Herbage yield and crude protein concentration of rangeland and pasture following hog manure application in southeastern Alberta

Laura J. Blonski[1,3], Edward W. Bork[1,4], and Peter V. Blenis[2]

[1]Department of Agricultural, Food, and Nutritional Science, 410 AgFor Center, University of Alberta, Edmonton, Alberta, Canada T6G 2P5; [2]Department of Renewable Resources, 751 General Services Building, University of Alberta, Edmonton, Alberta, Canada T6G 2H1.
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Blonski, L. J., Bork, E. W. and Blenis, P. V. 2004. **Herbage yield and crude protein concentration of rangeland and pasture following hog manure application in southeastern Alberta.** Can. J. Plant Sci. **84**: 773–783. Intensive hog production is expanding into semi-arid regions of Alberta, where perennial forage lands are increasingly targeted for manure application despite limited guidelines for its efficient use. Herbage yield and crude protein were assessed over two consecutive years within two native rangelands and two tame pastures, following different rates (10, 20, 40, 80 and 160 kg ha^{-1} NH_4-N), methods (surface banding vs. subsurface injection) and seasons (fall vs. spring) of one-time liquid hog manure (LHM) application. Increasing manure rates improved grass yield across all sites the first growing season after treatment, from 1626 to 3576 kg ha^{-1}. Although absolute increases in production were greatest on tame pasture, relative yield increases were similar among sites. Average crude protein (CP) concentration also increased from 69 to 91 g kg^{-1} in the first year. Despite low rainfall and the absence of a yield response in the second year, grass CP and crude protein yield (CPY) were maximized with increased manure application, highlighting the positive effects of manure on forage production, even with drought. Forb yields demonstrated variable effects among sites, with increasing manure decreasing alfalfa and increasing native forbs. Overall, both semi-arid tame pastures and native rangelands responded positively to LHM application, highlighting the complementary nature of hog and forage production under these conditions.

Key words*:* Crude protein yield, forage, hog manure, injection, native rangeland, precipitation

Blonski, L. J., Bork, E. W. et Blenis, P. V. 2004. **Rendement fourrager et concentration de protéines brutes des grands parcours et des pâturages du sud-est de l'Alberta après application de purin**. Can. J. Plant Sci. **84**: 773–783. L'élevage industriel de porcins est en train de prendre de l'expansion dans les régions semi-arides de l'Alberta et les terres sur lesquelles poussent des vivaces fourragères servent de plus en plus à l'épandage du fumier, malgré le peu de lignes directrices dont on dispose pour garantir l'efficacité d'une telle pratique. Pendant deux années consécutives, les auteurs ont évalué le rendement fourrager et la teneur en protéines brutes de deux grands parcours naturels et d'autant de prairies artificielles en fonction du taux (10, 20, 40, 80 et 160 kg de NH_4-N par hectare), de la méthode (épandage par bande en surface c. injection dans le sol) et du moment (automne c. printemps) d'une application unique de lisier. Le rendement fourrager augmente avec le taux d'application à tous les endroits la saison végétative suivant le traitement pour passer de 1 626 à 3 576 kg par hectare. Bien que la production augmente davantage dans les prairies artificielles en termes absolus, le rendement relatif demeure le même aux différents endroits. La quantité moyenne de protéines brutes s'accroît elle aussi la première année, soit de 69 à 91 g kg^{-1}. Malgré la pluie et l'absence de réaction du rendement la deuxième année, la concentration de protéines brutes des herbages et le rendement en protéines brutes atteignent leur maximum avec l'augmentation du taux d'application, ce qui souligne les effets positifs du fumier pour la production fourragère, même quand il y a sécheresse. Le rendement en herbacées dicotylédones révèle que la réaction varie d'un site à l'autre, la production de luzerne diminuant et celle d'herbacées dicotylédones indigènes augmentant avec l'application de fumier. Dans l'ensemble, les prairies artificielles et les grands parcours naturels des régions semi-arides réagissent bien à l'application de lisier, signe que l'élevage de porc et la culture fourragère sont complémentaires dans de telles conditions.

Mots clés: Rendement en protéines brutes, fourrages, purin, injection, parcours naturels, précipitations

Intensive livestock operations have expanded in the province of Alberta to include semi-arid environments, with nearly 30% of hog production now occurring in south-central regions (Alberta Agricultural Statistics Branch 1997). Expansion of hog production also coincides with increasing societal concerns over manure disposal. Traditional sinks for hog manure have been primarily cultivated lands. However, these areas are scarce in southeastern Alberta, where landscapes are dominated by perennial tame forages and native rangelands adapted to sparse and variable rainfall, as well as low fertility soils (Willms and Jefferson 1993). Given that it is not practical to transport manure to distant cultivated lands, locally abundant forage lands, including tame pasture and native rangeland, are increasingly being considered for manure application. Tame pastures consist of areas cultivated after European settlement

[3]*Current address is Department of Forest, Range, and Wildlife Science, Old Main Hill, Utah State University, Logan, Utah, USA, 84322-5230.*
[4]*To whom correspondence should be addressed.*

Abbreviations: **CP**, crude protein; **CPY**, crude protein yield; **CWG**, crested wheatgrass; **DM**, dry matter; **FG**, Fescue Grassland; **LHM**, liquid hog manure; **MP**, Mixed Prairie; **MB**, meadow bromegrass; **OM**, organic matter and seeded with introduced forage species, while rangeland is unbroken prairie dominated by native vegetation. Both vegetation types are used for cattle production, and manure application has the potential to enhance forage supplies. Proper manure management must be compatible with efficient and timely agronomic production (Evans et al. 1977).

Previous research in western Canada has primarily examined manure application to annual cropland leading to comprehensive guidelines for the application of manure to these areas (Intensive Livestock Operations Committee 1995). Moreover, although the benefits of nutrient application to forage lands adapted to high moisture conditions (e.g., the Aspen Parkland or Boreal regions) have been relatively well established (e.g., Nuttall et al. 1991; Bittman et al. 1997; Kowalenko and Bittman 2000), specific information on fertilizer application to semi-arid rangeland and adjacent tame pasture (e.g., the Mixedgrass region) is less common (McCaughey and Simons 1996a). Intensive forage management, including the application of manure, is generally uncommon in semi-arid regions, including on native rangelands.

Rangelands tend to occupy regions with unfavorable edaphic and climatic conditions for crop production. In semi-arid regions, both native rangelands and adjacent tame pastures frequently lack the stable and sufficient levels of precipitation necessary for successful use of nutrient amendments (McCaughey and Simons 1996b; Rubio et al. 1996). Another limitation to the use of nutrients under these conditions has been the economic risk associated with fluctuating livestock and fertilizer costs (Godfrey and Wight 1985).

Where research has been conducted in semi-arid environments, the focus of that work has been on herbage yield responses to the addition of commercial fertilizer, with favorable yield increases documented on both native rangeland (Johnston et al. 1968, 1967; Read 1969; Jacobsen et al. 1996) and tame pasture (Johnston et al. 1968; Lutwick and Smith 1977; Campbell et al. 1986; Bittman et al. 1997). The magnitude of yield responses has often been variable, however, depending on pre-treatment soil nutrient levels, vegetation type, and seasonal growing conditions (Johnston et al. 1969; Power 1985; Belanger and Gastal 2000). In southern Alberta, growing season precipitation is particularly important for determining herbage growth (Smoliak 1986), but is variable and unpredictable (Coupland 1959). Nutrient addition was found to benefit forage growth in Saskatchewan only when moisture was plentiful (Kilcher 1958).

Previous research specifically examining the impact of manure application to forage land in western Canada has been limited to tame pasture, and generally under favorable moisture conditions (e.g., Bittman et al. 1999; Pastl et al. 2000). On native rangelands, previous research on nutrient addition has been largely restricted to commercial fertilizers (e.g., Lorenz and Rogler 1957; Wight and Black 1979; Samuel and Hart 1998). An exception is the work of Smoliak (1965), who showed that herbage yield increased with the application of solid beef manure to Mixed Prairie rangeland in southern Alberta. However, information on the specific agronomic response of rangelands to liquid hog manure is lacking.

The use of perennial forage lands for manure utilization limits the methods of application that can be used to non-invasive surface application or low-disturbance injection. Despite this, information on the comparative effects of different manure application methods in Canada is scarce and, to date, limited to tame pastures (e.g., Bittman et al. 1999; Olson and Papworth 1999). The benefits of alternative manure application methods to splash-plate application have included a greater capture of nutrients, particularly N (DeKlein et al. 1996; Sanderson and Jones 1997; Bittman et al. 1999).

Given the diverse vegetation found in southeast Alberta and the increasing presence of intensive hog production, the primary goal of this research was to determine forage yield and protein responses over a 2-yr period following treatment. This study examines the agronomic response of two tame pastures and two native rangeland sites to various rates (10, 20, 40, 80 and 160 kg ha^{-1} NH_4-N), methods (injected vs. surface banded), and seasons (fall vs. spring) of one-time liquid hog manure (LHM) application. A secondary objective was to compare the relative response of different perennial forage stands, including native rangeland and tame pasture.

MATERIALS AND METHODS

Study Area

Research was conducted in southeastern Alberta between the municipal centers of Hanna and Drumheller (51°22′N; 112°13′W) between 1998 and 2000. This region represents a transition from Mixed Prairie to Aspen Parkland (Strong and Leggat 1992), and includes northern Fescue Grasslands. The area has undulating topography and experiences a continental climate. The 30-yr average annual precipitation from Craigmyle, Alberta, 25 km north of the study area, is 394 mm (Environment Canada 1993), with growing season precipitation (May to August, inclusive) averaging 217 mm.

Manure application trials were conducted at four sites, including two native rangelands consisting of dry Mixed Prairie (MP) and moist Fescue Grassland (FG). Specific range types on the MP and FG sites were the *Stipa-Agropyron* and *Festuca-Stipa* faciations, respectively (Coupland 1961). The latter community was situated within a topographic lowland, creating conditions favorable for domination by plains rough fescue [*Festuca hallii* (Vasey) Piper], with lesser amounts of western porcupine grass (*Stipa curtiseta* (A.S. Hitchc.) Barkworth). In contrast, the MP site was on an upland bench and dominated by needle and thread grass *(Stipa comata* Trin. & Rupr.), northern [*Elymus lanceolatus* (Scribn. & Smith) Gould] and western [*Pascopyrum smithii* (Rydb.) A. Love] wheatgrass, as well as blue grama grass [*Bouteloua gracilis* (HBK) Lag.].

The remaining two sites were a moist meadow brome grass (*Bromus biebersteinii* Roem & Schult.) pasture seeded in 1996, and a xeric crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] pasture established in 1986 on an upland bench. These sites are hereafter referred to as the MB and CWG sites, respectively. Both tame pastures contained alfalfa (*Medicago sativa* L.), and the MB pasture contained crested wheatgrass as a subdominant.

All study sites were 150 × 50 m in size, and selected in 1998 on the basis of internal homogeneity of ecosite conditions (e.g., slope, aspect, topographic position) and vegetation, with all plant communities in good to excellent condition. Soils ranged from an Orthic Black Chernozem at the FG site, to Orthic Dark Brown Chernozems at the other three. Soil organic matter (OM) levels ranged from 3.2 to 4.9%. Total available N levels (0–20 cm) in the soil prior to treatment in October 1998 ranged from 11.5 kg ha^{-1} (CWG) and 10.4 kg ha^{-1} (MB) within the tame pastures, to 5.0 (MP) and 3.8 (FG) kg ha^{-1} within the native rangeland sites. Levels of available phosphate were 23 kg ha^{-1} within the tame pastures, and 6.1 and 9.2 kg ha^{-1} at the MP and FG sites, respectively.

Manure Application

Manure treatments were conducted using a randomized block design. Ten plots (7 × 50 m) at each site consisted of combinations of five different target rates of LHM (10, 20, 40, 80, and 160 kg ha^{-1} NH_4-N), applied with each of two methods (surface banded and coulter injected) 1998 Oct. 05–07. Another 10 plots were treated at each site 1999 Apr. 12–13. All treatments were randomly assigned to plots.

Manure was applied using the Greentrac™ liquid injection system by the Prairie Agricultural Machinery Institute of Humbolt, Saskatchewan. This system was used because of its capability to achieve accurate LHM application rates. The Greentrac has a pressurized tank and distributor to deliver manure through hoses to injector shanks that lie behind vertical coulters spaced 25 cm apart. Where manure was injected into the soil, injection was to a depth of 7.5 to 10 cm. Surface applications were made using the same equipment, with the applicator raised 25 cm above the ground, enabling manure to be top dressed. This technique differed from traditional splash-plate application in that the latter generates greater agitation (i.e., atomization and susceptibility to drift) but is less conducive to controlled research trials.

All hog manure was obtained from the first of a three-pit, uncovered, non-agitated open lagoon storage system associated with a 4000-head farrowing barn. Manure samples were taken from the lagoon and analyzed for nutrient content 2 wk prior to each application period (fall and spring) so that the applicator could be calibrated to obtain the appropriate application rates. Because all equipment and application rates were calibrated in advance, pits were not agitated prior to or during treatment. Orifice diameters within the distributor on the applicator and ground speeds were adjusted to obtain required application rates. However, because the lowest rate could not be achieved due to an excessive machine speed requirement, this rate (10 kg ha^{-1} NH_4-N) was obtained by mixing LHM and water at a 1:1 ratio.

During treatment, each truckload of manure was sampled and subsequently tested for nutrient content to ensure consistency among loads. Total concentrations of N, mostly ammonium (> 99%), ranged from 0.17% (±0.01) in October to 0.21% (±0.01) during April. Bulk volumes of manure depended on target application rates and seasonal nutrient levels, varying from 11 000 to 107 000 L ha^{-1} (Table 1). Final actual N application levels were 7% below target levels (Table 1), likely due to changes in manure nutrient content between preliminary sampling and field application as well as to differences in the location of manure removal from the lagoon. A 1-m buffer strip was maintained between plots during application and subsequent field sampling.

Vegetation Sampling

All sites were fenced in late April 1999 to ensure cattle grazing did not confound vegetation measurements. Within every plot at each of the four sites, herbage yield (i.e., aboveground net primary production) was measured at estimated peak standing biomass during the growing seasons of 1999 and 2000. Sampling was carried out 1999 Jun. 28 to July 24 and 2000 Jul. 08 to Aug. 02 on the two tame pasture sites. Native rangeland, which was visibly slower to commence active growth and reach peak biomass, was sampled 1999 Aug.15 to 26 and 2000 Aug. 19 to 24.

Within each plot, all herbage was clipped to ground level in four randomly located 0.5 m^2 quadrats. Harvested samples were separated into grass, forb, and shrub components on native rangelands, and into perennial grasses, alfalfa and weeds (mostly annuals) on tame pastures. Shrubs and weeds represented a very small fraction of samples (<1%) and, as a result, harvested material was simplified into two categories for analysis: grasses and forbs. All subsamples were oven-dried at 60°C to constant mass, weighed and converted to kg ha^{-1}. All sites were grazed by cattle at a moderate stocking rate following sampling in the fall of 1999 to prevent excessive litter accumulation.

Crude Protein Assessment

Grass and forb samples harvested from two of the four quadrats within each treatment plot in 1999 were randomly selected and ground through a 1-mm screen using a Wiley mill and analyzed for total N using a LECO FP-428 nitrogen determinator (Lee et al. 1996), which was then converted to crude protein (CP) by multiplying by 6.25. Herbage yield and quality data were also combined to assess changes in overall crude protein yield (CPY) among treatments. CPY was calculated by multiplying the proportion of CP (%/100) by biomass yield, with the product expressed in kg ha^{-1}. This variable combines quantity and quality characteristics and consequently may be a better index of overall forage response. CPY was assessed for grass samples within all plots at each of the four sites in 1999 and 2000, and for the forb samples in 1999. In 2000, residual CPY responses were assessed for the forb component (primarily alfalfa) within the MB site only, as forb biomass levels in 2000 were too small for analysis at the remaining three sites.

Data Analyses

Grass yield and CP data from 1999 and 2000 were analyzed from each of the 80 plots using ANOVA (Proc GLM; SAS Institute, Inc. 1989) for a randomized block design (where sites were considered blocks) to assess each main treatment effect (e.g., rate, method, and season of LHM application) and their interactions. Individual years of sampling were analyzed separately to check for the presence of residual treatment effects during the second growing season follow-

Table 1. Target and actual nitrogen application rates and associated water depth equivalents for the October 1998 and April 1999 LHM applications

Season applied	Target N application rate (TAR) (kg ha^{-1} NH_4-N)	Actual N application rate (AAR) (kg ha^{-1} NH_4-N)	LHM volume application rate (L ha^{-1})	Water depth equivalent (WDE)^z (mm)
October				
	10	9.3	13 000	1.3
	20	18.6	13 000	1.3
	40	37.1	27 000	2.7
	80	74.2	53 000	5.3
	160	148.4	107 000	10.7
April	10	9.5	11 000	1.1
	20	19.0	11 000	1.1
	40	37.9	21 000	2.1
	80	75.8	42 000	4.2
	160	151.6	84 000	8.4

^{z}WDE for the 10 and 20 kg ha^{-1} NH_4-N TARs are the same depth because the 10 rate was achieved by mixing LHM and water at a 1:1 ratio.

ing manure application the previous year. Forb data were also analyzed in 1999 for both yield and CP.

All data were checked for normality prior to analysis, with forb biomass requiring a square root transformation. Where significant rate effects were found, trend analysis was used to assess the nature of those relationships (e.g., linear vs. quadratic). Results were considered significant at $P < 0.05$, unless otherwise noted.

Although this study was not designed to test for variation in the effect of all treatments among sites (i.e., block), because sites differed in initial vegetation and because soil conditions and LHM rate represented a continuous variable, we conducted preplanned regressions of herbage response against LHM rate. In these situations, regression analysis (linear and/or quadratic) was used to more fully characterize rate impacts within individual sites.

RESULTS

Growing Conditions

Seasonal growing conditions in 1999 were favorable for plant growth, with summer precipitation at Craigmyle totaling 391 mm from May to August, 80% above the 30-yr mean. In contrast, growing season conditions during 2000 were near normal, with May to August precipitation totaling 198 mm, 9% below the long-term mean for the area.

Forage Crude Protein Responses

Grass CP in 1999 and 2000 responded significantly ($P < 0.001$) to LHM application rate (Table 2). The response was non-linear in both years, as CP levels did not increase until LHM application was maximized at 160 kg ha^{-1} NH_4-N (Table 3). Grass CP also responded to the method of LHM application ($P < 0.01$) in 1999 (Table 2), with injected treatments averaging 77 g kg^{-1} CP, 5 g kg^{-1} greater than within surface-banded plots.

Forb CP responded significantly ($P < 0.01$) in 1999 only to method of LHM application (Table 4), with surface-banded and injected treatments generating CP levels of 135 and 147 g kg^{-1}, respectively. Unlike the grass component, forb CP did not respond to LHM rate (Table 4). Residual changes in forb CP during 2000 could be assessed only within the MB site, where levels of alfalfa exhibited a linear trend toward increasing CP levels, varying from 109 g kg^{-1} at 10 kg ha^{-1} NH_4-N, to 128 g kg^{-1} at 160 kg ha^{-1} NH_4-N ($Y = 110 + 0.11X$; $r^2 = 0.84$; $P = 0.03$).

Forage DM Yield Responses

In 1999 and 2000, grass dry matter (DM) yield did not respond significantly ($P > 0.05$) to either method or season of LHM application (Table 2). However, grass yield increased non-linearly ($P < 0.001$, Table 2) from 1626 kg ha^{-1} at the lowest application rate, to 3576 kg ha^{-1} at the greatest rate (Table 3). Examination of specific yield responses among sites revealed prominent relative yield increases of 65, 64, and 52% for the MP, CWG, and FG sites (Fig. 1), respectively, as LHM rates increased across the range of treatments. In contrast, a smaller increase of 35% was evident within the MB community, which was primarily due to the non-linear trend evident at this location ($Y = 2131 + 25.3X - 0.109X^2$; $r^2 = 0.77$). Increases in grass yield at the MB site occurred primarily at rates up to 40 kg ha^{-1}, with no further positive effect at greater levels of LHM (Fig. 2).

Although grass yields ranged from 945 to 1141 kg ha^{-1} across LHM rates in 2000 (Table 3), significant yield responses to LHM application more than a year previous were not evident within any of the main treatments ($P > 0.05$, Table 2). However, regression analysis of the site-specific data revealed grass production at the two dryer sites (i.e., CWG and MP) continued to demonstrate positive responses to LHM. For example, on the MP site, grass yields at the 10, 40, and 160 kg ha^{-1} rates of LHM were 579, 638, and 862 kg ha^{-1}, respectively, representing an overall increase of 49%.

Our initial analysis of forb yield in 1999 demonstrated no significant effects of LHM application (Table 4). However, because only two of the sites (MB and MP) had a substantial fraction of forbs (>5%), forb yield responses to LHM rate were examined separately for these sites. Notably, forb yields on the MB site in 1999 displayed a pattern opposite that of the grass component described earlier, decreasing non-linearly through greater rates of LHM up to 40 kg ha^{-1} NH_4-N ($Y = 4107–11.0X + 0.025X^2$; $r^2 = 0.89$; Fig. 2). In

Table 2. Summary of analyses of variance results from grass DM yield and CP concentration responses to different rates, methods, and seasons of LHM application

		1999			2000		
Factor	df	CP ($g\ kg^{-1}$)	DM Yield ($kg\ ha^{-1}$)	CPY ($kg\ ha^{-1}$)	CP ($g\ kg^{-1}$)	DM Yield ($kg{\cdot}ha^{-1}$)	CPY ($kg{\cdot}ha^{-1}$)
Site	3						
Rate (R)	4	***	***	***	***	NS	***
Linear		***	***	***	***	–	***
Quad		***	***	NS	***	–	*
Method (M)	1	**	NS	NS	NS	NS	NS
Season (S)	1	NS	NS	NS	NS	NS	NS
R × M	4	NS	NS	NS	NS	NS	NS
R × S	4	NS	NS	NS	NS	NS	NS
M × S	1	NS	NS	NS	NS	NS	NS
R × M × S	4	NS	NS	NS	NS	NS	NS
Error	57						

***, **,* Denote significant effects at $P < 0.001$, $P < 0.01$, and $P < 0.05$, respectively; NS, not significant.

Table 3. Mean grass CP concentration, biomass and CPY in the first (1999) and second (2000) growing seasons following LHM application at different LHM rates. Mean responses are averaged over method and season

	1999			2000		
NH_4-N level	Grass CP ($g\ kg^{-1}$)	Grass yield ($kg\ ha^{-1}$)	Grass CPY ($kg\ ha^{-1}$)	Grass CP ($g\ kg^{-1}$)	Grass yield ($kg\ ha^{-1}$)	Grass CPY ($kg\ ha^{-1}$)
10	69*a*	1626*a*	105*a*	59*a*	945	56*a*
20	70*a*	1759*a*	119*a*	59*a*	991	59*a*
40	69*a*	2527*b*	168*b*	58*a*	1025	58*a*
80	74*a*	2770*b*	199*c*	60*a*	1046	62*a*
160	91*b*	3576*c*	323*d*	74*b*	1141	83*b*
SEM	2	141	11	3	57	4

a–d Within a column, means with different letters differ, $P < 0.05$.

contrast, forb yield on the MP site was bolstered by increasing rates of LHM application in 1999 ($Y = 188 + 4.58X$; $r^2 = 0.96$; $P < 0.01$), partly due to an increase in pasture sage abundance (*Artemisia frigida* Willd.) (Blonski 2001).

One year later, forb yields demonstrated a significant ($P < 0.01$) non-linear response to LHM application rate (Table 4), characterized by lower levels of forb CP ($P < 0.05$) at moderate rates of LHM (40 and 80 kg ha^{-1} NH_4-N) compared to the lowest LHM rates (10 and 20). Forb yields were 441, 449, 258, 294, and 373 kg ha^{-1} at rates of 10, 20, 40, 80, and 160 kg ha^{-1} NH_4-N, respectively. This effect also coincided with a significant ($P < 0.01$) rate × season effect (Table 4).

The rate effect observed in 2000 was confined to the MB site, where forb (mostly alfalfa) yields were much greater (1376 kg ha^{-1}) in comparison to the other three sites (< 60 kg ha^{-1}). Forb yields in 2000 were also greater where LHM had been applied in the fall of 1998 than in spring of 1999 (1546 vs. 1088 kg ha^{-1}), respectively, with these differences magnified at greater rates of LHM. Moreover, when the 1999 forb data from the MB site were examined, the opposite trend was apparent, with forb yields (pooled among rate and method treatments) averaging 3042 and 4146 kg ha^{-1} for the fall and spring treatments, respectively.

Forage Crude Protein Yield Responses

Grass crude protein yield (CPY) was examined within both years. Trends in CPY during 1999 were similar to those evident for biomass, with a significant ($P < 0.001$) positive linear response to LHM application rate in both years (Table 2). CPY varied from 105 to 323 kg ha^{-1} across the range of LHM rates from 10 to 160 kg ha^{-1} NH_4-N in 1999 (Table 3), values which represented a theoretical recovery of 23% of applied N over this range.

In 1999, CPY increased linearly ($P < 0.01$) at the MP, FG, CWG and MB sites by 138, 235, 309 and 183 kg ha^{-1}, respectively, as LHM application rates increased from 10 to 160 kg ·ha^{-1} NH_4-N (Fig. 3). These changes represented an increase of 170 to 273%, with the greatest increases on the CWG and FG sites.

In 2000, despite an overall reduction in CPY of 65% relative to the previous year, grass CPY demonstrated a significant ($P < 0.05$) positive non-linear response to LHM rate (Table 2), with CPY values ranging from 56 to 83 kg ha^{-1} (Table 3). While no response was observed on the FG site ($P > 0.05$), the other three demonstrated residual increases in grass CPY ranging from 28 to 51 kg ha^{-1} as rates of manure increased from 10 to 160 kg ha^{-1} NH_4-N. Although these responses are comparatively lower than during the high rainfall year of 1999, these increases still represent increases of 68, 89, and 97% on the CWG, MB, and MP sites, respectively. In terms of incremental N recovery, however, this increase in CPY represented only 3% of applied N. No CPY response was evident in the alfalfa component at the MB site during 2000.

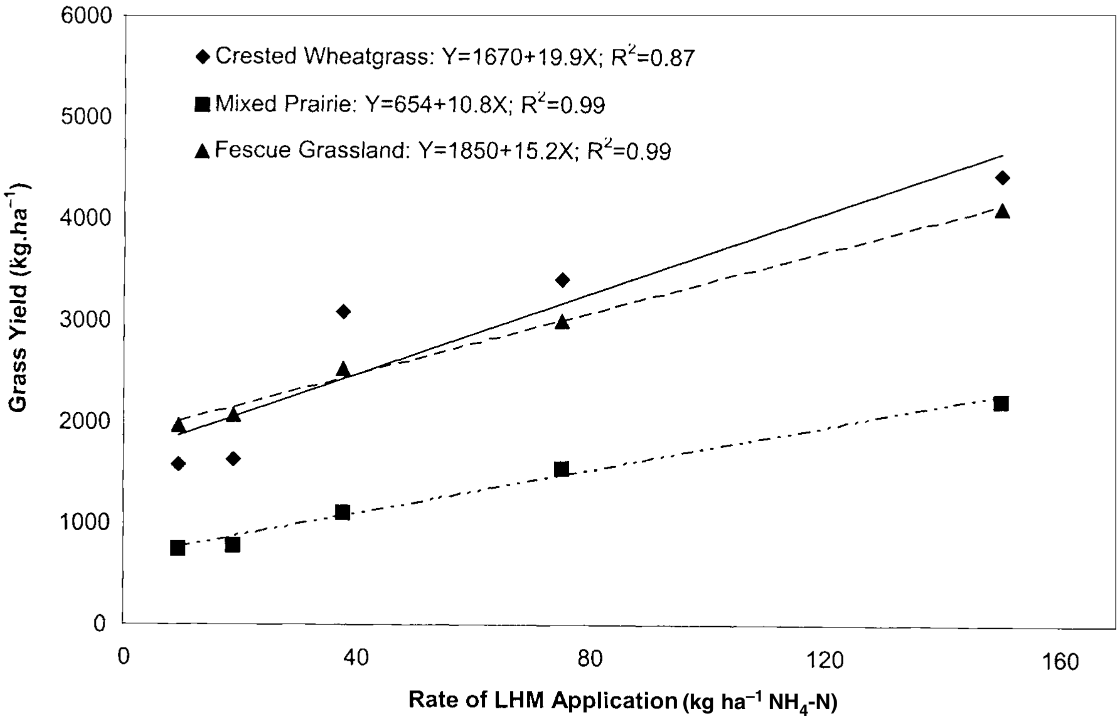

Fig. 1. Grass dry matter yield responses in 1999 to increasing LHM rates within the Mixed Prairie, Fescue Grassland, and Crested Wheatgrass plant communities. All linear responses significant ($P < 0.05$).

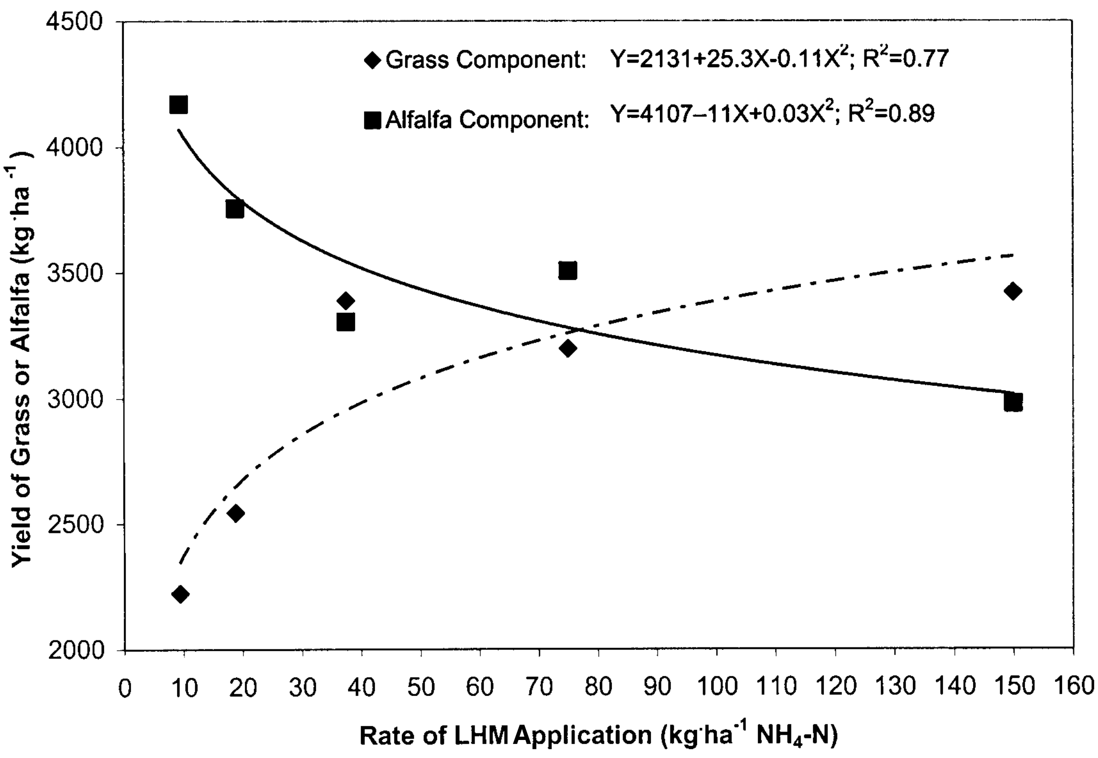

Fig. 2. Contrasting yield responses of grass and alfalfa in 1999 to increasing rates of LHM within the MB site.

Table 4. Summary of analyses of variance results on forb DM yield and forage crude protein[z] responses to different rates, methods, and seasons of LHM application

		1999			2000
Factor	df	CP ($g\ kg^{-1}$)	DM Yield ($kg\ ha^{-1}$)	CPY ($kg\ ha^{-1}$)	DM Yield ($kg\ ha^{-1}$)
Site	3				
Rate (R)	4	NS	NS	NS	***
Linear		–	–	–	*
Quad		–	–	–	**
Method (M)	1	**	NS	NS	NS
Season (S)	1	NS	NS	NS	NS
R × M	4	NS	NS	NS	NS
R × S	4	NS	NS	NS	**
M × S	1	NS	NS	NS	NS
R × M × S	4	NS	NS	NS	NS
Error	57				

[z]Evaluation of forb crude protein was limited to the 1999 sampling because three of the four sites had insufficient biomass for analysis in 2000.
***, **,* Denote significant effects at $P < 0.001$, $P < 0.01$, and $P < 0.05$, respectively; NS, not significant.

DISCUSSION

Grass Crude Protein

Manure application improved grass CP, although observed increases occurred primarily at the greatest LHM application rates tested. The initial increase during 1999 may have partly arisen from a visible phenological delay in plant development on plots treated with more manure, which in turn would have maintained greater CP through harvest in late summer. High rainfall during the 1999 growing season would have helped maintain those plots treated with more manure in a vegetative state. Regardless of the mechanism, continued improvements in CP concentration during 2000 indicate these benefits can extend into the longer term, especially under drought conditions.

Although observed mean CP levels in this study were all generally adequate for cows on a maintenance diet, CP levels at LHM application rates below 160 kg ha^{-1} NH_4-N were marginal (<7.5%) for lactating cows, which require closer to 11% CP (National Research Council 1996). Thus, LHM application at greater rates improved the suitability of forage for lactating beef cattle. While forage nitrate levels were not examined in this investigation, the risk of nitrate accumulation may increase at greater rates of LHM application and is therefore another important consideration for livestock production.

Injection of manure also increased grass CP levels compared to surface application in both grass and forb components during 1999. However, these differences were not reflected in CPY levels, though injected plots (185 kg ha^{-1}) tended to be greater in this parameter than broadcast plots (178 kg ha^{-1}). Notably, biomass levels were actually lower (though non-significantly; $P > 0.05$) within injected plots (2421 kg ha^{-1}) than broadcast plots (2479 kg ha^{-1}), a trend particularly apparent on three of the four sites (all but the MP), which may account for the lack of CPY differences between methods. These results suggest that LHM injection may have damaged some of the forage stands in 1999, an impact that was offset by the increase in CP concentration. Specialized manure application treatments (punch aeration) have been linked to better overall N uptake following manure application relative to broadcasting in other studies (Bittman et al. 1999), likely due to reduced atmospheric losses and/or improved root–manure contact immediately following application. A parallel study conducted here found a 45% reduction in ammonia loss with injection (Lambert and Bork 2003), which in turn may have contributed to the observed increase in CP.

Grass Yield

Grass CPY appeared to be more responsive to LHM application than biomass alone, particularly with low precipitation in 2000. Protein yield provided a better indication of the longer-term agronomic responses of overall forage production across the study sites following treatment with LHM. The variable CPY response among sites likely reflects variation in plant growth due to moisture and initial soil nutrient (particularly N) conditions, as well as the maximum potential responses of each plant community. Available soil N was generally low at all sites (< 12 kg ha^{-1}), suggesting N was limiting forage growth prior to application and led to the positive response to LHM.

Residual CPY increases in 2000 at high rates of LHM on the dryer sites (CWG and MP) parallel those of other studies that have found increased water use efficiency (Smitka et al. 1965; White and Brown 1972) and subsequent forage yields (e.g., Black 1968; Read 1969) following nutrient addition. Increases in water use result from root proliferation to greater soil depths (Lorenz and Rogler 1967) and may be responsible for the increased CPY. Notably, the apparent recovery of N based on the observed grass yield increases across both years totalled only 26% of applied N. Thus, nearly three-quarters of applied N remained unaccounted for, and may have been immobilized in the soil. Nutrients may also be stored in plants for future use or, as suggested by Jacobsen et al. (1996), temporarily immobilized by forage plants only to become available in subsequent years following root death and decomposition.

The inconsistent residual grass yield responses during 2000 among all sites in the current study can be attributed, at least in part, to reduced rainfall during that growing season. Furthermore, the highly favorable growing conditions of the previous year appeared to have depleted most of the available N (Lambert 2002), particularly within those plant communities accustomed to greater moisture (e.g., FG and MB), thereby limiting the potential for longer-term yield increases. Enhanced plant growth may also have intensified water use during 1999, leading to greater restrictions on plant growth with moisture deficits the following year.

Another way of examining the site-based differences is to assess N use efficiency, which quantifies incremental biomass yield changes for each additional unit of N applied. Using this approach, the greatest increase in grass yield occurred on the CWG and FG sites, where yield increased by 18.7 and 14.2 kg ha^{-1}, respectively, with each additional kg of N applied above 10 kg ha^{-1} NH_4-N. The CWG site expressed the most marked increase in CPY, reinforcing its

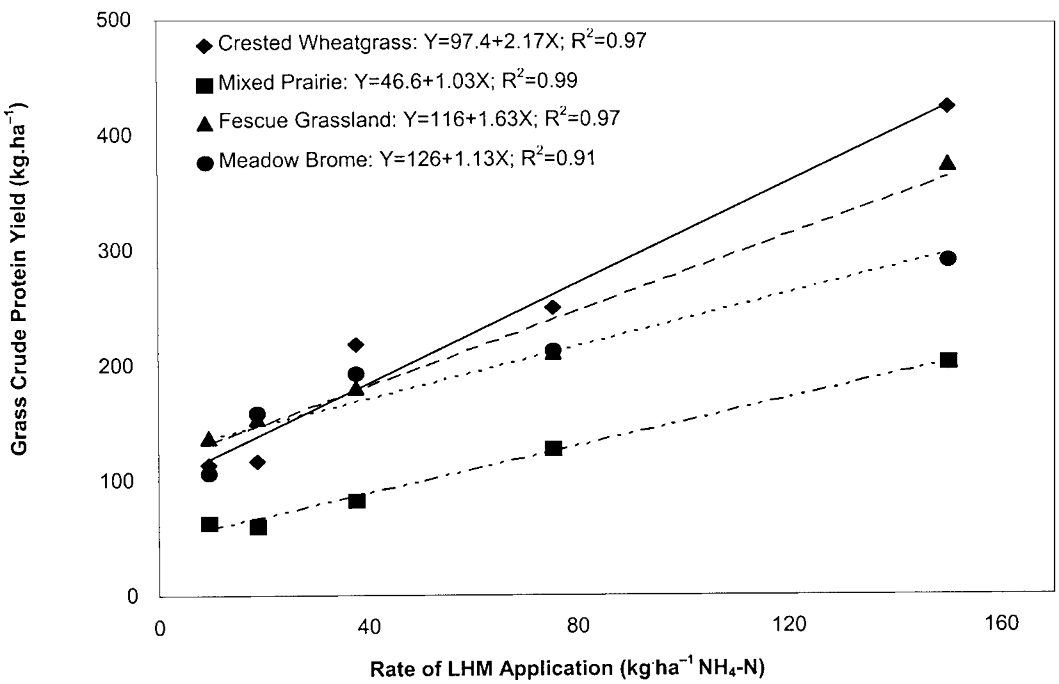

Fig. 3. Grass crude protein yield responses in 1999 to increasing LHM rates within each of the four plant communities examined. All linear responses significant ($P < 0.01$).

previously documented responsiveness to high fertility (e.g., McCaughey and Simons 1996a; Lutwick and Smith 1977), particularly when moisture is abundant.

At the MB site, both grass biomass and CPY increases occurred only up to 40 kg ha^{-1} NH_4-N. This response was likely due, in part, to the abundance of forbs (i.e., alfalfa) at this location and their direct competition with grasses. Forbs comprised 55% of the total standing biomass at this site in 1999. Moreover, the application of manure high in N may have been of less importance for increasing forage yield at this site because of ongoing N fixation by alfalfa.

The favorable grass response within the native plant communities (MP and FG) to manure addition indicated forage yield increases can be obtained on these areas as well as tame pasture. These results contradict the common notion that native vegetation is unresponsive to intensive management, including nutrient application (Looman and Kilcher 1983). Initial soil N levels were lowest within the FG and MP sites, and may account for the large positive yield increase observed at these locations with LHM application. The greater absolute yield responses to manure on tame pasture, however, reinforced earlier findings that these stands produce more dry matter yield compared to native range following N fertilization (Johnston et al. 1968). Although other research involving fertilization has found that native vegetation may respond by preferentially increasing root rather than shoot biomass (Black and Wight 1979), no root measurements were taken in the current study.

Continued grass CPY increases during the second year highlight the longer-term agronomic benefits of applying LHM to perennial forage lands. Given that CPY increases were evident even during drought, these results provide clarification to the notion that moisture rather than N availability limits production in arid regions of the prairies (e.g. Willms and Jefferson 1993; Campbell et al. 1986; Lorenz and Rogler 1972). Furthermore, it is plausible that had rainfall in 1999 been closer to average and nutrient depletion less extensive in the year immediately following LHM application, greater residual increases in CPY may have been realized during 2000 despite the dry conditions.

The practical utility of using LHM must take into account the cost-benefit of any additional yield increases. To assess this, measured total herbage increases in 1999 were used to quantify the relative value of additional forage (based on regional AUM grazing rates) produced under different rates of LHM application (Table 5). Although this procedure assumed similar CP levels among treatments and based grazing opportunities on peak standing biomass, regardless of growth form, this procedure provided a relative comparison of the incremental total grazing opportunities associated with LHM treatment. Review of these data indicate the economic benefit of total forage production increases on the MB site were minimal, including at maximal rates of LHM, presumably due to the trade-off between grass and alfalfa production described earlier. In contrast, the greatest additive value for grazing was found on the CWG site following LHM application (Table 5). Although the native rangeland sites exhibited lower levels of potential return than the CWG site, they both demonstrated a positive trend between increasing rates of LHM and the increased value of grazing.

Table 5. Comparison of the economic value of increased forage production (grass and forb combined) arising from LHM application at different rates within each of the four sites in 1999. Data are based on yield increases relative to that observed at the lowest LHM rate (10 kg ha^{-1} NH_4-N)

Site	LHM rate	Change in yield[z] (kg ha^{-1})	Additional AUM supported[y] (AUM ha^{-1})	Additive value[w] of AUM[x] ($ ha^{-1})
Meadow bromegrass	20	–93	–0.10	–1.54
	40	579	0.64	9.56
	80	311	0.34	5.14
	160	7	0.008	0.12
Crested wheatgrass	20	77	0.08	1.27
	40	1517	1.67	25.06
	80	1812	2.00	29.93
	160	2847	3.14	47.03
Fescue prairie	20	148	0.16	2.44
	40	623	0.69	10.29
	80	1116	1.23	18.44
	160	2208	2.43	36.48
Mixed prairie	20	38	0.04	0.63
	40	440	0.48	7.27
	80	1170	1.29	19.33
	160	2084	2.30	34.43

[z]Changes in forage production are relative to those observed at the lowest rate of LHM application (10 kg ha^{-1}).
[y]Assumes 50% safe use of increased forage and 454 kg forage requirement per AUM for consumption and trampling (lactating cow with calf).
[x]Assumes a conservative value of $15 AUM^{-1} based on grazing rates for the central region of Alberta (Farm Operations Cost Guide 2003). Most common range is $14–24 AUM^{-1}.
[w]Final value does not include the cost of manure, its hauling or application, which are assumed to be constant among sites. Provincial costs for these factors were not available (Farm Operations Cost Guide 2003).

These results collectively suggest that forage swards dominated by grass, including either native rangeland or tame pasture, are most likely to maximize cattle production under nutrient application although, on rangelands, factors other than forage production must be considered such as the maintenance of native flora.

Forb Yield

Similar to the grass component, forb CP was enhanced by the use of injection, reinforcing the earlier documented benefit of this technique for increasing nutrient capture (Bittman et al. 1999). Other responses in the forb component were variable, in part due to the limited abundance of forbs at two sites (CWG and FP). Thus, interpretation of forb responses to LHM is best done using sites containing greater amounts of this vegetation, namely the MB and MP sites.

The explanation for the variable response in forb yield during 2000 to different rates and seasons of LHM application are unknown, but may arise from temporal variation in the competitive relationship between grasses and forbs throughout the monitoring period. For example, grasses may have taken up nutrients better during periods of slow growth and dormancy, placing alfalfa within the MB site at a competitive disadvantage on plots treated with LHM the previous fall. This would account for the greater forb yield on spring-treated plots in 1999. Alternatively, alfalfa may be less able to take up and assimilate nitrate than ammonium, as the fall-applied ammonium in LHM was converted during the late fall and early spring through nitrification (Lambert 2002).

The following year, fall-treated plots on the MB site were greater in forb production. Forb growth in spring-treated plots may have experienced a continuing negative response due to intensified competition from the marked increase in grass biomass the year before, coupled with the dry conditions of 2000. Grasses are generally superior to forbs at responding rapidly to increasing N application (Lutwick and Smith 1977). These observations are consistent with other studies that have found nutrient (N) addition may increase the proportion of grasses at the expense of the leguminous fraction (Bittman et al. 1997; Russelle 1992; Nuttall et al. 1991; Dougherty and Rhykerd 1985), in large part due to intense competition from grasses (Russelle 1992). The absence of a decrease in forb yield at the greatest rate of LHM (160 kg ha^{-1} NH_4-N) in 2000 could indicate forb production was able to overcome this suppressive effect when sufficient nutrients were available. As discussed earlier, variation in availability and uptake of various forms of N may explain seasonal effects, and merits further investigation. Regardless of the cause, the observed results provide evidence that variation in the season of LHM application will alter the abundance of alfalfa in mixed forage swards.

Within the MP site, the observed increase in pasture sage during 1999 is in agreement with other studies that have found the initial response to nutrient addition on arid rangeland is often characterized by an increase in this species (Goetz 1969). Both the forementioned study and the results found here, however, indicate pasture sage increases are short-lived, as no residual increase in sage was observed during 2000 (Blonski 2001).

Overall, this research demonstrated that forage responses to LHM on both native rangeland and tame pasture were affected by the rate of manure applied. Changes in CP concentration and yield were generally positive as application rates increased. However, these responses were most evident in the first year following treatment, in part due to favorable precipitation. During the second year and despite dry conditions, further improvements in CP and CPY were evident, though this response was restricted to the grass component. Subsurface coulter injection of LHM resulted in limited changes to forage production, but improved the CP of grasses and forbs. Notably, no reduction in forage production was observed with LHM application, including low-disturbance coulter injection. One year after application, little physical evidence remained of injection (i.e., surface scarring), including on native rangelands. Despite these positive outcomes, the decision to utilize this technology will have to consider other aspects of its use, including the cost and logistical challenges of operating such machinery. The decision on whether to use this technology should also consider other benefits, including environmental and aesthetic (i.e. odor) considerations, as well as improved consistency in crop responses (Bittman et al. 1999). Further research is recommended investigating the specific relationship between growing conditions and treatment effects within semi-arid forage lands, including the agronomic responses to repeated, long-term applications.

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