate nutrient distribution maps would require very intensive transect sampling patterns. As well the significant portion of inorganic N in the ammonium form should be taken into consideration as well as nitrate. Areas of high P concentration in the pasture feeding sites appear to be linked to heavy levels of manure and residue that contained high amounts of P and suppressed plant growth and thereby nutrient removal.

The amounts of residue left after pasture feeding were high in areas, especially where straw was fed, with a significant content of organic N. It appears that feeding this amount of straw either by bale grazing or bale processing without bunks or feeders can leave a considerable amount of material left on the field.

Nutrient capture calculations showed that approximately twice the amount of N was hauled onto the field in the feed and bedding as compared to the raw manure spreading treatment, together with large amounts of K. Total P in the feed and bedding was half of that hauled in the raw manure. Published values in the literature for animal nutrient retention and urine/dung cycling together with measurements of feed nutrients consumed by the animals made it possible to estimate nutrient capture in soil and surface residue. The amount of manure, bedding, and feed the cattle left in the field on a dry matter basis was only 50% of that applied on the raw manure treatment, due to differences in the moisture content of manure applied by cattle and by equipment.

Nitrogen to P ratios were closer to the ratios of required by and found in healthy plants (~7:1 to 10:1) on the winter feeding sites due to the retention of extra N compared to the raw manure and compost treatments. Total P applied by the cattle was considerably lower due to the much smaller amount of P hauled on to the field initially.

In conclusion, it appears that winter feeding cattle on pasture under Canadian prairie conditions promotes better capture and recycling of nutrients in feed, bedding and urine compared to feeding in a drylot and spreading the manure or compost by equipment. The concentration of cows on the pasture of 16 per ha^{-1} for a winter feeding period of 130 d, or 2080 cow d ha^{-1} was sufficient to give a significant inorganic N gain for a grass pasture in western Canada and a reasonable balance between N and P that would promote good forage growth.

5.0 FORAGE RESPONSE

5.1 Materials and Methods

5.1.1 Sampling procedure

Forage clippings of the first year of regrowth were taken at the same intensive grid points as the soil samples (Figures 4.2, 4.3) using hand clippers and quarter meter squares. Forage dry matter was determined July 16th 2004 and again on Sept 26th 2004. In the second year only a first cut was taken June 23rd 2005, with quarter meter squares used where manure was spread and 10 cm square quadrats on the sampling points in the winter feeding sites. All samples were dried at 40 ºC in a forced air oven, then weighed, ground and analyzed for total N and P using the same H_2SO_4 digestion and analysis used for the manure samples as described in section 3.2.2.

Aerial photos of the forage regrowth were taken in the fall of 2004 using a kite based aerial camera photo system (Appendix E).

5.1.2 Statistical analysis

For calculation of means and least significant differences (LSD at $p \leq 0.10$) the results of the replicate treatments or transects were analyzed with SAS software (SAS inst. Inc. 1985) using the General Linear Model procedure.

5.2 Results and Discussion

5.2.1 Dry matter yield and distribution

In the first growing season total dry matter yield of russian wildrye (RWR) forage (Table 5.1) was increased over the check in all treatments. While the raw manure and compost treatments produced significant gains over the check, forage growth was much greater in the winter feeding areas and highest in the bale processing treatment. Differences between the spread manure and the bale grazing and processing treatments in the first cut were not as great as they were by the time of the second clipping.

Table 5.1 Forage (RWR) dry matter yield of treatment areas in 2004.

Treatment	Yield					
	Total		First cut		Second cut	
	kg DM† ha^{-1}	%	kg DM ha^{-1}	%	kg DM ha^{-1}	%
Bale processing	4714 a‡	297	2726 a	213	1987 a	657
Bale grazing	3720 b	235	2424 ab	189	1295 b	428
Spread composted	2757 c	174	2210 ab	172	547 c	181
Spread raw	2337 c	147	1942 b	151	395 d	131
Check	1585 d	100	1283 c	100	302 d	100
LSD $_{(0.10)}$ ^{1}	700		648		142	

† DM, dry matter

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Forage growth relationships were similar to that reported in the literature. Powell et al. (1998) also found much higher forage yields from wintering the cattle directly on the pasture compared to mechanically spreading manure from a drylot. The doubling of RWR yield after pasture feeding in the first cut and increases of up to six times in the second cut of the first year is similar to that reported by Griffin (1997), who was winterfeeding cattle on a smooth bromegrass (*Bromus inermis* Leyss.) site. Smoliak (1965), who spread 67 tonnes ha^{-1} of straw on pasture in southern Alberta for rejuvenation, suggested that grass needs time to adapt to high amounts of residue. The author observed an initial yield depression followed by a sharp and sustained increase after some decay had taken place, especially when immediately available nutrients, in the form of commercial fertilizer, had been added. In a study on South Dakota native range, residue thicknesses up to 2.5 cm were measured and forage yields were reported to be directly proportional to the depth of this surface mulch (Larson and Whitman, 1942). The authors pointed out that a thick layer of residue would be effective at both increasing moisture infiltration into the soil and in decreasing the evaporation of moisture back into the atmosphere. The presence and density of a litter layer is now used as a standard factor in rating healthy rangeland and tame pasture, especially in the drier areas (Adams et al., 2004). Russian wildrye is noted for a long season of growth, (Smoliak et al., 1981) and it appears in this study to have taken advantage of additional moisture provided by the heavy mulch and the available nutrients in the winter feeding system to promote additional yield of forage in the second clipping.

Trials that have examined farmyard manure applied on RWR stands are rare in the literature. Both Smika et al. (1960) and Lardner (2002) reported lower dry matter yield responses of RWR compared to the check in the first year after treatments were applied than was found in this study. Yield of crested wheatgrass (*Agropyron crisatum*) in the same trials were double or greater than that of RWR, suggesting that RWR does not respond well to manure application. Yield responses of various grass species to farmyard manure application in all field trials found in the literature were generally small, ranging from 0 to 1600 kg ha^{-1} with a mean of 762 kg ha^{-1} in six experiments, (Smika et al., 1960; Smoliak, 1965; Holt and Zentner, 1985; Lardner, 2002; Lardner, 2003; Zhang et al., 2006), similar to the 752 kg ha^{-1} gain found in this trial.

The compost treatment had a trend to outyield the raw manure, but the difference was not significant except in the second cut. Trials testing farm yard cattle manure compost on RWR could not be found, however there is limited information on other grasses. Lardner (2003) reported somewhat larger forage yield from compost than raw manure on crested wheat, using an application of three times the amount of compost as used in this study.

Despite the increased yield of forage in the winter feeding areas, aerial photos taken after the second cut was harvested show substantial areas of no growth (Figure 5.1), mainly where straw was fed. On both the bale processed and bale grazed sites, the absence of growth was in areas of high surface residue concentration, generally in areas covered in 50 to 130 tonnes ha^{-1} of residue, as shown in Figures 5.2 and 5.3.

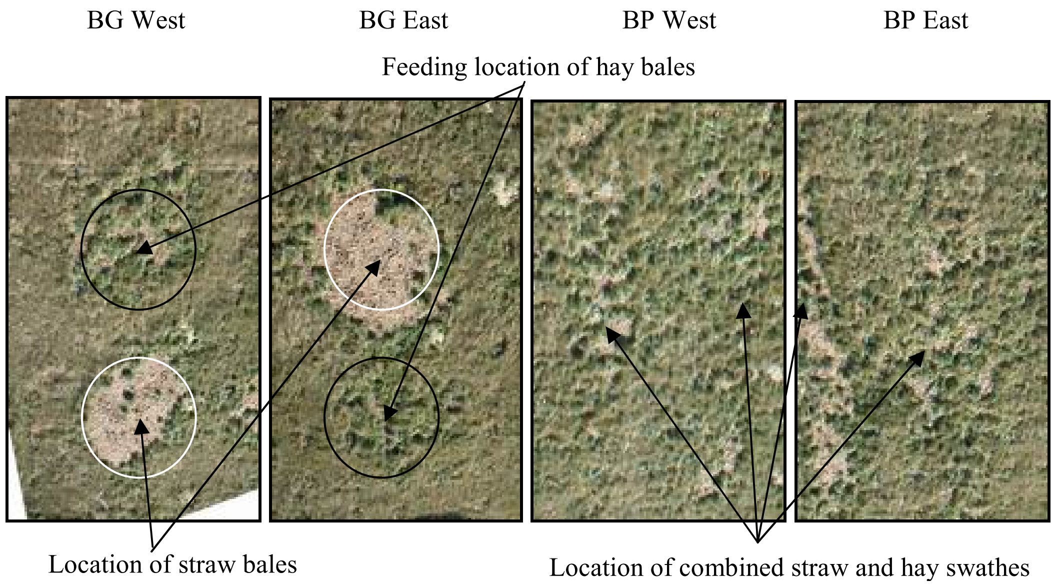

Figure 5.1 Aerial photos of forage regrowth in the sampled areas of the pasture feeding treatments, fall of 2004.

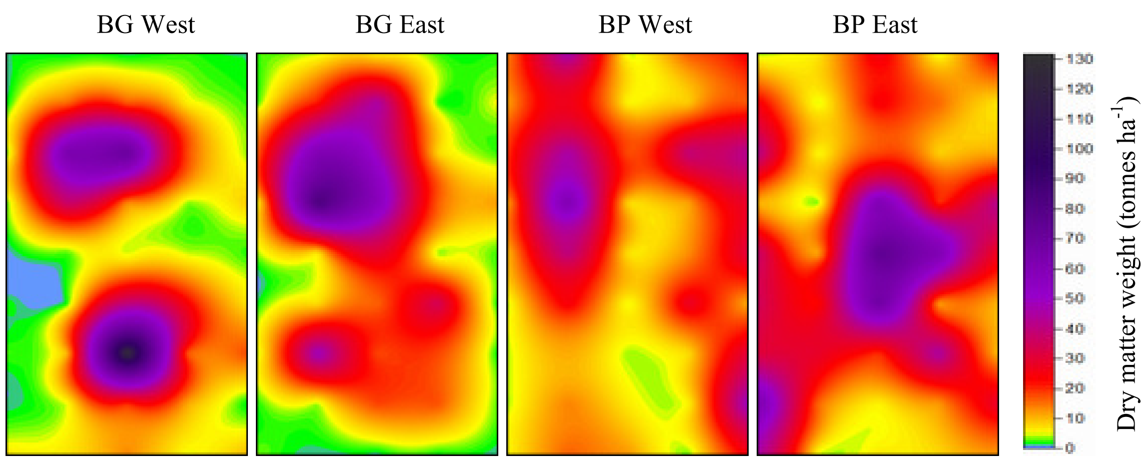

Figure 5.2 Surface residue weight as dry matter in the sampled areas of the pasture feeding treatments, spring 2004.

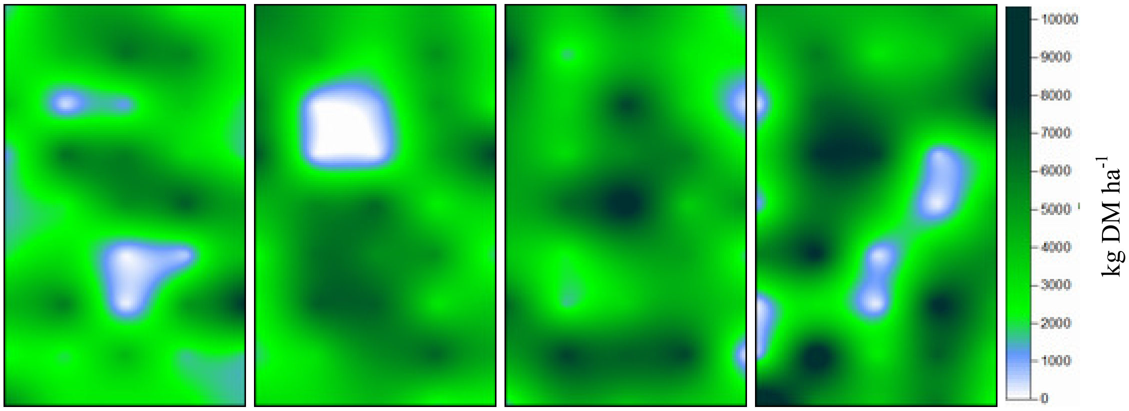

Figure 5.3 Total harvested forage as dry matter in the sampled areas of the pasture feeding sites in 2004.

In contrast to the straw, the hay residue did not appear to cause large bare areas on the study sites even at rates over 50 tonnes ha^{-1}. An explanation for this would be the much thinner surface residue thickness where the hay was fed; up to 5 cm thick while straw locations had residue thicknesses of up to 20 cm. The shallower depth of residue on the hay feeding sites left areas that grass could grow through. Combined with the high amount of available inorganic nutrients (Figures 4.6, 4.7) in these locations and the moisture conservation ability of the surface residue, this explains the very high yield of forage in the locations where hay was fed (Figure 5.3), up to 10,000 kg ha^{-1} of dry matter.

The areas with no forage growth were circular in the bale grazing areas, corresponding with the circular shape and placement of the straw bales. On the bale processing site the areas of missing growth correspond to the long narrow swath laid down by the bale processor. These areas of non-growth were larger on the bale grazing site and covered much bigger continuous areas. The ability of the bale processor feeding method to spread the feed and bedding more evenly over the pasture areas appears to be beneficial as far as grass regrowth on this type of pasture. As the areas of missing grass growth (Figures 5.1, 5.3) correlated with the areas of greatest soil and surface residue nutrients (Figures 4.6, 4.7, 4.10, 4.11), it is reasonable to assume that, while both pasture feeding techniques were affected, the ability of the bale grazing treatment in this trial to convert nutrients to forage growth was reduced the most.

Some bare areas can be expected as RWR is a bunchgrass. Producers with prior experience in winter feeding on pasture had advised during trial setup that the high levels of residue left after feeding straw can be detrimental to a bunchgrass with its non-rhizomatous roots (Boyd and Lastiwka, personal communication, 2003). If the winter feeding had been done on a rhizomatous type grass such as smooth bromegrass, this species has been known to have aggressive regrowth (Stacy et al., 2005) which may have been able to compensate for the heavy residue. Also, a more palatable feed such as greenfeed could have been fed instead of straw, reducing residue amounts. Reducing or eliminating bare areas would lead to possible increases in forage production and nutrient recovery, especially with the bale grazing treatment.

Compared to the winter feeding areas, forage growth in the mechanically applied manure and control treatments was relatively even as can be seen in Figure 5.4. There were only limited areas of missing growth due to applicator bunching of manure and rodent damage.

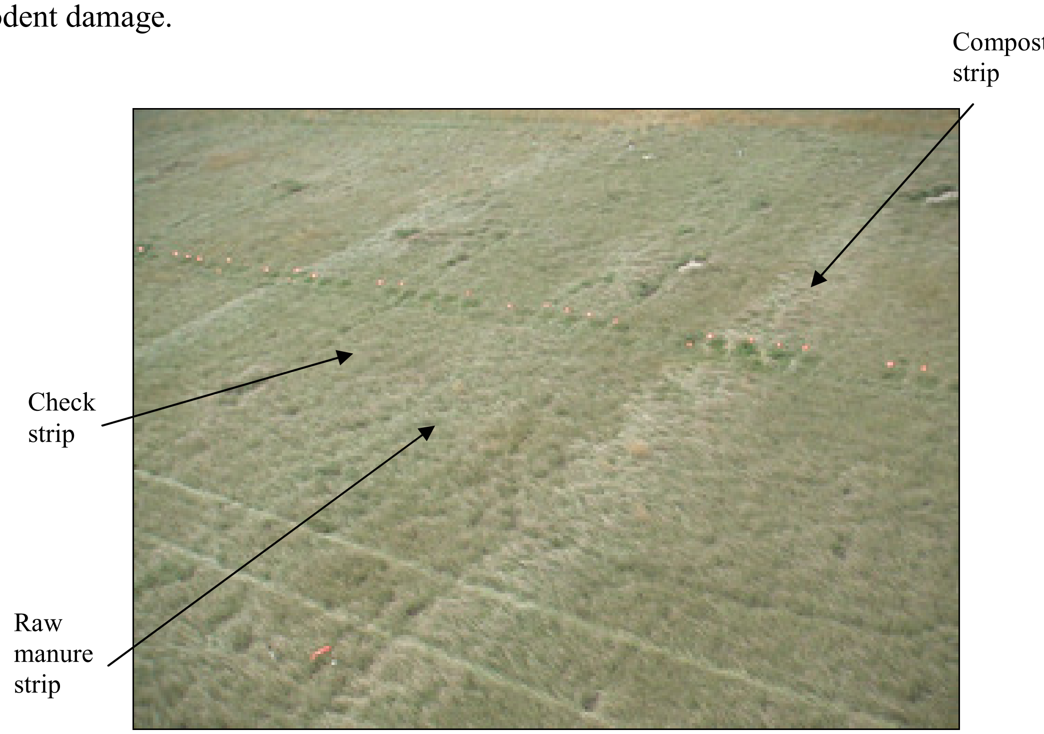

Figure 5.4 Aerial photo of spread raw manure, compost, and check strips, in the fall of 2004.

In the second growing season (Table 5.2), forage dry matter yield increase on the winter feeding sites was as high as eight times the check in the bale processing treatment. The yield of the bale grazing treatment was also increased, to five times that of the check, similar to the quadrupling of forage yield reported by Griffin (1997) on bale grazing sites in the second year. However, yield on the composted and raw manure treatments were not significantly different than the check in the second year, although mean levels were numerically higher.

Table 5.2 Forage (RWR) dry matter yield from the first cut in 2005 alone and combined with total 2004 yield.

Treatment	Yield			
	First cut 2005		First cut 2005 plus 2004 total	
	kg DM† ha^{-1}	%	kg DM ha^{-1}	%
Bale processing	6313 a‡	821	11026 a	468
Bale grazing	3964 a	515	7683 b	326
Spread composted	1191 b	155	3948 c	168
Spread raw	1052 b	137	3389 c	144
Check	769 b	100	2355 c	100
LSD $_{(0.10)}$	2493		2255	

† DM, dry matter

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Due to a second cut not being taken in the second year, it is difficult to compare total dry matter yields from year one to year two. Total forage yields in the winterfeeding sites appear to greatly increase from year one to year two, as the first cut from the winter feeding sites in 2005 was almost 1000 kg ha^{-1} greater than the total of both cuts in the previous year, despite being harvested a month earlier than the first cut taken in 2004. It would be reasonable to assume that the dry matter yield of a second harvest would have been substantial, as a RWR trial in Saskatchewan with similar yields to the winter feeding sites (Lawrence and Knipfel, 1981) reported additional yields of 34 to 43% from the second cut when the same cutting dates are used, and the additional yield from the second cut in 2004 was in the 53-72% range.

At the same time as yield was increased in the second year on the winterfeeding sites those of the control, raw manure, and compost treatments were 50% lower compared to 2004. Higher yields in the bale processing and bale grazing treatments in 2005 versus 2004 likely reflects continued nutrient availability, greater moisture retention, and less smothering from surface residue. When both years are combined the winter feeding sites yielded 3 to 5 times the check while the spread manure treatments showed much less gain.

5.2.2 Protein and phosphorus yield

While dry matter yield is the most commonly used measured parameter of forage production studies, an important consideration for raising beef cattle is the nutrient content of the feed and the total amount of nutrients harvested. In year one, forage protein levels where raw manure or compost was spread were not significantly different from the check (Table 5.3). However, forage protein levels doubled over the check on the winter feeding sites. Differences in plant P concentrations among all treatments were small.

Table 5.3 Protein and phosphorus content as a percentage of dry matter weight, of the forage, (RWR) harvested from the first cut in June 2004.

Treatment	Content			
	Protein†		**Phosphorus**	
	%			
Bale processing	19.8 a‡	193	.19 ab	115
Bale grazing	18.4 a	180	.19 ab	115
Spread composted	9.9 b	97	.15 c	91
Spread raw	10.6 b	104	.20 a	122
Check	10.2 b	100	.17 bc	100
LSD $_{(0.10)}$	2.5		.03	

† Nitrogen content multiplied by 6.25

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Forage protein levels found in the winter feeding areas in the first year are similar to that found when RWR was fertilized with rates of 400 kg ha^{-1} of fertilizer N (Lawrence et al., 1982) and are similar to that found in alfalfa (White and Wight, 1984). Forage protein levels found in RWR on the spread manure and check sites were similar to that found in unfertilized RWR fields (Smika et al., 1960). Another estimate of feed quality, organic matter digestibility, has been found to increase in RWR with increased fertilization and the resulting higher protein levels (Lawrence and Knipfel, 1981; Karn et al., 2004). Therefore, it may be suggested that the increased level of dry matter produced on these winter feeding areas is also likely to be more digestible.

The total amount of nutrient contained in the forage biomass (concentration times yield) shows large differences (Table 5.4) in nutrients removed by the forage, especially between the winter feeding and spread manure areas. Protein removed where the cattle were winter fed was about five times that of the check and two times the check where manure was spread with machinery. Phosphorus amounts in the biomass above ground follow the same pattern, although the differences between winterfeeding and manure spreading were not quite as great as for protein.

Table 5.4 Amount of protein and phosphorus contained in above ground RWR biomass in both cuts of forage (RWR) in 2004.

Treatment	Amount			
	Protein†		Phosphorus	
	kg ha^{-1}	%	kg ha^{-1}	%
Bale processing	890 a‡	553	8.7 a	337
Bale grazing	714 b	443	6.9 b	266
Spread composted	272 c	169	4.2 c	163
Spread raw	250 c	155	4.8 c	186
Check	161 d	100	2.6 d	100
LSD $_{(0.10)}$	70.1		1.52	

† Nitrogen content multiplied by 6.25

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Increases of protein in the RWR in the winter feeding areas are greater as they are driven by both increased plant concentration and the greater amounts of dry matter harvested, while increases in P reflect increased dry matter only and so follow the yield relationships. Whalen and Chang (2001) found the same phenomenon with P on long-term cattle manure plots, where they concluded that the greater P removal in irrigated fields compared to dryland was associated with greater plant growth as a result of higher moisture availability, not from greater concentration in the plants. It is observed that despite the spring soil mineral N levels being similar to the check in the spread manure treatments (Table 4.3) the spread manure treatments provided a significant amount of extra N for the grass in the first growing season, indicating that some mineral N was released from the manure and compost throughout the summer. The limited amount supplied was only enough to increase dry matter production while keeping the protein level unchanged. Availability of N on the winter feeding sites appears to have been much greater, such that both dry matter yields and protein concentration increased at the same time, resulting in a much higher N uptake by the forage and a greater protein harvest.

In the second year of forage growth after the treatments, protein content (Table 5.5) of the forage was considerably lower in the winter fed areas than in the first year (Table 5.3), although still significantly greater than the check. Phosphorus differences were still small in the second year but there is a trend to lower P concentrations compared to the check in the highest yielding winter feeding area and significantly greater P concentrations than the check in the compost treatment.

Table 5.5 Nutrient content as a percent of dry matter weight of the forage (RWR) harvested in the first cut in June 2005.

Treatment	Content			
	Protein†		**Phosphorus**	
	%			
Bale processing	12.6 a‡	138	.20 d	70
Bale grazing	11.3 b	123	.27 c	93
Spread composted	9.4 c	103	.35 a	123
Spread raw	9.1 c	100	.32 ab	112
Check	9.1 c	100	.29 bc	100
LSD $_{(0.10)}$	1.1		.05	

† Nitrogen content multiplied by 6.25

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Smika et al. (1960) noted a similar decrease in P concentration in RWR biomass when N fertilizer was applied without P. The results in the current study are consistent with high plant P removal in the first year from the winter feeding areas combined with the low amount applied. Reduced plant uptake of P in the machine spread manure areas in year one combined with the higher amount applied can explain the higher concentrations in the plant in the second year.

Despite the decrease in protein concentration in the forage in the winter feeding areas in 2005 compared to 2004, the total amounts of nutrient harvested (Table 5.6) is similar in the first cut of 2005 as in both cuts in 2004 due to increased in dry matter harvested in the first cut of 2005.

Table 5.6 Amount of protein and phosphorus contained in above ground RWR biomass in the first cut of forage (RWR) in June 2005, as dry matter.

Treatment	Amount			
	Protein†		**Phosphorus**	
	kg ha^{-1}	%	kg ha^{-1}	%
Bale processing	830 a‡	1251	12.3 a	623
Bale grazing	512 a	771	9.5 ab	480
Spread composted	112 b	168	4.1 bc	207
Spread raw	94 b	142	3.3 c	168
Check	66 b	100	2.0 c	100
LSD $_{(0.10)}$	339		5.7	

† Nitrogen content multiplied by 6.25

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

Over the year and a half of harvesting, the total amounts of nutrients contained in the forage biomass are much higher in the pasture feeding systems (Table 5.7), with protein in the forage biomass averaging 6.5 times greater than the check and P four times greater, versus a mean gain of less than twice the check for the spread manure methods.

Table 5.7 Nutrient yield in 2004 and the first half of 2005.

Treatment	Yield			
	Protein†		Phosphorus	
	kg ha^{-1}	%	kg ha^{-1}	%
Bale processing	1719 a	756	21 a	457
Bale grazing	1225 b	539	16 a	356
Spread composted	383 c	169	8 b	180
Spread raw	344 c	152	8 b	176
Check	227 c	100	5 b	100
LSD $_{(0.10)}$	336		5.5	

† Nitrogen content multiplied by 6.25

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

5.2.3 Nutrient recovery in the forage regrowth

Capture of N added in the feed and bedding by the forage in the winter feeding systems was calculated (Table 5.8). As a proportion of added feed and bedding N, the N recovered in the above ground forage harvested in the two cuttings in 2004 and the spring cutting in 2005 from the winter feeding systems was as high as 45% on the bale processing. Recovery of the N in the manure and compost was much lower, with recovery ranging from 5% of the N added in raw manure to 9% of that added in compost.

Table 5.8 Recovery in the above ground forage (RWR) biomass of feed, bedding, and manure nitrogen, as measured in two cuttings in 2004 and one cutting in 2005.

Treatment	Nitrogen					
	Applied to the pasture		Forage content		Recovery	
	Imported on field	After animal retention†	Total	Minus check	From imported	After animal retention
	------------------------- kg N ha^{-1}	----------------------			------------- % -----------	
Bale processing	582	532	275 a‡	239	41	45
Bale grazing	576	526	196 b	160	28	30
Spread composted	278	-	61 c	25	9	-
Spread raw	343	-	55 c	19	5	-
LSD $_{(0.10)}$			54			

† N retention of 10% from Bierman et al. (1999) and Fisher et al. (2000), subtracted from feed eaten.

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

The higher N capture rates from the winter feeding systems are similar to the range that was reported in grass trials using commercial N fertilizer. A mean N recovery of 25% was found by Smika et al. (1960) on RWR, with 48% reported by Holt and Zentner (1985) at Swift Current and 28% by Zhang et al. (2006) on bromegrass. Stumborg et al. (2007) reported a similar recovery of 38% in the above ground biomass of applied urea N fertilizer on cropland. As most of the N consumed by the animal in the feed is converted to the urea form and excreted in the urine (Ball and Ryden, 1984; Bierman et al., 1999), these results show that the winter pasture environment in this trial captured this N quite efficiently.

The N recovery rates observed from the spread manure treatments are also similar to the recovery rates of 11% reported on forages by Holt and Zentner (1985) and Zhang et al. (2006). The incorporation of solid cattle manure into soil, possible in cropping trials, has resulted in a similar N recovery to the surface applied method used in forages, with a 7-10% recovery of solid cattle manure N reported by Mooleki et al. (2004) and 10% reported by Stumborg et al. (2007) with cereals on stubble.

The amount of N originally present in the feed and bedding that was recovered in the grass harvested from the winter feeding areas averaged 34% for the two winter feeding systems. For every 100 kg of N fed (the amount found in 8 hay bales used in this trial), 34 kg was recovered in the grass. Even when the amount of nutrients retained by the animals is not considered, the N present in the bales still appears to be used by the pasture at a similar efficiency as N in the form of commercial fertilizer.

The drylot system requires careful calculations to account for the pen losses before the manure and compost are hauled to the field. The nutrient content in the drylot feed combined with measurements of refused feed was combined with literature figures for nutrient retention and corral losses and is reported in Appendices I and J. Overall N recovery in the harvested forage in the drylot systems was estimated to be only 1% of that fed to the animals. Therefore, for every 100 kg of N fed in the yard, 1 kg was recovered in the grass biomass. This recovery is very low, and agrees with the findings of Bierman et al. (1999) who indicated that the N lost in drylot systems is the immediately plant available forms, mostly easily volatilizable ammonia. The N that ends up being hauled to the pasture is associated with high carbon content organic matter with a high C:N ratio, resulting in low plant availability in both raw manure (Qian and Schoenau, 2002) and compost (Helgason et al., 2007).

Winter feeding on the pasture was done at a stocking rate of 2080 cow-days ha^{-1} and using the same 130 day feeding period, the drylot system was maintained at a stocking rate of 43,043 cow-days ha^{-1}, 21 times the density of the winter feeding site. Using the same estimates for N intake and excretion, the winter feeding animals excreted 325 kg ha^{-1} of liquid urea N and 126 kg ha^{-1} of solid manure N, while the drylot animals excreted 6728 kg ha^{-1} of liquid urea N and 2608 kg ha^{-1} of solid manure N.

Phosphorus recovery by the grass in the winter feeding areas averaged 26% of hauled P after consumption (Table 5.9). Recovery in the spread manure areas was much lower, averaging only 4 percent. Recovery of the feed and bedding P remaining after animal retention on the winter feeding areas was above that reported with commercial fertilizer P on forage grass. In this study, P recovery was 26% which was well above the 8% reported by Smika et al. (1960) with commercial fertilizer P on RWR and the 18%

recovery reported by Holt and Zentner (1985) on bromegrass. The high P recovery appears to be a result of high dry matter yield of the grass.

Table 5.9 Recovery in the forage (RWR) of added feed, bedding, and manure phosphorus, as measured in two forage cuttings in 2004 and one in 2005.

	Phosphorus					
	Applied to the pasture		Forage content		Recovery	
Treatment	Hauled on field	After animal retention†	Total	Minus check	From hauled	After animal retention
	---------------------------- kg P ha^{-1} ---------------------- ----				-------------- % -----------	
Bale processing	61	51	21 a‡	16	27	32
Bale grazing	68	57	16 a	12	17	21
Spread composted	78	-	8 b	4	5	-
Spread raw	114	-	8 b	4	3	-
LSD $_{(0.10)}$			6			

† P retention of 19% from Erickson et al. (2000), and Cole (1999), subtracted from feed eaten.

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

The recovery in the grass of about 4% of the P from the spread raw manure and compost is the same as the 4% recovery Zhang et al. (2006) reported over two years of harvesting after a single application of solid cattle manure on a grass stand in Alaska. This level is slightly lower than the 8% reported by Holt and Zentner (1985) where manure was applied every year for four years. Similar to what was found with N, incorporation of farmyard manure into the soil may not increase P availability to the plant, as indicated in an 8 year trial on cropland (Stumborg, 2006) where varying rates of manure resulted in an average recovery of 7% of the applied phosphorus. The cause of low plant recovery of P appears to be the reduced plant growth as a result of low N availability in spread manure compared to the winter feeding systems, as the % content of P in the plant tissues were similar.

The P efficiency in the winter feeding systems of hay and bedding hauled to the field was 22 percent. This means that out of 100 kg of P hauled onto the field in the feed (the content of 83 hay bales) 22 kg was recovered in the harvested forage after a year and a half. For the drylot systems again calculations were made using amounts of feed eaten by the animals combined with literature figures for animal retention and corral loss, retention in the animal being higher than N and losses in the corrals much lower. Overall P recovery in the harvested forage in the drylot systems was estimated to be only 3% of that fed to the animals. Therefore, for every 100 kg of P fed in the drylot, 3 kg was recovered in the grass biomass.

5.2.4 General Discussion: pasture feeding and manure spreading as pasture fertilization and rejuvenation techniques

The finding of similar recovery and utilization by RWR of the nutrients in feed and bedding hauled to the winter feeding sites to that reported in the literature for commercial inorganic fertilizer is important when considering different approaches to rejuvenation of long term pasture. The use of commercial inorganic fertilizer on dryland pastures on the Great Plains of North America has been repeatedly shown to be unprofitable or to carry high risk of unprofitability due to variable rainfall (Kilcher, 1958; Kopp et al., 2003). However, without replenishing soil fertility, the yield of forage grasses drops significantly one or two years after stand establishment (White and Wight, 1984). In the long term, continued grazing without added fertility has been found to reduce soil P and N levels (Sigua et al., 2006), cause losses of soil organic matter, and degrade soil quality over time unless grazing intensities are kept very light (Dormaar and Wilms, 1998). Low fertility pastures with the accompanying minimal plant growth also become more vulnerable to pests such as grasshoppers (Craig et al., 1999), and rodents such as Richardson's ground squirrel (*Spermophilus richardsonii*). Rodent damage has been reported as the major reason for forage termination in Saskatchewan and Manitoba (Entz et al., 1995).

The most common method of rejuvenating a pasture without fertilization is breaking up the pasture mechanically and reseeding. As measured by Smoliak and Dormaar (1985) in southern Alberta, organic N in the roots of a grass field is substantial, varying from 256 to 339 kg ha^{-1} in the top 15 cm of soil. Nitrogen found in these roots after the grass is killed by tillage is estimated to be available over the next 3-4 years to the subsequent new pasture as the roots slowly decay (White and Wight, 1984).

Disadvantages with this type of rejuvenation include loss of pasture production in the year of establishment, costs of breaking and reseeding the pasture, and weed control during establishment. There are also substantial risks of establishment failure and erosion before cover is returned to the field, especially if moisture is poor during the reseeding year (Lorenz and Rogler, 1962).

Previous attempts at finding rejuvenation alternatives to adding expensive commercial fertilizer or complete destruction of the existing stand such as scarification, burning, and mowing (Lorenz and Rogler, 1962; Lardner et al., 2000), have been disappointing. The conclusion has been that adding commercial inorganic fertilizer, with the resultant cash outlay and economic risk, was a much more effective method of rejuvenating even old stands of grass if the stand was not to be broken up.

The most promising alternative method at present to increase pasture productivity without tillage or commercial inorganic fertilizer has been the use of legumes to provide atmospheric N through N fixation (Kopp et al., 2003). However, there are considerable issues with using legumes for grazing, including animal losses through bloat and a lack of legume persistence. Because of establishment issues when interseeding legumes into an existing stand (Lorenz and Rogler, 1962; Cuomo et al., 2001) it is most common to take out the existing forage first with herbicides or tillage, with the already mentioned risks and costs.

As a means of fertilizing grass pasture, application of raw manure or compost provided significant yield gains in the first year of application. However, the reduced yield and the low nutrient recovery efficiency, especially when considering drylot losses, would appear to make it much less attractive to cow-calf producers as a means of recycling the nutrients from cattle feed into the pasture than the winter feeding on pasture method. If manure or compost can be obtained for little cost from commercial feedlots the low nutrient recovery would be of less economic concern. However the amounts of raw manure or compost necessary to produce high forage production annually could cause environmental nutrient loading concerns such as P loading on the pasture. An alternative may be to combine commercial manures high in available N such as liquid hog or dairy slurry with applications of the high P cattle manure or compost, resulting in more balanced plant nutrition.

Winter feeding directly on the pasture appears to be another method to incorporate nutrients from legume hay into a grass stand. Most of the nutrients fed to the animals in the winter feeding on pasture trial were provided by the high legume (alfalfa) hay (Appendix F). Total amounts of nutrients contained in the feed and bedding were very large with mean amounts of 579 kg ha^{-1} N, 64 kg ha^{-1} P, 723 kg ha^{-1} K and 62 kg ha^{-1} of S. Considering that the recovery of the nutrients was found to be similar to that of inorganic commercial fertilizer, the value of N, P, K, and S priced at current fertilizer market rates would be valued at \$1398.00 ha^{-1} (Appendix K). In a soil of high K fertility such as in this study, K is certainly being applied to excess and as such inflates the fertilizer value. However, removing most of the K still results in an effective fertilizer value of \$1000.00 ha^{-1}. This is without consideration of the value of other nutrients that may be valuable to plant growth such as the 232 kg ha^{-1} of Ca and 74 kg ha^{-1} of Mg provided, both important in reducing the risk of grass tetany (Grunes and Welch, 1989). Measuring the amount of nutrients hauled onto to a pasture winter feeding site in feed and bedding has been studied by Owens et al. (1982a, 1982b). Feeding at a somewhat lower rate of 1509 cow-days ha^{-1}, the authors reported that 297 kg ha^{-1} of N was hauled onto a pasture winter feeding site per year and also noted large amounts added of the elements P, K, Ca, and Mg (Owens et al., 2003). The high amount and recovery of the nutrients from the hay and bedding in this system could result in a fundamental reassessment in how producers value hay and feed. These feedstuffs could be a combined winter nutrition source and a pasture fertilization source.

Along with the high effective amount of nutrients applied with the feeding on pasture technique, another difference to fertilization with manure at these rates or the use of commercial inorganic fertilizer is the addition of a thick layer of surface mulch in the form of uneaten feed and bedding combined with manure. This provides a combination of a thatch ground cover and the provision of slow release nutrients in combination with the immediately available inorganic forms measured in the soil. An important attribute of thatch ground cover is that of moisture conservation, both by reducing surface temperature and allowing better infiltration of precipitation and reduction of evaporative losses (Larson and Whitman, 1942; Bristow, 1988). As a lack of timely moisture in the Prairies combined with excessive heat is seen as the main factor in limiting the effectiveness of N fertilizer in this region (Nuttall et al., 1991; Harapiak et al., 1992; McCaughey and Simons, 1998), the mulch layer provided by winter feeding systems may be contributing significantly to the high pasture growth and nutrient recovery found in this trial, especially in the second year when the forage yield on the control and the spread manure areas decreased by half. Further attention to the effect of winter feeding on water use efficiency and soil-water budgets is warranted.

The surface mulch is also likely to play a role in enhancing the ability of pasture plants to recapture nutrients from grazing animals in the following years and in protection to the pasture from insect predation. It has been found that the capture of N in the urine of grazing animals is greatly enhanced from lower surface temperatures and moist surface conditions (Stewart, 1970), both of which are provided by a heavy surface layer of uneaten feed and straw. Reduction in soil surface temperature is also an important method of reducing predation by grasshoppers (Craig et al., 1999) which have been found to consume as much or more of the forage allotted for livestock (Onsager, 2000).

One limitation of the winter feeding system as used in this trial is the small area of pasture where cows are fed. Using the concentration of 16 cows ha^{-1} and the 130 day feeding period used here, a producer with 500 cows could only rejuvenate an area of 31 ha per winter. Because of this the system may best be suited to rejuvenate low producing areas of a pasture rather than the whole field. Cattle on the prairies are generally fed harvested feed every winter period, and the effects of the rejuvenation in each feeding area should last for a considerable time. Holt et al. (1991) at Swift Current, Saskatchewan, found that a one time application of 390 kg ha^{-1} of commercial fertilizer N increased pasture production significantly for twelve years. Therefore, the total effect of rejuvenation by winter pasture feeding, in different field areas, could then be considerable when the effects are long lasting. More research is needed to determine how long these benefits may last and to what extent. Combined with good pasture management, a high intensity of plant growth over time may play a significant role in reducing infestation by Richardson’s ground squirrels as it has been noted these rodents prefer forage height under 30 cm for predator detection (Downey et al. 2006). Reducing the cattle concentration to stretch the nutrients over a larger area could sacrifice evenness of nutrient deposition, especially in the bale grazing system, and the thickness and evenness of the mulch layer would be reduced considerably. One method to increase the area covered by this system each winter that is already practiced by producers is the purchase of large quantities of inexpensive, poor quality feed. By leaving greater amounts of refused feed in return for more pasture rejuvenated per winter, the producer is trading off cattle feed efficiency for pasture improvement (Grant Lastiwka, personal communication, 2007).

Water has to be available for the animals out in the pasture to allow the full benefit of direct animal nutrient deposition. Temperatures during the winter on the prairies are below freezing much of the time and summer watering systems do not function during this time period. An alternative is new technology waterers that use geothermal heat, as was used in this trial (Appendix A). Other techniques include allowing the cattle to eat snow or hauling water. However, these alternatives have restrictions and management issues such as a lack of cattle concentration when consuming snow, which can affect the use of winter pasture feeding as a rejuvenation technique.

Environmentally, the intensity of grass response means that producers have a strong incentive for rotating the animal winter feeding sites throughout their pasture areas, especially if they are made aware of the economic value of the plant nutrients provided in this system, a fortunate case of producer's finances and environmental concerns going hand in hand. Feeding on the same site over and over again can result in nutrient overloading and subsequent losses, as reported by Owens et al. (1982a, 1982b, 2003). Another issue is soil compaction, as studied by Stephenson and Viegel (1987). On this study location the ground was frozen all winter and care was taken to move the animals off the site before the ground thawed in the spring. However, in more southern areas of the Great Plains unfrozen ground may become compacted. Loss of nutrients from winter feeding sites likely occurs via the same mechanism as that found on summer pastures. Areas lacking in ground cover are vulnerable to surface runoff with subsequent nutrient movement (Owens et al., 1982a, 1982b, 2003; Butler et al., 2007). Documentation of nutrient runoff losses in winterfeeding systems of the Canadian prairies is needed.

5.3 Summary and Conclusions

Over a period of 1.5 years following imposition of the treatments, yields of RWR forage dry matter were quadrupled where the cattle were fed on the pasture and increased by about 50% where raw manure and compost was spread, compared to an unmanured, unfertilized check. The increase in yield from winter feeding was most obvious in the second cut of the first season and in the second year of production.

Despite the yield advantage to winter feeding, forage growth was uneven where the cattle were fed, especially on the bale grazing treatment where straw was fed and accumulated to the point of causing some smothering. Using a bale processor to distribute feed and bedding appears to be preferable when feeding straw on a bunchgrass, although still not ideal. Plant growth was much more even on the spread manure treatments.

Forage protein concentration in the winter feeding areas were double that of the spread manure and control treatments during the first year, and remained higher in the second year. Differences in forage P concentration were much less among treatments. Overall, nutrient amounts harvested from the winter feeding sites in the forage were six and a half times the protein of the check and four times the P, while the spread manure treatments contained 1.5 times the protein and P in the forage biomass as did the check.

Recovery of applied nutrients in the RWR on the winter feeding sites was in the range of that found with commercial fertilizer in other studies, while recoveries with the spread manure systems were much smaller, and similar to other studies with spread manure on forages. When assumed nutrient losses in the drylot systems prior to hauling are taken into account, the pasture winterfeeding systems were forty times as efficient at recycling N as the drylot base systems and thirteen times as efficient when recycling P. A value of \$1398.00 ha^{-1} of equivalent commercial fertilizer nutrients applied to the pasture when winter feeding as calculated in this study could cause a fundamental reassessment as to how cow-calf producers view the value of winter fed hay and bedding.

As a pasture rejuvenation system, feeding cattle directly on the pasture appears to have the potential of supplying pastures with a high amount of plant available nutrients along with surface mulch that aids in nutrient capture and utilization. These benefits translated into substantially increased forage yield and quality. However, there are limitations with respect to the pasture area that can be covered each winter and management issues that need to be addressed to allow winter feeding on pasture to work optimally. Suggested issues for future work include runoff measurements and following the rejuvenation effects for a longer time.

In conclusion, the extensive method of winter feeding animals directly on pasture allowed increases in both forage quantity and quality compared to the intensive method of feeding animals in a drylot and spreading the manure afterward. It also appears to be a more efficient method of recycling winter feed nutrients into pasture forage growth than drylot feeding.

6.0 CATTLE PERFORMANCE

6.1 Materials and Methods

6.1.1 Animal performance

In the fall of 2003, 96 commercial crossbred cows from the main herd at Termuende were randomly assigned to one of the three feeding treatments. The pasture fed animals were initially weighed on two consecutive dates to minimize rumen fill variation. At the end of a 96 day trial period a final single day weight was taken. Single day weights were also taken at 30 day intervals. Drylot animals were weighed on two consecutive dates at the beginning of a 93 day trial period and on one date at the end, with additional single day weights taken at 21 day intervals. Body condition scoring (Lowman et al., 1976) was done at the beginning and ending of a 150 day trial period for the pasture fed animals, and similarly for a 93 day trial period for the drylot animals. Guidelines of the Canadian Council on Animal Care (Olfert et al., 1993) were followed at all times.

6.1.2 Feed measurements

The period chosen to compare cattle feed consumption between all systems measured 74 d from Nov 22nd 2003 to Feb 3rd 2004. The average weight of bale per load for the pasture cattle system was calculated as the weight of load purchased divided by the number of bales per load. This average weight was then multiplied by the number of bales actually fed over the winter. The bale grazing system ended up with a 7 % higher average weight of hay bales due to the differences in the load averages.

Uneaten feed material was measured by taking quarter meter quadrat samples of surface residue in the spring of 2004. The feeding sites of 3 hay and 3 straw bales were chosen per replicate, with locations approximately in the center of the replicate and equilaterally between the center and the far edge. Samples were taken in a transect across each feeding site and the material collected was spread out for drying and manure removal. The samples were then air-dried in a forced air oven set at 40 ºC and weighed. Mean residue weights per feeding area were multiplied by the total feeding area per bale to calculate the amount of residue left in the field on a per ha basis.

Drylot feed was measured daily by the operator through the use of an on board feed wagon weigh scale. Refused feed was measured weekly by weighing uneaten material in the feed bunk. Proportions of greenfeed and straw in the refused feed was estimated to be the same as was fed.

Bedding was considered included with the straw fed in the field feeding systems. The drylot system received wood chips instead of straw, however straw use was estimated at the rate of 1 bale per week for 30 cows.

6.1.3 Statistical analysis

For mean totals and least significant differences (LSD) ($p \leq 0.10$) the results of the animal data were analyzed with SAS software (SAS inst. Inc. Cary NC) using the General Linear Model procedure.

6.2 Results and Discussion

6.2.1 Weight change and body condition score

Cattle weight increased more with the pasture feeding systems than in the drylot system (Table 6.1), but this difference was only 12 kg. Of the pasture feeding systems cows on the bale grazing gained 8 kg more than the cows on the bale processing treatment.

Table 6.1 Effect of winter feeding system on the body weight change of beef cows.

Treatment	Weight		
	Change	Initial	Final
	---------------------------	kg	---------------------------
Bale processing	21.5 b†	632.6 a	654.0 a
Bale grazing	29.2 a	635.1 a	664.3 a
Drylot	13.7 c	593.1 b	606.8 b
LSD $_{(0.10)}$	7.1	20.6	18.9

† Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

The body condition of the cows, approximately 3.0 at the beginning of the trial, was optimum for the start of a winter feeding program (Marx, 2006). Changes measured (Table 6.2) were small, with a slight body condition increase of 0.2 for the animals on the bale grazing and almost no change on the other treatments, indicating that the cattle in all treatments were still in good condition at the end of the trial periods. The drylot animals were evaluated for changes in body condition during the first 93 d of the winter, while the pasture fed animals were evaluated over a 150 day period, extending longer in the season. This may have biased the results towards improvement for the drylot animals as the body condition score of beef cattle normally drops during the winter (Kunkle et al., 1994).

Table 6.2 Effect of winter feeding system on the body condition of beef cows, on a scale of 1-5†.

Treatment	Condition		
	Change	Initial	Final
Bale processing	-.03 b‡	3.02 a	2.98 a
Bale grazing	.20 a	2.84 a	3.05 a
Drylot	.05 ab	2.86 a	2.91 a
LSD $_{(0.10)}$	.23	.22	.24

† Where 1 is an emaciated animal and 5 is grossly fat.

‡ Within columns, means followed by the same letter are not significantly different according to LSD $_{(0.10)}$

While the differing feeds and feeding methods used in the trial makes it difficult to directly compare the effect of extensive and intensive feeding systems, animal performance appears to be related to the quantity and quality of feed consumed, and not to where or how they were fed. While the feedstuffs in all treatments contained similar amounts of total digestible nutrients (energy), the animals fed directly on the pasture consumed a slightly greater amount of total feed than those in the drylot (Table 6.3), and a greater proportion of this feed was of the higher quality portion of the ration. Together this would explain the slightly better performance of the pasture fed cattle compared to those in the drylot. While the tub grinding together of greenfeed and straw for the drylot combined with daily feeding in steel feeders was successful at increasing the straw intake of the animals and in reducing uneaten feed, it did not appear to result in greater efficiency of feed actually ingested by the cattle.

Table 6.3 Feed intake and quality.

Treatment	**Feed**				
	DM† Weight	**TDN‡**		**Protein**	
	Consumed	**Analysis**	**Consumed**	**Analysis**	**Consumed**
	kg cow^{-1} day^{-1}	%	kg cow^{-1} day^{-1}	%	kg cow^{-1} day^{-1}
Bale processing hay	8.3	60.1	5.0	15.0	1.2
Bale processing straw	3.4	45.7	1.5	6.1	0.2
Bale processing total	*11.7*		*6.5*		*1.4*
Bale grazing hay	8.9	58.3	5.2	13.4	1.2
Bale grazing straw	3.4	45.2	1.5	6.4	0.2
Bale grazing total	*12.3*		*6.7*		*1.4*
Drylot greenfeed	6.3	60.0	3.8	8.1	0.5
Drylot straw	5.0	43.4	2.2	6.4	0.3
Drylot total	*11.3*		*6.0*		*0.8*

† Dry matter

‡ Total digestible nutrients

When comparing the performance of the animals in the two pasture feeding systems, a slightly higher consumption of hay was noted in the bale grazing system. This was probably due to the higher average bale weight, and may be related to the slightly higher cattle performance over the winter. The processing of the feed by the bale processor did not appear to result in greater feed efficiency than the direct consumption of long stem feed when bale grazing, and also did not increase straw consumption.

Direct comparisons of winter feeding cows by bale grazing or bale processing on pasture versus drylot feeding are not reported in the literature. There have been comparisons of drylot feeding with winter grazing systems, results of which differ from those found here. Wilms et al. (1993) found that cattle grazed on standing fescue for the winter in southern Alberta lost more weight and backfat than those wintered in a drylot. McCartney et al. (2004) in central Alberta estimated that cattle swath grazing barley required 18 to 21% more energy than those fed barley silage and straw in pens. In both cases the winter grazing systems in these studies would appear to require more energy by the cattle than either the bale grazing or bale processor feeding methods used in this trial. Wilms et al. (1993) noted that the necessity for the cattle to forage through snow when winter grazing would have had effects in forage availability and may have caused restrictions in feed intake. Swath grazing has been found by Nayigihugu et al. (2007) to have similar issues, as feed intake by cattle was restricted at times due to snow and ice cover on the feed swaths. Other contributing factors mentioned by Wilms et al. (1993) for the poorer weight and condition of pasture grazed cattle was a complete lack of winter shelter and a low protein content (4.1%) in the fescue forage due to weathering, neither of which were found in this trial.

6.3 Conclusions

The system by which the animals were fed had little influence on animal weight and condition. All systems performed favorably in maintaining body weight and condition overwinter . Slight gains in weight and condition found for the pasture feeding systems appear to be related to slightly increased feed intake.

7.0 ECONOMICS

7.1 Materials and Methods

Economic comparisons of the different systems were limited to that of feed, manpower, equipment and net return as expressed in commercial fertilizer value and extra pasture growth. The costs of infrastructure were deemed to be outside the scope of this study and therefore were not included in this analysis. Infrastructure would include the capital outlay, operation, and maintenance costs of electric fencing, shelters, and waterers in the case of the pasture feeding systems, and that of solid fencing, bunk feeders, and watering systems in the case of the drylot feeding.

Costs used were calculated by system and reported as cost per cow per day. The feed associated with bale processing and drylot were assumed to be stored directly beside the system where the cattle were fed. The bales for the bale grazing system were assumed to have been hauled directly from the harvested field to the bale grazing site at no extra cost.

The feed measurement procedure is outlined in section 6.1.2. Feed prices used for all trials were alfalfa brome at \$68.95 per 907 kg bale, oat straw at \$23.00 per 408 kg bale, and greenfeed at \$37.70 per 614 kg bale. All prices included freight. The tubgrinding cost of the drylot feeding system was based on the cost to grind 40 bales at \$85.00 hr^{-1} (\$5.31 per bale), plus the cost of a tractor to load the tubgrinder.

Bedding was considered included with the straw fed in the field feeding systems. The drylot system received wood chips instead of straw, however straw use was estimated at the rate of 1 bale per week for 30 cows with an equipment cost added equivalent to feeding the same amount of material with the bale processor.

The time spent feeding was measured by timing the entire feeding process on two separate days and then averaging the results. The various activities during feeding were noted during the timing process and were separated by equipment operation and labour used. The cost of labour for feeding was \$15.00 hr^{-1}.

Equipment costs were calculated using the Farm Machinery Custom and Rental Rate Guide (SAF, 2006). The time each piece of equipment was used was multiplied by the cost per hr for repair, fuel, lube/oil and fixed costs. Assumptions include interest on investment at 5.6% with machinery investment 50 per cent owned and 50 per cent borrowed. Diesel fuel cost was \$0.71 per L with lube and oil cost at \$0.44 per hr for each 100 horsepower.

Fuel consumption was measured by filling the 100 hp tractor fuel tank to the top, feeding the main herd and the bale processing herd, then refilling the tank and measuring the amount of fuel needed to refill. The amount of fuel used was then divided by the time used and that rate was applied to the different feeding systems. Fuel consumption figures from the Farm Machinery Custom and Rental Rate Guide (SAF, 2006) were used for feeding operations that were not directly measured.

Tractor winter starts were recorded as the number of times a tractor would be started for each feeding system from November 21st, 2003 to March 31st, 2004. Custom manure removal plus application at 67.2 tonnes ha^{-1} were estimated at \$259.45 ha^{-1} using quotes from custom operators in southern Alberta. The additional cost of composting was calculated using figures supplied by the AgTech Centre, Lethbridge, Alberta.

The value of pasture growth was estimated at a value of \$.043 kg^{-1} of dry matter, half of the value of baled hay fed to the animals to allow for the extra cost of swathing, baling, and transportation combined with feed losses.

7.2 Results and Discussion

7.2.1 Feed and bedding

A detailed breakdown of feed and bedding costs in the different systems (Table 7.1) shows relatively similar costs, with the drylot being slightly higher than the in-field systems. Total amounts of feed and bedding provided to the animals were similar.

Table 7.1 Cost of feed and bedding.

System	Provided (as fed)	Cost: Feed		Cost: Grinding		Cost: Total	
	kg cow^{-1} day^{-1}	\$ kg^{-1}	\$ cow^{-1} day^{-1}	\$ kg^{-1}	\$ cow^{-1} day^{-1}	\$ kg^{-1}	\$ cow^{-1} day^{-1}
Bale processing hay	10.5	.076	.80	0	0	.076	.80
Bale processing straw	7.1	.056	.40	0	0	.056	.40
Bale processing total	*17.6*		*1.20*	*0*	*0*		*1.20*
Bale grazing hay	11.0	.076	.83	0	0	.076	.83
Bale grazing straw	6.9	.056	.39	0	0	.056	.39
Bale grazing total	*17.9*		*1.22*	*0*	*0*		*1.22*
Drylot greenfeed	8.3	.061	.51	.018	.11	.079	.62
Drylot feed straw	7.0	.056	.39	.020	.14	.076	.53
Drylot bedding straw	1.9	.056	.11	0	0	.056	.11
Drylot total	*17.3*		*1.02*		*.25*		*1.27*

Although the purchase price of greenfeed for the drylot systems was lower (\$ .015 kg^{-1}) than that of the hay used in the pasture feeding systems, the tubgrinding increased the total cost of both greenfeed and straw. The combined average cost of \$ .078 kg^{-1} for ground greenfeed and straw was thus higher than the combined average cost of \$ .066 kg^{-1} for the unground hay and straw used on the pasture feeding treatments. This higher effective feed cost negated the slightly lower amount fed in the daily feeding system used in the drylot, resulting in the somewhat higher feed cost of the drylot systems. While the rate for custom tubgrinding in this trial was the same as that recommended by the Farm Machinery Custom and Rental Rate Guide (SAF, 2006), it was approximately half the rate charged in a 2006 survey of custom operators in Alberta (AAFRD, 2006), suggesting that tubgrinding can add considerably more cost to a feeding system. Raising the rate to the AAFRD level would increase the drylot feed and bedding cost to a level significantly higher than the pasture feeding systems.

In the pasture feeding the bale grazing system used more hay and less straw than the bale processing system. The amount of extra hay consumption of the bale grazing system (5%) is similar to the extra weight of the bale grazing hay bales (7%) and probably results from the operator feeding similar amounts of bales based on bales per day rather than bale weight. The bale processing system, by further processing the feed, did not result in increased feed efficiency compared to the bale grazing. Processing also did not result in better utilization of the low quality straw by the cattle, probably due to the limited ability to thoroughly mix hay and straw.

Hay and straw left by the cows and measured in the spring (Table 7.2), was similar between the pasture feeding treatments, with little hay left and considerable straw left over. Material left by the drylot animals was much lower.

Table 7.2 Efficiency of each feeding system.

	Feed and bedding		
System	**Amount provided (as fed)**	**Amount uneaten (as fed)**	
	kg cow^{-1} day^{-1}	%	kg cow^{-1} day^{-1}
Bale processing hay	10.5	7.7	.81
Bale processing straw	7.1	38.0	2.69
Bale processing total	*17.6*		*3.50*
Bale grazing hay	11.0	4.4	.49
Bale grazing straw	6.9	44.4	3.06
Bale grazing total	*17.9*		*3.55*
Drylot greenfeed	8.3	5.6	.47
Drylot straw	7.0	6.0	.42
Drylot bedding straw	1.9	70.0	1.36
Drylot total	*17.3*		*2.21*

Tubgrinding greenfeed and straw together made it easier to feed straw with low refusal, probably because of the thorough mixing of feedstuffs. The daily feeding method used in the drylot system also made it easier to limit feed to what was actually consumed daily.

7.2.2 Machinery

Machinery costs were lowest for the bale grazing system, followed by the bale processing system and the drylot systems (Table 7.3). Feeding the cattle in the bale grazing system involved little equipment use, requiring only a tractor for a short period in the fall to set out the bales. Feeding throughout the winter was done by moving electric fence by hand. Therefore, it appears to be ideally suited for farmers who would like to reduce equipment costs and investment to a minimum while still being able to feed baled forage.

Table 7.3 Machinery costs in the winter feeding systems.

Machinery	Cost			
	Bale grazing	**Bale processing**	**Drylot (raw)**	**Drylot (compost)**
	------------------------------- $ cow^{-1} day^{-1} -------------------------------			
Tractor, 250 hp, and tubgrinder (custom)†	0	0	.16	.16
Tractor, 100 hp, FEL‡§	0	0	.07	.07
Feed tractor, 100 hp, FEL	.04	.12	.09	.09
Bale processor	0	.08	0	0
Tractor, 80 hp	0	0	.07	.07
Feed wagon	0	0	.09	.09
Bedding application	incl in feeding	incl in feeding	.04	.04
Manure hauling and processing (custom)¶	0	0	.03	.15
Total	.04	.19	.55	.67

† Included in the feed price, includes contractor wages and profit.

‡ Included in the feed price

§ Front end loader

¶ Includes contractor wages, expenses and profit

As the bale processing system substituted a tractor and bale processor for manual labour to distribute feed, the machinery costs were considerably higher. The bale processor was a large capital expense as the fixed cost of the machine is only applied to one enterprise of the farming operation. The costs presented here for tractors are most applicable to a farming operation that can spread out these expenses over a number of other income generating areas on the farm such as crop production. For example, the cost per hr of the 100 hp tractor is based on a yearly use of 600 hrs. Feeding 100 cows with the bale processor for the 130 d feeding period required 33 tractor hrs, so 566 additional hrs spent on other operations are needed to spread the fixed costs. Using the tractor for only 200 hrs per year almost doubles the cost of operation per hr, raising the total cost of feeding the animals by bale processing.

The feeding system for the drylot animals was elaborate, with the tubgrinding of the feed and daily feeding of the ground ration. While not a typical drylot system, and therefore making a true comparison between intensive and extensive systems difficult, it did show that a complicated feeding system can greatly increase machinery time and costs.

The additional cost of manure handling in a drylot system, however is an unavoidable consequence of feeding animals in a confined location. This cost further increased for the compost system. Composting has other benefits in some operations that may offset its extra cost, such as greatly reducing the hauling time needed when spreading is done on distant fields (Larney et al., 2006), a factor that is becoming more important in intensive livestock operations due to proposed lowering of allowable application rates due to a switch to P limits instead of N. This advantage of composting was not accounted for in this trial as the field where the manure was assumed to be spread was immediately beside the drylot. Compost also has an advantage as a method for safely managing dead farm animals (Fonstad et al., 2003).

Winter tractor starts that would have been necessary in each feeding system (Table 7.4) were measured during the winter and further illustrate the difference in the mechanization of the different feeding systems. The number of cold starts was much greater in the drylot system due to the practice of feeding every day with two tractors, whereas for the bale grazing system no winter feeding starts were needed. The bale processing system ranked between these systems as only one tractor was needed which only had to be started approximately every four d.

Table 7.4 Number of winter tractor starts necessary by feeding system, November 21st to March 31st.

System	Starts					
	November	**December**	**January**	**February**	**March**	**Total**
Bale grazing	0	0	0	0	0	0
Bale processing	3	9	9	8	10	39
Drylot	20	62	62	58	62	264

Winters in the prairie region of Canada are normally severe and the cold conditions are adverse for starting and running heavy diesel equipment. Therefore, most producers that winter feed with tractors provide storage facilities for the equipment. These are usually provided with power for engine heaters and sometimes heat for the facility itself. These additional costs were considered infrastructure and were not included in the cost estimates.

The difference in mechanization between the systems is also illustrated in fuel use (Table 7.5), which increases by 23 times between the bale grazing and the drylot compost systems. When comparing the pasture feeding systems, bale grazing reduced fuel consumption by 3 times when compared to feeding with a bale processor.

Table 7.5 Fuel use and cost in each feeding system.

System	Fuel						
	Feeding and bedding	**Tubgrinding**	**Manure handling**	**Total**	**Fuel .71 liter^{-1} †**	**Fuel .83 liter^{-1} ‡**	**Fuel 1.92 liter^{-1} §**
	---------- liters 100 cows^{-1} 130 days^{-1} -------------				--- \$ 100 cows^{-1} 130 days^{-1} ---		
Bale grazing	109	0	0	109	77	90	209
Bale processing	327	0	0	327	232	271	627
Drylot raw	661	1222	165	2048	1454	1700	3931
Drylot compost	661	1222	581	2464	1749	2045	4730

† .71 liter^{-1} from the Farm Machinery Custom and Rental Rate Guide (SAF, 2006).

‡ .83 liter^{-1} on farm price in Oct 2007, Lethbridge, Alberta (UFA Calgary).

§ 1.92 liter^{-1} British price, Sept 2007 (A.A. Ireland).

Fuel cost used in the calculations was \$0.71 L^{-1}. The total fuel cost for each system ranged from \$77.00 for the bale grazing to \$1749.00 for the drylot compost, based on feeding 100 cows. Tubgrinding was the largest share of total fuel use in the drylot systems. Fuel prices are predicted to increase substantially, with farmers in Alberta already paying 0.83 L^{-1} for diesel in 2007 (UFA Calgary, personal communication, 2007). Bale grazing, and to a lesser extent, bale processing, appear to offer a way to buffer the impact of rising fuel prices. For example, increasing diesel prices to levels of 1.92 L^{-1} which the British are experiencing now, (A.A. Ireland, 2007) increased the fuel cost on the bale processing to \$209.00, while the drylot compost system increased to \$4730.00.

7.2.3 Labour

Labour needed for each system (Table 7.6) was lowest in the bale processing system, followed by the bale grazing system. The drylot systems, especially when using composting, required the most labour.

Table 7.6 Labour requirements for each feeding system (hours).

	Hours					
	Feeding			Feed	Manure	Total
System				prep†	handling‡	
	---------------------------- hours 100 $cows^{-1}$ 130 $days^{-1}$ --------------------------					
	Outside	In machine	Total			
Bale grazing	47	11	58	0	0	58
Bale processing	0	33	33	0	0	33
Drylot raw	0	36	36	25	5	67
Drylot compost	0	36	36	25	20	81

†Cost of feed preparation labour was included in the feed costs.

‡Cost of manure handling labour was included in the manure handling costs.

While feeding the cattle by bale grazing had low equipment requirements, it could be considered more demanding on the operator as most of the time was spent outside in the cold. Feeding with the bale processor was spent inside a warm tractor, and feeding in the drylot was similarly done inside a warm machine. The most difficult part of the bale grazing system on this trial was removing iced on plastic twine (R. Kirzinger, personal communication, 2004). Popular options for farmers who bale graze are removing all the twine in the fall, cutting the twine only, or leaving the twine on the bales uncut, preferably with sisal fiber twine if possible (G. Lastiwka, personal communication, 2007). While a trial removing all twine in the fall did not reduce the time required, it did transfer that time from cold winter weather to warm fall conditions. Simulating a cutting only system reduced the time spent with twine by 87% and the total manpower required by 31%, making the feeding labour required similar to the bale processing system. These options therefore appear worthwhile for farmers to consider.

Labour skill required was proportional to the level of mechanization. The operator feeding the animals on the bale grazing system had only to be able to perform manual labour functions such as removing string and moving electrical wire. The bale processing system required the ability to operate a front end loader tractor and a bale processor. The drylot systems were more complicated with the operation of two tractors, a front end loader, and a feed wagon, as well as the contracted labour for the tub grinding and the manure removal. Composting added more specialized equipment to the operation. This has implications with regards to the ease of a farmer to be able to find substitute labour during holidays or over a period of ill health. The more mechanized the system, the more skilled the replacement labour required and therefore the more difficult for a farmer to take time off.

7.2.4 Pasture growth

The additional pasture growth measured against the unfertilized, unmanured check for the different feeding systems (Table 7.7) shows a considerable advantage for the pasture feeding systems as compared to the drylot systems.

Table 7.7 Additional pasture growth compared to the unfertilized check produced by each feeding system.

System	Additional growth					
	2004 -2005 measured	Value at .043 kg^{-1}†	2005 2nd cut ‡	2006 to 2008 §	Final total	Final value at .043 kg^{-1}
	kg ha DM^{-1}	\$ cow day^{-1}	---------------	kg ha DM^{-1}	-------------	\$ cow day^{-1}
Bale grazing	5328	.11	1504	9583	16462	.34
Bale processing	8672	.18	2514	16629	27861	.58
Drylot raw	1034	.02	74	74	1108	.02
Drylot compost	1593	.03	110	110	1703	.04

† 50% of the hay DM price

‡ Estimated, Lawrence and Knipfel, (1981), Zhang et al. (2006)

§ Estimated, 4^{th} year observations, Zhang et al. (2006)

Only the increased yield in forage growth of each treatment in the first 18 months after winter feeding was used in the overall economic calculations. However the increase in yield in the last harvest of forage on the pasture feeding sites suggested a much larger amount of forage could be returned from the winter feeding treatments in the long term. Since no literature is available on the length of effect pasture winter feeding has on forage growth, the long term yield calculation is based on observations of the pasture 4 years post treatment. This suggests that the winter feeding pastures could provide additional growth per year at least as great as that found on the first cut of the second year of production, with this yield increase lasting for at least three additional years. Holt et al. (1991) at Swift Current, Saskatchewan, found that a one time application of 390 kg ha^{-1} of commercial fertilizer N increased pasture production significantly for twelve years, therefore the values calculated here are probably very conservative.

7.2.5 Soil nutrients

Another way of calculating the benefit to the pasture of the different feeding systems is to measure the nutrient value added to the soil. Mean apparent recovery in the pasture forage of N and P from the feed and bedding imported onto the field by the pasture feeding systems was found to be similar to that reported in the literature from commercial fertilizer (Table 7.8). The recovery from drylot systems was calculated to be much lower, reflecting poor recovery of N and P from the manure by the forages in the pasture and high losses of feed N in the drylot itself according to the literature (Appendices I, J).

Table 7.8 Recovery of nitrogen and phosphorus added in feed, bedding, and manure in the forage crops grown.

System	Recovery	
	Nitrogen	**Phosphorus**
	---------------------------- %	-------------------------
Bale grazing	27.7	17.4
Bale processing	41.0	26.9
Drylot raw	0.9	2.3
Drylot compost	1.0	2.8
Commercial fertilizer (literature)	34.8†	13.0‡

† Average of Smika et al. (1960), Holt and Zentner (1985), Zhang et al. (2006) and Stumborg et al. (2007)

‡ Average of Smika et al. (1960) and Holt and Zentner (1985)

Because the recovery of feed nutrients in the harvested forage on the winterfeeding sites was as high or higher than found with commercial fertilizer in the literature, the entire \$1398.00 ha^{-1} commercial value of the nutrients hauled onto the field on the winterfeeding sites (Appendix K) was used as a value when calculating the cost of wintering the animals with bale processing or bale grazing. For the drylot systems a value was given proportional to how much their nutrient recovery rates were compared to literature recovery for commercial fertilizer. The value of nutrients provided for each animal per day was \$0.67 cents in the pasture feeding systems, over half the purchase price of feed and bedding. The values of \$0.07 cents provided in the raw manure system and \$0.08 cents per day in the compost system were much lower. For a herd of a hundred animals winter fed for 130 d, this amounts to a loss of approximately \$8000.00 in readily available soil nutrients in the drylot systems.

7.2.6 Overall

The cost of feed and bedding was similar between all systems, with the savings from using the lower cost feed in the drylot systems canceling out the extra cost of tub grinding (Table 7.9). Machinery costs increased sharply from the bale grazing system, where only a tractor was needed to set out the bales, to the drylot compost system, where manure was composted by machine and hauled out to the field. In contrast labour was highest for the bale grazing system, mainly due to the removal of twine. Total system cost for bale grazing was lower than the bale processing system, with both pasture wintering systems less than drylot feeding. When the value of increased pasture growth over an 18 month period is subtracted from the costs, the systems that feed cattle directly on pasture are about two thirds the costs of the drylot systems.

Table 7.9 Cost comparison of the different feeding systems, including subtraction of additional pasture growth revenue.

	Cost			
	Bale grazing	**Bale processing**	**Drylot (raw)**	**Drylot (compost)**
	$\$ \text{ cow}^{-1} \text{ day}^{-1}$			
Feed and bedding	1.22	1.20	1.27	1.27
Feed tractor 1	.04	.10	.09	.09
Bale processor	0	.07	0	0
Feed tractor 2	0	0	.07	.07
Feed wagon	0	0	.09	.09
Bedding application	0	0	.04	.04
Manure removal	0	0	.03	.12
Total	*1.26*	*1.39*	*1.58*	*1.71*
Feeding labour	.07	.04	.04	.04
Total	*1.33*	*1.43*	*1.63*	*1.75*
Pasture growth	.11	.18	.02	.03
Final total	*1.22*	*1.25*	*1.60*	*1.71*

When a value is given to the plant available nutrients left behind by the animals in terms of equivalent value of commercial fertilizer (Table 7.10), the net cost of the pasture feeding systems is reduced until it is under half that of the drylot systems.

Table 7.10 Cost comparison of the feeding systems, including subtraction of nutrient value added to the pastures.

	Cost			
	Bale grazing	**Bale processing**	**Drylot (raw)**	**Drylot (compost)**
	---------- $ cow^{-1} day^{-1} ----------			
Feed and bedding	1.22	1.20	1.27	1.27
Machinery (feed tractor 1)	.04	.10	.09	.09
Machinery (bale processor)	0	.07	0	0
Machinery (feed tractor 2)	0	0	.07	.07
Machinery (feed wagon)	0	0	.09	.09
Machinery (bedding appl.)	0	0	.04	.04
Manure removal	0	0	.03	.12
Total	*1.26*	*1.39*	*1.58*	*1.71*
Feeding labour	.07	.04	.04	.04
Total	*1.33*	*1.43*	*1.63*	*1.75*
Soil nutrients	.67	.67	.07	.08
Final total	*.65*	*.76*	*1.56*	*1.66*

7.3 Conclusions

Feed and bedding costs were similar in all systems, with a cheaper feed used in the drylot systems more than offset by the expense of tubgrinding. The weight of material used in all systems was similar. The intensive feeding method used in the drylot did reduce uneaten straw considerably, but this did not result in cost savings overall.

Machinery costs were extremely low when bale grazing due to the substitution of labour for machinery. They were greatly increased in the drylot systems by the tubgrinding used to prepare the feed and by composting. There was an increase of approximately 23 times in fuel consumption in the drylot composting system compared to the bale grazing system.

The bale processing in-field feeding required the least labour hours. The drylot systems had the highest amount of operator time, but with a significant portion being contracted labour necessary for specialized jobs. Bale grazing took double the hours of the other methods when feeding but required the lowest operator skill level.

Improved pasture growth provided additional economic return to the pasture feeding systems. However the short monitoring time may not have accounted for much of the potential comparative gain. The effective value of the feed nutrients in the soil on the pasture feeding systems amounted to over half of the feed cost, while nutrient capture and its associated value on the drylot were much smaller.

Costs in the pasture feeding systems were approximately two thirds the cost of feeding in the drylot when a cost credit was assigned for extra revenue realized from additional pasture growth. These costs dropped to under half when the commercial fertilizer value of nutrients added in feed and bedding and taken up in the forage was used instead. The drylot systems used in the comparison were considerably more expensive than necessary due to the elaborate feeding system used with intensive feed preparation through tubgrinding. Still, both pasture feeding systems appear to be promising methods for prairie cow-calf producers to economically winter cattle while adapting to rising machinery, fuel, and fertilizer prices.

8.0 GENERAL CONCLUSIONS

Both winter pasture feeding systems (in-field bale grazing and bale processing) greatly increased nutrient retention and recycling efficiency in the pasture compared to drylot systems, while reducing equipment and fuel input costs. This was accomplished without reducing cattle performance. The implications of these findings are timely as concerns mount about increasing fertilizer, fuel and equipment costs as well as nutrient losses to the environment.

With over five million beef cattle in cow-calf operations in Canada (Statistics Canada, 2007), and using a winter feeding period of 130 d, the economic benefits found here of between $.46 and $.91 saved per cow per day for wintering cows in pasture feeding systems would provide potential savings up to 620 million dollars per year to Canadian cow-calf operators, assuming the majority of feeding systems are currently drylot. Included are savings of 107 million L of diesel fuel and a gain of 900,000 tonnes of commercial fertilizer. The conservation of nutrients possible with these systems may be of special importance to organic farmers, as they can face nutrient depletion more rapidly (Roberts et al., 2008).

The greater nutrient recycling in pasture feeding systems, especially noted for N, will enable farmers to more easily meet nutrient management regulations that regulate manure deposition based on P amounts , as well as future regulations that could be based on nutrient balance and net retention in a system. Other factors that should be considered include greenhouse gas emissions. For example, DeRamus et al. (2003) found up to a 22% reduction in methane emissions from cattle that grazed high-quality forages originating from better fertilized pastures. As well a reduction in machinery operation, fuel, and fertilizer use is anticipated to reduce net greenhouse gas production.

Together with economic and environmental considerations covered in this thesis, there are also potential marketing and perception impacts on the cattle industry that were not directly addressed in this current study. These include perceived improvements in cattle welfare by the free range method of winter feeding, and the idea of ranchers working to improve the environment by voluntarily conserving scarce natural resources and reducing nutrient losses to the environment.

9.0 GAPS AND DIRECTIONS FOR FURTHER RESEARCH

As there is a limited body of published information on winter pasture feeding systems, and the results of this thesis point to significant advantages for farmers adopting them, some additional studies on the subject of winter pasture feeding would be useful. Suggestions are outlined below.

1. There is a need for trials looking at pasture feeding systems specifically as a pasture rejuvenation method. Feeding straw on a bunchgrass such as RWR, as done in the trial for this thesis, appeared to be somewhat problematic in pasture rejuvenation as it resulted in smothering of the forage. A comparison of feeds, including those that are utilized better by the cattle, or creeping rooted grasses that may be more suited to high surface residue levels would be useful. Effects of different cattle concentrations in cow-days ha^{-1} and measurement of the temperature and moisture differences under thatch layers would be valuable in understanding relationships. Harvesting and assessing of the pasture forage production for a number of years to see how many years the rejuvenation benefits last, especially if performed under current rotational grazing systems, would be useful, as the work in this thesis only covered 18 months after winter feeding. Direct comparisons with traditional methods of pasture rejuvenation such as application of commercial fertilizer, tillage and reseeding would also be useful.

2. The drylot system used to feed in the comparison in this thesis was intensive in nature, being directed towards high efficiency in cattle feed consumption. However many other models for drylot feeding systems exist and may be more common. Comparisons of winter pasture feeding with other drylot feeding systems such as whole round bales in feeders would be useful to provide more data on the variety of different pasture feeding and drylot systems that are in use today. Economic comparisons between

pasture feeding techniques that minimize waste (ex. feeding in bunks) would also be useful with those that provide more pasture nutrients and thatch, as trade-offs would likely exist between feeding for better cattle economics and feeding for better pasture rejuvenation.

3. Consideration of nutrients that may have moved deeper in the profile or off-site in the runoff. This trial utilized surface soil sampling. Measurements of nutrient movement from the winter feeding sites in run-off and leaching from snowmelt and rainfall are needed. With the large amounts of nutrients applied to pasture wintering sites, it would be useful to determine what losses of nutrients there are, and what factors affects these losses. A trial with deeper sampling depths would be useful, especially after repeated in-field feeding.

4. Finally, the applicability of using livestock to recycle nutrients in-field needs to be explored as it pertains to other areas of agriculture. One system that may be of interest would be agroforestry. Here the high levels of nutrients combined with large amounts of thatch may be of considerable benefit in providing a sustained supply of nutrient and help in control weed growth. Another is organic production systems. As most forage production uses no synthetic fertilizers or pesticides, sources of cattle feed that would satisfy organic standards should be easy to find.

10.0 LITERATURE CITED

AA Ireland Limited. 2007. AARoadwatch.ie. [Online]. Available at http://www.aaroadwatch.ie/eupetrolprices/ (accessed 20 October 2007, verified 23 October, 2007). AA Ireland Limited, Dublin.

Adams, B.W., G. Ehlert, C. Stone, M. Alexander, D. Lawrence, M. Willoughby, D. Moisey, C. Hincz, and A. Burkinshaw. 2004. Range health assessment for grassland, forest, and tame pasture. Public Lands and Forests Division, Alberta Sustainable Resource Development. Pub. No. T/044.

Afzal, M., and W.A. Adams. 2002. Heterogeneity of soil mineral nitrogen in pasture grazed by cattle. Soil Sci. Soc. Am. J. 56:1160-1166.

Alberta Agriculture and Food. 2006. Custom rates survey, livestock operations. 2006. [Online]. Available at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd11400/$file/livestock.pdf?OpenElement (accessed 22 October, 2007, verified 23 October, 2007). Alberta Agriculture and Food, Edmonton, AB.

Ball, R., D.R. Keeney, P.W. Theobald, and P. Nes. 1979. Nitrogen balance in urine affected areas of a New Zealand pasture. Agron. J. 71:309-314.

Ball, P.R., and D.R. Keeney. 1981. Nitrogen losses from urine-affected areas of a New Zealand pasture, under contrasting seasonal conditions. p. 342-344. *In* J. Allan Smith (ed.) Proc. XIV Int. Grassl. Cong. Lexington, USA. 15-24 June 1981. Westview Press, Boulder, Colorado.

Ball, P.R., and J.C. Ryden. 1984. Nitrogen relationships in intensively managed temperate grasslands. Plant Soil 76:22-23.

Beckwith, C.P., P.J. Lewis, A.G. Chalmers, M.A. Froment, and K.A. Smith. 2002. Successive annual applications of organic manures for cut grass: short term observations on utilization of manure nitrogen. Grass Forage Sci. 57:191-202.

Bierman, S, G.E Erickson, T.J. Klopfenstein, R.A. Stock, and D.H. Shain. 1999. Evaluation of nitrogen and organic matter balance in the feedlot as affected by level and source of dietary fiber. J. Anim. Sci. 77:1645-1653.

Bittman, S., C.G. Kowalenko, D.E. Hunt, and O. Schmidt. 1999. Surface-banded and broadcast dairy manure effects on tall fescue yield and nitrogen uptake. Agron. J. 91:826-833

Booth, D.T., S.E. Cox, M. Louhaichi, and D.E. Johnson. 2004. Lightweight camera stand for close-to-earth remote sensing. J. Range. Manage. 57:675-678.

Bristow, K.L. 1988. The role of mulch and its architecture in modifying soil temperature. Aust. J. Soil Res. 26:269-80.

Bromfield, S.M., and O.L. Jones. 1972. The initial leaching of hayed-off pasture plants in relation to the recycling of phosphorus. Aust. J. Agric. Res. 23:811-824.

Butler, D.M., N.N. Ranells, D.H. Franklin, M.H. Poore, and J.T. Green, Jr. 2007. Ground cover impacts on nitrogen export from manured riparian pasture. J. Environ. Qual. 36:155-162.

Canadian Cattleman's Association. 2005. History of the cattle industry. [Online]. Available at http://www.cattle.ca/about_cca/history.htm. (accessed 22 June 2005; confirmed 25 April 2007). Canadian Cattleman's Association, Calgary, AB.

Chen, W. W.P McCaughey, and C.A. Grant. 2004. Pasture type and fertilization effects on N-2 fixation, N budgets and external energy inputs in western Canada. Soil Biol. Biochem. 36:1205-1212.

Cherney, J. H., Mikhailowa, E. A. and Cherney, D. J. R. 2002. Tetany potential of orchardgrass and tall fescue as influenced by fertilization with dairy manure or commercial fertilizer. J. Plant Nutr. 25: 1501-1525.

Cole, N.A. 1999. Nitrogen retention by lambs fed oscillating dietary protein concentrations. J. Anim. Sci. 77:215-222.

Craig, D.P., C.E. Bock, B.C. Bennet, and J.H. Bock. 1999. Habitat relationships among grasshoppers (Orthoptera : Acrididae) at the western limit of the Great Plains in Colorado. Am. Midl. Nat. 142: 314-327.

Cuomo, G.J., D.G. Johnson, and W.A. Head. 2001. Interseeding kura clover and birdsfoot trefoil into existing cool-season grass pastures. Agron. J. 93:458-462.

Davis, J.G., K.V Iversen, and M.F. Vigil. 2002. Nutrient variability in manures: implications for sampling and regional database. J. Soil Water Conserv. 57:473-478.

DeRamus, H.A., T.C. Clement, D.D. Giampola, and P.C. Dickinson. 2003. Methane emissions of beef cattle on forages: efficiency of grazing management systems. J. Environ. Qual. 32:269-277.

Dixon, J.E., G.R. Stephenson, A.J. Lingg, D.V. Naylor, and D.D. Hinman. 1981. Stocking rate influence upon pollutant losses from land wintering rangeland cattle: a preliminary study. p. 261-264. *In* Livestock Waste, a Renewable Resource. Proc. 4th Int. Symposium on Livestock Wastes, 15-17 Apr. 1980. Am. Soc. Ag. Eng. St Joseph, MI.

Dormaar, J.F., and Willms W.D. 1998. Effect of forty-four years of grazing on fescue grassland soils. J. Range. Manage. 51:122-126.

Downey B.A., P.F. Jones, R.W. Quinlan, and G.J. Scrimgeour. 2006. Use of playback alarm calls to detect and quantify habitat use by richardson's ground squirrels. Wildlife Soc. Bull. 34:480-484.

Edwards, D.R., B.T. Larson, and T.T. Lim. 2000. Runoff nutrient and fecal coliform content from cattle manure application to fescue plots. J. Am. Water Res. Assoc. 36:711-721.

Eghball, B., J.F. Power, J.E. Gilley, and J.W. Doran. 1997. Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. J. Environ. Qual. 26:189-193.

Entz M.H., W.J. Bullied, and F. Katepa-Mupondwa. 1995. Rotational benefits of forage crops in Canadian prairie cropping systems. J. Prod. Agric 8:521-529.

Environment Canada 2007. Canadian climate normals for Guernsey, Sask. [Online]. Available at http://climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=SASK&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=2914&&autofwd=0 (accessed 10 Dec 2007, verified 12 Dec, 2007). Environment Canada, Ottawa, ON.

Erickson, G.E., C.T. Milton, and T.J. Klopfenstein. 2000. Dietary phosphorus effects on performance and nutrient balance in feedlots. In: Proc. 8th Int. Symp. Anim. Agric. Food Processing Wastes. Am. Soc. Eng., St. Joseph, MI. p.10-17.

Erickson, G.E. and T. Klopfenstein. 2001. Managing N inputs and the effect on N losses following excretion in open-dirt feedlots in Nebraska. TheScientificWorld 1(S2): 830-835.

Fisher, L.J., N.E. Dinn, J.A. Shelford, and J.W. Paul. 2000. The effect of concentration and form of dietary nitrogen on the utilization and excretion of nitrogen by lactating dairy cows. Can. J. Anim. Sci. 2000:207-209.

Fonstad et al. 2003. Evaluation and demonstration of composting as an option for dead animal management in Saskatchewan. Can. Biosys. Eng. 45:6.19-6.25.

Franzluebbers, A.J., J.A. Stuedemann, and H.H. Schomberg. 2000. Spatial distribution of soil carbon and nitrogen pools under grazed tall fescue. Soil Sci. Soc. Am. J. 64:635-639.

Gerrish, J.R., P.R. Peterson, and J.R. Brown. 1995. Grazing management affects soil phosphorus and potassium levels. p 175-179. *In* Proc. Amer. Forage and Grassl. Coun. Lexington, KY. March 12-14, 1995.

Griffin, G. 1997. Effect on water quality, soil fertility, and subsequent forage yield as a result of wintering cows on a forage stand. [Online]. Available at http://h1.ripway.com/Paul%20Jungnitsch/Griffin%20bale%20grazing/Bale-grazingTrial1SoilFertility.wpd (accessed 12 Sept 2003; verified 20 Aug 2007). North Peace Forage Association, Fairview, AB. Farming for the Future Report No. 1997a; 7pp.

Grunes, D. L. and Welch, R. M. 1989. Plant contents of magnesium, calcium and potassium in relation to ruminant nutrition, J. Anim. Sci. 67: 3485-3494

Gustafson, G.M., E. Salomon, S. Jonsson, and S. Steineck. 2003. Fluxes of K, P, and Zn in a conventional and an organic farming system through feed, animals, manure, and urine-a case study at Ojebyn, Sweden. Europ. J. Agron. 20:89-99.

Harapiak, J.T., S.S. Malhi, G. M. Nyborg, and N.A. Flore. 1992. Dry matter yield and nitrogen recovery from bromegrass in south-central Alberta as affected by rate of long-term nitrogen applications. Commun. Soil. Sci. Plant Anal. 23:1245-1256.

Hardin, P.J. and M.W. Jackson. 2005. An unmanned aerial vehicle for rangeland photography. Range Ecol. Manage. 58:443-442.

Haynes, R.J., and P.H. Williams. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Adv. Agron. 49:119-199.

Helgason, B.L., F.J. Larney, H.H. Janzen, and B.M. Olson. 2007. Nitrogen dynamics in soil amended with composted cattle manure. Can. J. Soil Sci. 87:43-50.

Henry, L. 2003. Henry's handbook of soil and water. Henry perspectives. Saskatoon, SK.

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

Holt, N.W., R.P. Zentner, T. Lawrence, M.R. Kilcher, and H. Peters. 1991. Effect of nitrogen fertilizer on beef production and forage quality of Russian wildrye. Can. J. Anim. Sci. 71:833-843.

Joffe, J.S, and A.K. Levine. 1944. Fixation of potassium in relation to exchange capacity of soils: II. associative fixation of other cations, particularly ammonium. Soil Sci. 63:151-158.

Jolley, L.W., and C.A. Raguse. 1981. Responses of annual range grasses and legumes to comparable applications of manurial and inorganic fertilizers. J. Range. Manage. 34:294-299.

Kaliel D. and J. Kotowich. 2002. Economic evaluation of cow wintering systems – provincial swath grazing survey analysis. Alberta production economics branch, Alberta Agriculture Food and Rural Development, Edmonton, AB.

Kallenbach, R. 2000. Reducing losses when feeding hay to beef cattle. [Online]. Available at http://extension.missouri.edu/explorepdf/agguides/crops/g04570.pdf. (accessed 22 May, 2005, confirmed 25 April, 2007.) University of Missouri-Columbia, Columbia MO.

Kansas State Agricultural College. 1915. Soil survey of Cherokee county, Kansas. Bull. No. 207. Kansas state printing plant. Topeka, KS.

Karn, J.F., A.B. Frank, J.D. Berdahl, and W.W. Poland. 2004. Ploidy, water, and nitrogen effects on Russian wildrye chemical composition. J. Range Manage. 57:503-510.

Keeney, D.R. and D.W. Nelson. 1982. Nitrogen – inorganic forms. *In*: A.L. Page, R.H. Miller, and D.R. Keeney (eds.). Methods of soil analysis. Part 2. Chemical and microbiological properties. Agronomy Monograph no. 9. 2nd Edition. ASA-SSSA: Madison, WI, USA. p643-698.

Kilcher, M.R. 1958. Fertilizer effects on hay production of three cultivated grasses in southern Saskatchewan. J. Range Manage. 11:231-234.

Kirkman, J.H., A. Basker, A. Surapaneni, and A.N. MacGregor. 1994. Potassium in the soils of New Zealand – a review. N.Z. J. Agric. Res. 37:207-227.

Kissinger, W.F., R.K. Koelsch, G.E. Erickson, and T.J. Klopfenstein. 2005. Managing phosphorus in beef feeding operations. Paper 054061. 2005 ASAE annual meeting.

Kopp, J.C., W.P. McCaughey, and K.M. Wittenberg. 2003. Yield, quality and cost effectiveness of using fertilizer and/or alfalfa to improve meadow bromegrass pastures. Can. J. Anim. Sci. 83:291-298.

Kunkle, W.E., R.S. Sand, and D.O. Rae. 1994. Effects of body condition on productivity in beef cattle. Doc. SP-144. Dep. Animal Sci, Florida Cooperative. Ext. Serv., Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.

Lardner, H.A. 2002. Livestock manure on perennial pasture. Fact sheet #2002-03. Western Beef Development Centre. Lanigan, SK.

Lardner, H.A. 2003. Effect of composted and non composted manure on soil nutrients, forage yield, and animal performance. Fact sheet #2003-02. Western Beef Development Centre. Lanigan, SK.

Lardner, H.A., S.B.M. Wright, R.D.H. Cohen, P. Curry, and L. MacFarlane. 2000. The effect of rejuvenation of Aspen Parkland ecoregion grass-legume pastures on dry matter yield and forage quality. Can. J. Plant Sci. 80:781-791.

Larney, F.J., A. F. Olson, A.A. Carcamo, and C. Chang. 2000. Physical changes during active and passive composting of beef feedlot manure in winter and summer. Bioresour. Technol. 75:139-148.

Larney, F.J., and R.E. Blackshaw. 2003. Weed seed viability in composted beef cattle feedlot manure. J. Environ. Qual. 32:1105-1113.

Larney, F.J., K. E. Buckley, X. Hao and W. P. McCaughey. 2006. Fresh, stockpiled, and composted beef cattle feedlot manure: nutrient levels and mass balance estimates in Alberta and Manitoba. J. Environ. Qual. 35:1844-1854

Larson, F., and W. Whitman. 1942. A comparison of used and unused grassland mesas in the badlands of South Dakota. Ecology. 23:438-445.

Lawrence, T., and J.E. Knipfel. 1981. Yield and digestibility of crested wheatgrass and russian and altai wild ryegrasses as influenced by N fertilization and date of first cutting. Can. J. Plant Sci. 61:609-618.

Lawrence, T., G.E. Winkleman, and F.G. Warder. 1982. The chemical composition of russian and altai wild ryegrass and crested wheatgrass as influenced by N fertilization and date of harvest. Can. J. Plant Sci. 62:373-390.

Lenehan, N.A., J.M. DeRouchey, T.T. Marston, and G.L. Marchin. 2005. Concentrations of fecal bacteria and nutrients in soil surrounding round bale feeding sites. J. Anim. Sci. 83:1673-9.

Lim, T.T., D.R. Edwards, S.R. Workman, B.T. Larson, and L.Dunn. 1998. Vegetated filter strip removal of cattle manure constituents in runoff. Trans. ASAE. 41:1375-1381.

Lorentz, R.J. and G.A. Rogler. 1962. A comparison of methods of renovating old stands of crested wheatgrass. J. Range Manage. 15:215-219.

Lowman, B.G., Scott, N.A. and Sommerville, S.H. 1976. Condition scoring for cattle. East of Scotland College of Agriculture, November 1976. Bull. No. 6. Edinburgh School of Agriculture, Edinburgh, UK.

Lupwayi, N.Z., G. W. Clayton, J. T. O'Donovan, K. N. Harker, T. K. Turkington, and Y. K. Soon. 2006. Potassium release during decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 86:473-481.

Marx, T. 2006. Body condition scoring your cow herd. Alberta Agriculture Food and Rural Development. Edmonton, AB.

Mathews, B.W., L.E. Sollenberger, V.D. Nair, and C.R. Staples. 1994. Impact of grazing management on soil nitrogen, phosphorus, potassium, and sulphur distribution. J. Environ. Qual. 23:1006-1013.

McCartney, D., J.A. Basarab, E.K. Okine, V.S. Baron, and A.J. Depalme. 2004. Alternative fall and winter feeding systems for spring calving beef cows. Can. J. Anim. Sci. 84:511-522.

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

Mooleki, S.P., J.J. Schoenau, J.L. Charles, and G. Wen. 2004. Effect of rate, frequency and incorporation of feedlot cattle manure on soil nitrogen availability, crop performance and nitrogen use efficiency in east-central Saskatchewan. Can. J. Soil Sci. 84:199-210.

Morse, D., H.H. Head, and C.J. Wilcox. 1992. Disappearance of phosphorus in phytate from concentrates *in vitro* and from rations fed to lactating dairy cows. J. Dairy Sci. 75:1979-1986.

Muck, R.E., and T.S. Steenhuis. 1981. Nitrogen losses in free stall dairy barns. p. 406-409. *In* Livestock Wastes: A Renewable Resource. Proc. 4th Int. Symposium on Livestock Wastes. 15-17 Apr. 1980. Am. Soc. of Agric. Eng., St. Joseph, MI.

Nayigihugu, V., A.D. Schleicher, D.W. Koch, L.J. Held, J.W.Flake, and B.W. Hess. 2007. Beef cattle production, nutritional quality, and economics of windrowed forage vs. baled hay during winter. Agron. J. 99:944-951.

Nennich, T. D., J.H. Harrison, L.M. VanWieringen, D. Meyer, A. J. Heinrichs, W.P. Weiss, N.R. St-Pierre, R.L. Kincaid, D.L. Davidson, and E. Block. 2005. Prediction of manure and nutrient excretion from dairy cattle. J. Dairy Sci. 88: 3721-3733.

National Research Council. 2000. Nutrient requirements of beef cattle. 7th rev ed [update 2000]. Natl. Acad. Press, Washington, D.C.

Nuttal, W.F., D.H. McCartney, S. Bittman, P.R. Horton, and J. Waddington. 1991. The effects of N,P,S fertilizer, temperature and precipitation on the yield of bromegrass and alfalfa pasture established on a luvisolic soil. Can. J. Plant Sci. 71:1047-1055.

Olfert, E.D., B.M. Cross, and A.A. McWilliams. (eds.) 1993. Guide to the care and use of experimental animals. Vol. 1. Canadian Council on Animal Care, Ottawa, ON.

Olson, B.M, and L.W. Papworth. 2006. Soil chemical changes following manure application on irrigated alfalfa and rainfed timothy in southern Alberta. Can. J. Soil Sci. 86: 119-132.

Onsager J.A. 2000. Suppression of grasshoppers in the Great Plains through grazing management. J. Range. Manage. 53: 592-602.

Owens, L.B., R.W. Van Keuren, and W.M. Edwards. 1982a. Environmental effects of a medium-fertility 12-month pasture program: I. hydrology and soil loss. J. Environ. Qual. 11:236-240.

Owens, L.B., R.W. Van Keuren, and W.M. Edwards. 1982b. Environmental effects of a medium-fertility 12-month pasture program: II nitrogen. J. Environ. Qual. 11:241-246.

Owens, L.B., R.W. Van Keuren, and W.M. Edwards. 2003. Non-nitrogen nutrient inputs and outputs for fertilized pastures in silt loam soils in four small Ohio watersheds. Agric. Ecosyst. Environ. 97:117-130.

Paul, J.W., N.E. Dinn, T. Kannangara, and L.J. Fisher. 1998. Protein content in dairy cattle affects ammonia losses and fertilizer nitrogen value. J. Environ. Qual. 27:528-534.

Pederson, J.A, G.E. Brink, and T.E. Fairbrother. 2002. Nutrient uptake in plant parts of sixteen forages fertilized with poultry litter: nitrogen, phosphorus, potassium, copper, and zinc. Agron. J. 94:895-904

Peterson, P.R. and J.R. Gerrish. 2005. Grazing management affects manure distribution by beef cattle. [Online]. Available at http://aes.missouri.edu/fsrc/research/afgc95pp.stm. (accessed 6 July 2005; verified 25 April, 2007). University of Missouri-Columbia, Columbia MO.

Potash & Phosphate Institute, 2005. Soil test levels in North America, 2005: Summary update. PPI/PPIC/FAR Technical Bulletin 2005-1. Norcross, GA.

Powell, J.M., F.N. Ikpe, Z.C. Somdas, and S. Fernandez-Rivera. 1998. Urine effects on soil chemical properties and the impact of urine and dung on pearl millet yield. Exp. Agric. 34:259-276.

Qian, P., J.J. Schoenau, and R.E. Karamanos. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test: A modification of the Kelowna extraction. Commun. Soil Sci. Plant Anal. 25, 627-635.

Qian, P, and J.J. Schoenau. 2002. Availability of nitrogen in solid manure amendments with different C:N ratios. Can. J. Soil Sci. 82:219-225.

Qian, P., J.J. Schoenau, T. King and M. Japp 2005.–Effect of repeated manure application on potassium, calcium and magnesium in soil and cereal crops in Saskatchewan. Can. J. Soil Sci. 85:397-403.

Qian, P., J.J. Schoenau, T. Wu, and P. Mooleki. 2004. Phosphorus amounts and distribution in a Saskatchewan soil after five years of swine and cattle manure application. Can. J. Soil Sci. 84:275-281.

Roberts, C.J., D.H. Lynch, R.P. Voroney, R.C. Martin, and S.D. Juurlink. 2008. Nutrient budgets of Ontario dairy farms. Can. J. Soil Sci. 88:107-114.

Rotz, C.A. 2004. Management to reduce nitrogen losses in animal production. J. Anim. Sci. 82 (E. Suppl.): E119-E137

Royer, I., R.R. Simard, G.M. Barnett, D. Cluis, and D.A. Angers. 2003. Long-term effects of liquid hog manure on the phosphorus state of a silt loam cropped to corn. Can. J. Soil. Sci. 83: 589-600.

Salazar, F.J., D. Chadwick, B.F. Pain, D. Hatch, and E. Owen. 2005. Nitrogen budgets for three cropping systems fertilized with cattle manure. Bioresour. Technol. 96:235-245.

SAS Institute, Inc. 1985. SAS user's guide. Statistics, Version 5, ed. SAS Institute Inc, Cary, N.C. USA.

Saskatchewan Agriculture and Food. 1997. Manual for developing a manure and dead animal management plan. Saskatchewan Agriculture and Food, Regina, SK.

Saskatchewan Agriculture and Food. 2000. Beef cattle feeding systems. [Online]. Available at http://www.agr.gov.sk.ca/docs/production/CattleFeedingSystems.asp. (updated March 2004, accessed 6 July, 2005, verified 25 April, 2007). Saskatchewan Agriculture and Food, Regina, SK.

Saskatchewan Agriculture and Food. 2006. Farm machinery custom and rental rate guide 2006-07. [Online]. Available at http://www.agriculture.gov.sk.ca/Default.aspx?DN=0657b8e6-6389-453e-b609-8eca49494d16 (accessed 22 October, 2007, verified 23 October, 2007). Saskatchewan Agriculture and Food, Regina. SK.

Saskatchewan Soil Survey. 1992. The Soils of Prairie Rose Rural Municipality No. 309, Saskatchewan. Saskatchewan Institute of Pedology. University of Saskatchewan, Saskatoon, Canada.

Satter, L.D., T.J. Klopfenstein, and G.E. Erickson. 2002. The role of nutrition in reducing nutrient output from ruminants. J. Anim. Sc. 80(E. Suppl. 2):E143-E156.

Schoenau, J.J. and J.G. Davis. 2006. Optimizing soil and plant responses to land-applied manure nutrients in the Great Plains of North America. Can. J. Soil Sci. 86:587-595.

Scholefield, D. and D.M. Hall. 1986. A recording penetrometer to measure the strength of soil in relation to the stresses exerted by a walking cow. J. Soil Sci. 37:165-176.

Schomberg, H.H., J.A. Studemann, A.J. Franzluebbers, and S.R. Wilkinson. 2000. Spatial distribution of extractable phosphorus, potassium, and magnesium as influenced by fertilizer and tall fescue endophyte status. Agron. J. 92:981-986.

Sigua, G.C. W. Kang, and S.W. Coleman. 2006. Soil distribution of phosphorus and other nutrients following wetland conversion to beef cattle pasture. J. Environ. Qual. 35:2374-2382.

Smika, D.E., H.J. Haas, and G.A. Rogler. 1960. Yield, quality, and fertilizer recovery of crested wheatgrass, bromegrass, and Russian wildrye as influenced by fertilization. J. Range. Manage. 13:243-246.

Smoliak, S. 1965. Effects of manure, straw, and inorganic fertilizers on northern great plains ranges. J. Range. Manage. 18:11-15.

Smoliak, S., D. Penney, A.M. Harper, and J.S. Horricks. 1981. Alberta Forage Manual. Alberta Agriculture, Food and Rural Development. Information Packaging Centre. Edmonton., AB.

Smoliak, S. and J.F. Dormaar. 1985. Productivity of Russian wildrye and crested wheatgrass and their effect on prairie soils. J. Range Manage. 38:403-405.

Sommer, S.G., and N. Hutchings. 1995. Techniques and strategies for the reduction of ammonia emission from agriculture. Water Air Soil Pollut. 85:237-248.

Stacy M.D., B.L. Perryman, P.D. Stahl, and M.A. Smith. 2005. Brome control and microbial inoculation effects in reclaimed cool-season grasslands. Range. Ecol. Manage. 58:161-166.

Stanford, K., F.J. Larney, A.F. Olson, L.J. Yanke, and R.H. McKenzie. 2000. Composting as a means of disposal of sheep mortalities. Compost Sci. Util. 8:135-146.

Statistics Canada. 2007. Cattle statistics. Catalogue no. 23-012-XIE. Vol. 6, no. 2. Statistics Canada. Ottawa, ON.

Stephenson, G.R., and A. Veigel. 1987. Recovery of compacted soil on pastures used for winter cattle feeding. J. Range Manage. 40:46-48.

Stewart, B.A. 1970. Volatilization and nitrification of nitrogen from urine under simulated cattle feedlot conditions. Env. Sci. Technol. 4:579-582.

Stout, W.L., S.A. Fales, L.D. Muller, R.R. Schnabel, W.E. Priddy, and G.F. Elwinger. 1997. Nitrate leaching from cattle urine and feces in northeast USA. Soil Sci Soc. Am. J. 61:1787-1794.

Stumborg, C. 2006. Phosphorus and nitrogen loading in manured Saskatchewan soils. Ms.C. diss. Univ. of Saskatchewan, Saskatoon, SK, Canada.

Stumborg, C., J.J. Schoenau, and Mahli, S.S. 2007. Nitrogen balance and accumulation pattern in three contrasting prairie soils receiving repeated applications of liquid swine and solid cattle manure. Nutr. Cycl. Agroecosyst. 78:15-25.

Thomas, R.L., R.W. Sheard, and J.P. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant materials using a single digest. Agron. J. 99:240-243.

Todd, T.W., W. Guo, B. Stewart, and C. Robinson. 2004. Vegetation, phosphorus, and dust gradients downwind from a cattle feedyard. J. Range Manage. 57:291-299.

Vallis, I., L.A. Harper, V.R. Catchpoole, and K.L. Weier. 1982. Volatilization of ammonia from urine patches in a subtropical pasture. Aust. J. Agric. Res. 33:97-107.

Vanderholm, D.H. 1979. Handling of manure from different livestock and management systems. J. Anim. Sci. 48:113-120.

Voorburg, J.H., and W. Kroodsma. 1992. Volatile emissions of housing systems for cattle. Livestock Prod. Sci. 31:57-70.

Watkin, B.R. 1957. The effect of dung and urine and its interactions with applied nitrogen, phosphorus, and potassium on the chemical composition of pasture. Grass Forage Sci. 12:264-277

Webb, J., D. Henderson, and S.G. Anthony. 2001. Optimizing livestock manure applications to reduce nitrate and ammonia pollution: scenario analysis using the MANNER model. Soil Use. Manage. 17:188-194.

Whalen, J.K. and C. Chang. 2001. Phosphorus Accumulation in Cultivated Soils from Long-Term Annual Applications of Cattle Feedlot Manure. J. Environ. Qual. 30:229-237.

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

White, S.L., R.E. Sheffield, S.P. Washburn, L.D. King, and J.T. Green, Jr. 2001. Spatial and time distribution of dairy cattle excreta in an intensive pasture system. J. Environ. Qual. 30:2180-2187.

Williams, B.L., C.A. Shand, S. Sellers, and M.E. Young. 1999. Impact of synthetic sheep urine on N and P in two pastures in the Scottish uplands. Plant Soil 214:93-103.

Willms, W.D., L.M. Rode, and B.S. Freeze. 1993. Winter performance of Hereford cows on fescue prairie and in drylot as influenced by fall grazing. Can. J. Anim. Sci. 73:881-889.

Wolton, K. 1955. The effect of sheep excreta and fertilizer treatments on the nutrient status of pasture soil. Grass Forage Sci. 10:240-253

Wu, Z. L.D. Satter, A.J. Blohowiak, R.H. Stauffacher, and J.H. Wilson. 2001. Milk production, estimated phosphorus excretion, and bone characteristics of dairy cows fed different amounts of phosphorus for two or three years. J. Dairy Sci. 84:1738-1748.

Zhang, M., R. Gavlak, A. Mitchell, and S. Sparrow. 2006. Solid and liquid manure application in a subarctic soil: bromegrass and oat production and soil properties. Agron. J. 98:1551-1558.

11.0 APPENDICES

APPENDIX A

Field history

2003 – no fertilizer, no grazing

2002 – no fertilizer

2001 – soil tested and fertilized with 56 kg ha^{-1} N as 46-0-0

2000 – beef cattle manure applied at 67.2 tonnes ha^{-1}

Note that generally the field was grazed in early spring and late fall.

APPENDIX B

Watering system

The natural heat energy from sub-surface water was used to keep the watering trough free-flowing in cold winter conditions. The insulation in the trough sides, bottom and top, combined with specially designed drinking tubes and an insulated ground tube was used to conserve the geothermal energy from the well water. This system worked well in the trial. It is dependent on a steady draw of subsurface water to stay unfrozen.

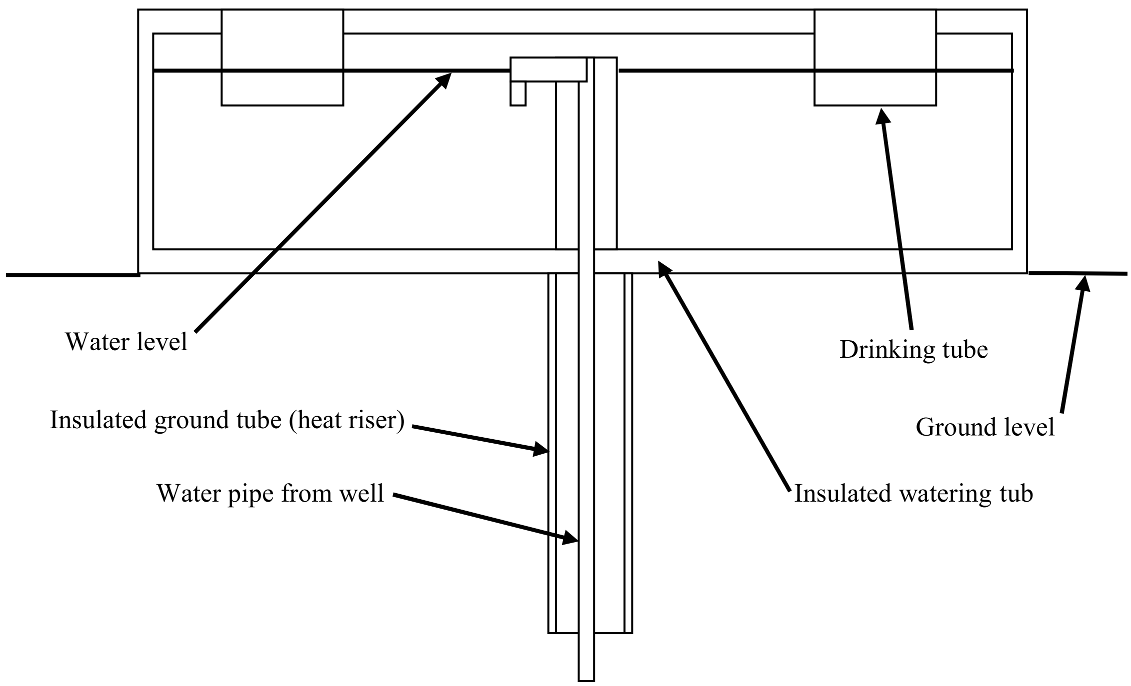

Figure B.1 Cross-section of geothermal cattle winter watering system, showing the insulated sides of the trough, the drinking tubes, and the insulated ground tube.

APPENDIX C

Analysis of loose salt and 1:1 mineral

Table C.1 Analysis of loose salt and 1:1 mineral

Supplement		Content		
		-------- % -------	----- mg kg^{-1} -----	---- IU† kg^{-1} ---
Salt	Sodium	39.0		
	Iodine		150	
	Cobalt		100	
1:1 Mineral	Calcium	16.0		
	Phosphorus	16.0		
	Iron		450	
	Iodine		125	
	Manganese		5300	
	Copper		4000	
	Cobalt		40	
	Zinc		10000	
	Fluorine (max)		2000	
	Vitamin A (min)			200000
	Vitamin D (min)			45000
	Vitamin E (min)			40

† International units

APPENDIX D

Site weather records

Table D.1 Monthly precipitation and air temperatures for 2003 and 2004 at the study site.

Month	Rainfall		Temperature					
			Mean Overall		Mean Maximum		Mean Minimum	
	Site†	30 yr‡	Site	30 yr	Site	30 yr	Site	30 yr
	------- mm ------		--------------------------------- ºC ----------------------------------					
Apr 03	19.1	15	4.7	4.3	10.3	10.7	-1.0	-2.1
May	27.7	48.1	11.9	11.6	19.6	18.5	3.9	4.6
June	41.8	62.8	16.0	16	23.0	22.8	8.0	9.1
July	45.0	66.8	18.5	18.5	25.8	25.3	10.3	11.6
Aug	25.2	47.8	20.0	16.9	28.6	24	10.8	9.7
Sept	37.0	39.5	10.4	10.9	17.7	17.4	3.2	4.3
Oct	9.5	12.7	5.2	4.3	13.0	10.5	-2.2	-1.9
Nov	N/A	3.4	-10.7	-6.4	-5.1	-1.7	-16.9	-11
Dec	N/A	1.4	-10.1	-14.4	-5.0	-9.5	-16.1	-19.3
Jan 04	N/A	0.3	-20.5	-16.5	-16.1	-11	-26.4	-21.9
Feb	N/A	0.1	-11.5	-13.3	-6.0	-8	-17.4	-18.5
Mar	N/A	2	-7.3	-6.7	-0.8	-1.5	-14.6	-11.9
Apr	6.7	15	3.5	4.3	10.6	10.7	-3.2	-2.1
May	56.2	48.1	7.4	11.6	14.4	18.5	-0.3	4.6
June	54.6	62.8	13.2	16	19.2	22.8	6.5	9.1
July	29.1	66.8	17.1	18.5	24.5	25.3	8.9	11.6
Aug	76.3	47.8	13.8	16.9	20.9	24	6.3	9.7
Sept	22.7	39.5	10.4	10.9	18.3	17.4	2.4	4.3
Oct	14.6	12.7	2.9	4.3	8.9	10.5	-3.2	-1.9
Nov	N/A	3.4	-2.9	-6.4	3.9	-1.7	-9.5	-11.0
Dec	N/A	1.4	-13.6	-14.4	-8.7	-9.5	-19.3	-19.3

† site measurements taken from a PFRA weather station immediately beside the site during the summer, and from an Agriculture Canada weather station located 2 km away during spring, fall, and winter.

‡ 30 year averages were taken from data provided by the Environment Canada weather station at Guernsey (Environ. Can. 2007).

Table D.2 Monthly precipitation and air temperatures for 2005 at the study site.

Month	Rainfall		Temperature					
			Mean Overall		Mean Maximum		Mean Minimum	
	Site†	30 yr‡	Site	30 yr	Site	30 yr	Site	30 yr
	------- mm ------		---------------------------------- ºC -----------------------------------					
Jan 05	N/A	0.3	-18.7	-16.5	-13.4	-11.0	-24.6	-21.9
Feb	N/A	0.1	-13.5	-13.3	-6.9	-8.0	-19.4	-18.5
Mar	N/A	2.0	-7.5	-6.7	-2.3	-1.5	-12.9	-11.9
Apr	2.4	15.0	5.7	4.3	-1.1	10.7	12.6	-2.1
May	52.9	48.1	9.3	11.6	1.8	18.5	16.4	4.6
June	61.2	62.8	14.8	16	9.3	22.8	20.2	9.1

† site measurements taken from an Agriculture Canada weather station located 2 km away.

‡ 30 year averages were taken from data provided by the Environment Canada weather station at Guernsey (Environ. Can. 2007).

APPENDIX E

Comparative K soil test results

Table E.1 Total soil K in the top 15 cm. A comparison of the soil test results from two soil testing laboratories of the same soil samples from the winter feeding sites.

Grid Point	**Soil Testing Laboratory**	
	U of S	**Envirotest**
	---------- kg ha^{-1} ----------	
151	853	750
145	1229	1236
158	1880	1840
173	2965	3100
169	4648	4780
163	6326	7740
Mean	2987	3241

APPENDIX F

Nutrient capture calculations

	B	C	D	E	F	G	H	I	J	K	L	M	N	O
						Excreted	Excreted	Urine			Excreted	Residue (uneaten feed, bedding, plus manure)		
	Amt Feed Fed	Protein	N	Total N	Consumed N	-10% retention	-28% dung	Amt extra recov	Urine N capture	Feed N left	Dung nutr (est)	Total F+D	Field measured	Amt recovered
	kg ha-1 as fed	% as fed	%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	(Soil test) kg ha-1	%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	%
				B times D	E minus uneaten feed	F minus 10%	G minus 28%	field measured	H compared to I	E minus F	G minus H	K plus L	Field measured	N compared to M
Bale Processing Hay	22793	12.8	2.0	466.8	430.9	387.8	279.2			35.9	108.6	144.5		
Bale Processing Straw	15309	4.7	0.8	115.1	71.3	64.2	46.2			43.8	18.0	61.8		
Total Bale Processing	38102			581.9	502.2	452.0	325.4	137	42	79.7	126.6	206.3	222.5	108
Bale Grazing Hay	24649	11.4	1.8	449.6	429.6	386.6	278.4			20.0	108.3	128.3		
Bale Grazing Straw	13880	5.7	0.9	126.6	70.4	63.3	45.6			56.2	17.7	73.9		
Total Bale Grazing	38529			576.2	500.0	450.0	324.0	97	30	76.2	126.0	202.2	161.4	80
Mean Pasture Feeding	38316			579.1	501.1	451.0	324.7	116.9	36	78.0	126.3	204.3	191.9	93.8
	Amt Feed Fed		K	Total K	Consumed K	-14% retention	-9%dung	Amt extra recov	Urine K capture	Feed K left	Dung nutr (est)	Total F+D	Field measured	Amt recovered
	kg ha-1 as fed		%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	(Soil test) kg ha-1	%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	%
Bale Processing Hay	22793		1.8	405.7	374.5	322.1	293.1			31.2	29.0	60.2		
Bale Processing Straw	15309		2.0	306.2	189.7	163.1	148.4			116.5	14.7	131.2		
Total Bale Processing	38102			711.9	564.2	485.2	441.5	997	225.8	147.7	43.7	191.4	not measured	not measured
Bale Grazing Hay	24649		1.8	433.8	414.5	356.5	324.4			19.3	32.1	51.4		
Bale Grazing Straw	13880		2.2	299.8	166.7	143.4	130.5			133.1	12.9	146.0		
Total Bale Grazing	38529			733.6	581.2	499.8	454.9	833	183.1	152.4	45.0	197.4		
Mean Pasture Feeding	38316			722.8	572.7	492.5	448.2	915.0	204.5	150.1	44.3	194.4		
	Amt Feed Fed		P	Total P	Consumed P	-19% retention	-98%dung	Amt extra recov	Urine P capture	Feed P left	Dung nutr (est)	Total F+D	Field measured	Amt recovered
	kg ha-1 as fed		%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	(Soil test) kg ha-1	%	kg ha-1	kg ha-1	kg ha-1	kg ha-1	%
Bale Processing Hay	22793		0.20	45.6	42.1	34.1	0.7			3.5	33.4	36.9		
Bale Processing Straw	15309		0.10	15.3	9.5	7.7	0.2			5.8	7.5	13.4		
Total Bale Processing	38102			60.9	51.6	41.8	0.8	not measured	not measured	9.3	40.9	50.3	31.33	62
Bale Grazing Hay	24649		0.19	46.8	43.2	35.0	0.7			3.6	34.3	37.9		
Bale Grazing Straw	13880		0.15	20.8	12.9	10.4	0.2			7.9	10.2	18.2		
Total Bale Grazing	38529			67.7	56.1	45.5	0.9	N/A	N/A	11.5	44.6	56.1	35.11	63
Mean Pasture Feeding	38316			64.3	53.8	43.6	0.9	N/A	N/A	10.4	42.7	53.2	33.2	62.5
Amount eaten	% eaten		N Retention from Bierman et al. (1999), steers fed in feedlot, Fisher et al. (2000), dairy cows											
Bale Processing Hay	92.3		N in urine from Bierman et al. (1999), mid point of 66 to 78 range											
Bale Processing Straw	62.0		K Retention from Cole (1999), lambs											
Bale Grazing Hay	95.6		K in urine from Gustafson et al. (2003), dairy cows											
Bale Grazing Straw	55.6		P Retention averaged from Erickson et al. (2000) with yearlings, and Cole (1999), with lambs											
			P in urine from Wu et al. (2001) with dairy cows											

Figure F.1 Nutrient capture calculations for the winter feeding systems.

APPENDIX G

Table G.1 Magnesium and calcium brought onto the winterfeeding sites in feed and bedding.

System	Feed and Bedding				
	Total weight (as fed)	Magnesium		Calcium	
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}
Bale processing hay	22793	.29	66.1	1.0	237.1
Bale processing straw	15309	.13	19.9	0.2	32.1
Total bale processing	*38102*		*86.0*		*269.2*
Bale grazing hay	24649	.21	51.8	0.8	184.9
Bale grazing straw	13880	.12	16.7	0.2	31.9
Total bale grazing	*38529*		*68.4*		*216.8*
Mean pasture feeding	*38316*		*77.2*		*243.0*

APPENDIX H

Aerial site photography

Vertical photography is commonly used to monitor plant cover (Booth et al., 2004) with small areas typically photographed from heights of 1.3 to 2.5 m. To get the proper height for photography of the surface residue distribution patterns and forage regrowth needed in this trial it was necessary to vertically photograph the site from stationary altitudes of 10 m and above. While unmanned aerial vehicles have also been used for photography of pastures at this type of altitudes (Hardin and Jackson, 2005), the cost for this trial would have been prohibitive. Therefore the choice was made to use a kite based system.

A winged box kite was used as the lift, with a camera suspended below the line using a self leveling Picavet suspension. The camera was activated by a wireless model airplane controller activating a servo on the cameras shutter button. The system performed well.

Figure H.1 Kite carrying suspended cradle with remotely activated camera.

APPENDIX I

Nutrient recovery from the drylot raw manure system

Nitrogen															
	Feed and bedding														
	weight as fed					per cow	eaten	retained	excreted	pen loss	hauled	capture	capture	from bale net capture	after fed net capture
	kg/cow/day	% Protein	% N	kg N/cow/day	# days	kg	%	kg	kg	%	kg	%	kg	%	%
Greenfeed	8.3	6.5	1.04	0.09	130	11.3	100	1.1	10.1	86.7	1.3	5.4	0.07		
Straw	7.0	4.8	0.768	0.05	130	7.0	100	0.7	6.3	86.7	0.8	5.4	0.05		
Bedding eaten	0.6	4.8	0.768	0.00	130	0.6	100	0.1	0.5	86.7	0.1	5.4	0.00		
Bedding not eaten	1.4	4.8	0.768	0.01	130	1.4	0	0	1.4	10.0	1.3	5.4	0.07		
						20.2		1.9	18.37		3.5		0.19	0.9	1.03

Phosphorus														
	Feed and bedding													
	weight as fed				per cow	eaten	retained	excreted	pen loss	hauled	capture	capture	from bale net capture	after fed net capture
	kg/cow/day	% P	kg P/cow/day	# days	kg	%	kg	kg	%	kg	%	kg	%	%
Greenfeed	8.3	0.17	0.014	130	1.8	100	0.3	1.5	10	1.3	3.1	0.042		
Straw	7.0	0.09	0.006	130	0.8	100	0.2	0.7	10	0.6	3.1	0.019		
Bedding eaten	0.6	0.09	0.001	130	0.1	100	0.0	0.1	10	0.1	3.1	0.002		
Bedding not eaten	1.4	0.09	0.001	130	0.2	0	0	0.2	10	0.1	3.1	0.005		
					2.9		0.5	2.38		2.1		0.066	2.3	2.8
Pen loss % average from Kissenger et al. 2005														
So for every 100 kg P in feed and bedding, recovery in the plants in a year and a half was 2 kg.														

Figure I.1 Nutrient capture calculations for the drylot raw manure system.

APPENDIX J

Nutrient recovery from the drylot compost system

Nitrogen	Feed and bedding														from bale	after fed
	weight as fed					per cow	eaten	retained	excreted	pen loss	compost loss	hauled	capture	capture	net capture	net capture
	kg/cow/day	% Protein	% N	kg N/cow/day	# days	kg	%	kg	kg	%	%	kg	%	kg	%	%
Greenfeed	8.3	6.5	1.04	0.09	130	11.3	100	1.1	10.1	86.7	32.8	0.9	9.0	0.08		
Straw	7.0	4.8	0.768	0.05	130	7.0	100	0.7	6.3	86.7	32.8	0.6	9.0	0.05		
Bedding eaten	0.6	4.8	0.768	0.00	130	0.6	100	0.1	0.5	86.7	32.8	0.0	9.0	0.00		
Bedding not eaten	1.4	4.8	0.768	0.01	130	1.4	0	0	1.4	10.0	32.8	0.8	9.0	0.08		
						20.2		1.9	18.37			2.4		0.21	1.1	1.16

Pen loss from Bierman et al. (1999), compost loss from Larney et al. (2006).
Kissenger et al. (2005) 30.7 hauled, Erickson et al (2001) 31.0, Bierman et al. (1999) 13.3 , Avg of all 25.0
Note, all these tests were feedlot trials and the manure was sampled immediately after the cattle were removed.
As in this trial the pens sat empty in the heat all summer before fall hauling, the lowest figure (Bierman) was used.
So for every 100 kg N in feed and bedding, recovery in the plants in a year and a half would be 1 kg

Phosphorus	Feed and bedding													from bale	after fed
	weight as fed				per cow	eaten	retained	excreted	pen loss	compost loss	hauled	capture	capture	net capture	net capture
	kg/cow/day	% P	kg P/cow/day	# days	kg	%	kg	kg	%	%	kg	%	kg	%	%
Greenfeed	8.3	0.17	0.014	130	1.8	100	0.3	1.5	10	18.3	1.0964	4.7	0.052		
Straw	7.0	0.09	0.006	130	0.8	100	0.2	0.7	10	18.3	0.4878	4.7	0.023		
Bedding eaten	0.6	0.09	0.001	130	0.1	100	0.0	0.1	10	18.3	0.0418	4.7	0.002		
Bedding not eaten	1.4	0.09	0.001	130	0.2	0	0	0.2	10	18.3	0.1204	4.7	0.006		
					2.9		0.5	2.38					0.082	2.8	3.5

Pen loss % average from Kissenger et al. 2005, compost loss from Larney et al. 2006.
So for every 100 kg P in feed and bedding, recovery in the plants in a year and a half was 3 kg.

Figure J.1 Nutrient capture calculations for the drylot compost system.

APPENDIX K

Winterfeeding hay and straw nutrient value

		bale weight	bale protein										
		as fed	as fed	N content	N content	N content			46-0-0 equiv	46-0-0 equiv	Price	Value	Value
		kg	%	%	kg/bale	kg/ha			kg/bale	kg/ha	$ per kg/46-0-0	$/bale	$/ha
Hay		628	12.1	1.9	12.2	463.2			26.4	1007.0	0.60	15.86	604.20
Straw		408	5.2	0.8	3.4	116.1			7.4	252.4	0.60	4.43	151.43
						579.3				1259.4		20.29	755.63
				P content	P content	P content	P2O5 equiv	P2O5 equiv	11-52-0 equiv	11-52-0 equiv	Price	Value	Value
				%	kg/bale	kg/ha	kg/bale	kg/ha	kg/bale	kg/ha	$ per kg/0-52-0	$/bale	$/ha
Hay		628		0.195	1.2	46.7	2.8	106.8	5.4	205.5	0.47	2.52	95.86
Straw		408		0.125	0.5	17.4	1.2	39.9	2.2	76.8	0.47	1.05	35.83
						64.1		146.8		282.3		3.56	131.69
				K content	K content	K content	K2O equiv	K2O equiv	0-0-62 equiv	0-0-62 equiv	Price	Value	Value
				%	kg/bale	kg/ha	kg/bale	kg/ha	kg/bale	kg/ha	$ per kg/0-0-62	$/bale	$/ha
Hay		628		1.8	11.3	430.7	13.7	521.1	22.1	840.5	0.34	7.50	285.78
Straw		408		2.1	8.6	293.0	10.4	354.6	16.7	571.9	0.34	5.69	194.44
						723.7		875.7		1412.4		13.19	480.22
				S content	S content	S content			20-0-0-24 equiv	20-0-0-24 equiv	Price	Value	Value
				%	kg/bale	kg/ha			kg/bale	kg/ha	$ per kg/0-0-0-24	$/bale	$/ha
Hay		628		0.20	1.26	47.9			5.2	199.4	0.12	0.61	23.35
Straw		408		0.103	0.42	14.4			1.8	59.9	0.12	0.21	7.01
						62.2				259.3		0.82	30.37
		Weight of feed as fed										Total Value	Total Value
		tonnes/ha										$/bale	$/ha
Hay		23.9										26.49	1009.19
Straw		14.0										11.37	388.71
		37.9										37.85	1397.91
Retailer		Price adjusted to											
blend price		primary nutrient only		Amt N	Price N								
	$/tonne		$/tonne	tonnes	$/tonne								
46-0-0	600.00	46-0-0	600.00	0.460	1304.35								
11-52-0	610.00	0-52-0	466.52	0.110	143.5								
0-0-62	340.00	0-0-62	340.00	0	0								
20-0-0-24	378.00	0-0-0-24	117.13	0.200	260.9								
Prices from Agricore United Broxburn June 7/2007. An adjustment was made becaused the price of phosphorus and sulphur fertilizer contains nitrogen													

Figure J.1 Winterfeeding feed and bedding nutrient value calculations

APPENDIX L

Feed test results

Table J.1 Nutrient analysis† of hay and straw.

Feed	Analysis		
	Property	**100% Dry Matter**	**As Received**
		------------------------ %	------------------------
Bale Processing Hay	Moisture	0	14.7
	Protein	15.0	12.8
	TDN‡	60.1	51.3
Bale Grazing Hay	Moisture	0	15.0
	Protein	13.4	11.4
	TDN	58.3	49.5
Drylot Greenfeed	Moisture	0	19.6
	Protein	8.1	6.5
	TDN	60.0	47.4
Bale Processing Straw	Moisture	0	22.7
	Protein	6.1	4.7
	TDN	45.7	35.3
Bale Grazing Straw	Moisture	0	10.6
	Protein	6.4	5.7
	TDN	45.2	40.4
Drylot Straw	Moisture	0	24.3
	Protein	6.4	4.8
	TDN	43.4	32.9

† Performed by Envirotest Labs, Saskatoon, SK.

‡ Total digestible nutrients