

Pasture productivity, cattle productivity and metabolic status following fertilization of a grassland with liquid hog manure: A three-year study

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Wilson, C., Undi, M., Tenuta, M., Wittenberg, K. M., Flaten, D., Krause, D. O., Entz, M. H., Holley, R. and Ominski, K. H. 2010. **Pasture productivity, cattle productivity and metabolic status following fertilization of a grassland with liquid hog manure: A three-year study.** *Can. J. Anim. Sci.* **90**: 233–243. Forage yield and quality, cattle and pasture productivity, and enteric methane (CH₄) emissions were determined from grass pastures receiving liquid hog manure. Three treatments were evaluated: grass pastures receiving no manure (Control), grass pastures receiving liquid hog manure applied as a single application of 142 ± 20 kg available N ha⁻¹ in the spring (Single) or a split application of 70 ± 6 kg available N ha⁻¹ in both the spring and autumn (Split). Each treatment was represented by two paddocks. The study was carried out over three grazing seasons, from 2004 to 2006, with each grazing season divided into three, 28-d periods. Growing steers (338 ± 32 kg) were introduced into pastures in early summer (May–June) of each year. Standing biomass, measured using quadrats, averaged 1.2, 2.6, and 2.0 ± 0.44 t dry matter (DM) ha⁻¹ for Control, Split and Single pastures, respectively, and was not influenced (*P* = 0.13) by liquid hog manure application. Liquid hog manure application caused a shift in pasture grasses resulting in a predominance of quackgrass [*Elytrigia repens* (L.) Nevski]. Nutrient profiles of forage samples collected by hand plucking showed no treatment response for forage gross energy (GE; *P* = 0.18) and neutral detergent fibre (NDF; *P* = 0.19), but forage crude protein (CP) (*P* = 0.027) as well as ash (*P* = 0.002), K (*P* = 0.001), P (*P* = 0.001), and Mg (*P* = 0.001) concentrations increased with manure application. Liquid hog manure application did not influence dry matter intake (DMI) (*P* = 0.56), GE intake (*P* = 0.58), and NDF intake (*P* = 0.79) of grass forages. Higher CP intake of steers on Split and Single pastures resulted in higher (*P* = 0.001) serum urea N (5.7 and 5.9 ± 0.42 mmol L⁻¹, respectively) compared with steers grazing Control pastures (2.5 ± 0.42 mmol L⁻¹). Enteric CH₄ emissions (L d⁻¹) tended to be lower (*P* = 0.09) in cattle grazing the Split pasture treatment. Though application of liquid hog manure did not improve individual animal gains, pasture carrying capacity increased (*P* = 0.001) from 89 to 324 grazing days ha⁻¹ and liveweight gain increased (*P* = 0.001) from 100 to 329 kg ha⁻¹ in Control and manured pastures, respectively. Application of liquid hog manure to grasslands generated significant benefits through improved forage quality and pasture productivity measured as carrying capacity and liveweight gain. Split liquid hog manure application may have a further benefit in terms of improved carrying capacity and lower enteric CH₄ emissions.

Key words: Liquid hog manure, enteric methane, beef cattle, carrying capacity, serum urea nitrogen

Wilson, C., Undi, M., Tenuta, M., Wittenberg, K. M., Flaten, D., Krause, D. O., Entz, M. H., Holley, R. et Ominski, K. H. 2010. **Productivité des pâturages, productivité des bovins et bilan du métabolisme après fertilisation d'une prairie avec du lisier de porc: une étude de trois ans.** *Can. J. Anim. Sci.* **90**: 233–243. Les auteurs ont déterminé le rendement et la qualité des fourrages, la productivité du bétail et des pâturages ainsi que les émissions de méthane (CH₄) entérique de prairies de graminées fertilisées avec du lisier de porc. Ils ont évalué trois traitements: aucune fertilisation (témoin) et prairies de graminées bonifiées soit par une seule application de lisier de porc de 142 ± 20 kg de N disponible par hectare au printemps (Simple), soit par une application en deux étapes de 70 ± 6 kg de N disponible par hectare au printemps et à l'automne (Partagée). Deux enclos ont été affectés à chaque traitement. L'étude s'est déroulée sur trois saisons, de 2004 à 2006, chaque saison de croissance étant divisée en trois périodes de 28 jours. Les bouvillons en croissance (338 ± 32 kg) ont été mis à l'herbe au début de l'été (mai-juin) chaque année. La biomasse sur pied, mesurée à partir de quadrats, s'établissait en moyenne à 1,2, à 2,6 et à 2,0 ± 0,44 t de matière sèche par hectare, respectivement, pour la prairie témoin, la prairie Partagée et la prairie Simple. Elle ne subit pas l'influence (*P* = 0,13) de l'application de lisier de porc. L'application de lisier modifie la composition des graminées en favorisant la prédominance du chiendent [*Elytrigia repens* (L.) Nevski]. Le profil des oligoéléments dans les échantillons de fourrage prélevés à la main révèle que le traitement ne modifie pas la quantité d'énergie brute (EB; *P* = 0,18) ni celle de fibres au détergent neutre (FDN; *P* = 0,19) du fourrage, mais que la concentration

Abbreviations: ADF, acid detergent fibre; ADG, average daily gain; CP, crude protein; CPI, crude protein intake; DM, dry matter; DMI, dry matter intake; NDF, neutral detergent fibre; SF₆, sulphur hexafluoride; SUN, serum urea nitrogen

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de protéines brutes ($P=0,027$) ainsi que celle de cendres ($P=0,002$), de K ($P=0,001$), de P ($P=0,001$) et de Mg ($P=0,001$) augmente avec le fumier. L'application de lisier porc n'agit pas sur la quantité de matière sèche ($P=0,56$), d'EB ($P=0,58$) et de FDN ($P=0,79$) des graminées fourragères ingérée. La plus forte absorption de protéines brutes par les bouvillons paissant sur les prairies Partagée et Simple débouche sur une plus grande ($P=0,001$) concentration de N uréique dans le sang ($5,7$ et $5,9 \pm 0,42$ mmol par litre, respectivement) que chez les sujets paissant sur la prairie témoin ($2,5 \pm 0,42$ mmol par litre). Les émissions de CH_4 entérique (litres par jour) ont tendance à être plus faibles ($P=0,09$) chez les animaux qui paissent sur la prairie Partagée. Bien que l'application de lisier de porc n'augmente pas le gain des animaux, on remarque une hausse de la capacité de charge des pâturages ($P=0,001$), qui passe de 89 à 324 jours de paissance par hectare, ainsi qu'une hausse du poids vif ($P=0,001$), de 100 à 329 kg par hectare, pour les prairies témoin et celles fertilisées, respectivement. L'application de lisier de porc aux prairies a d'importantes retombées avec l'amélioration de la qualité des fourrages et une productivité accrue des pâturages sous forme d'une hausse de la capacité de charge et du poids vif. L'application partagée de lisier de porc pourrait présenter un avantage supplémentaire en augmentant la capacité de charge et en diminuant les émissions de CH_4 entérique.

Mots clés: Lisier de porc, méthane entérique, bovins, capacité de charge, concentration d'urée dans le sang

Approximately 79% of the 0.72 million ha of Manitoba pasture land utilized by grazing cattle is native or naturalized (Statistics Canada 2005). Grass species in native pastures are characterized by low yields and low crude protein (CP) contents (Looman 1983), and hay from such pastures can contain CP contents as low as 63 g kg^{-1} (Walton 1983). Therefore, it is common practice to add nitrogen to grass pastures to improve pasture yield and quality (Dougherty and Rhykerd 1985). Increases in pasture productivity following N addition are mainly due to increase in pasture carrying capacity as well as animal liveweight gain per unit pasture area (Kopp et al. 2003). A source of nutrients that can be utilized to improve productivity of naturalized grass pastures is liquid hog manure. The timing of liquid hog manure application may be an important factor in ensuring that pasture plants have access to nutrients during active growth.

An added benefit of improving forage CP status of grass pastures may be the optimized rumen fermentation in cattle grazing such pastures. Ruminants require a minimum of 60 to 80 g kg^{-1} dietary CP for optimal rumen fermentation (Van Soest 1982). Increased enteric CH_4 emissions in growing beef cattle on low CP content [78 g kg^{-1} dry matter (DM)] grass forages were attributed to reduced rumen fermentation efficiency (Ominski et al. 2006). Reducing enteric CH_4 emissions has multiple benefits in that CH_4 production represents a loss of dietary energy (DeRamus et al. 2003) and contributes to global CH_4 output (Lassey 2007).

It is hypothesized that nutrient application in the form of liquid hog manure can substantially improve productivity of grass pastures with a potentially added benefit of reducing enteric CH_4 emissions from grazing cattle. Applying liquid hog manure twice during the grazing season is expected to show greater improvement than a single application. The objective of this study was to evaluate changes in pasture forage yield and quality, as well as growing animal productivity associated with liquid hog manure applied as a single or split application onto naturalized grass pastures. Parameters considered included botanical composition, pasture forage biomass

and nutrient composition, animal dry matter intake, average daily gain, enteric CH_4 production as well as pasture productivity in terms of carrying capacity and gains per hectare. Animal health status was monitored through serum urea N and serum enzymes. The study was conducted over three grazing seasons to examine response under varied environmental conditions.

MATERIALS AND METHODS

Site Description

The research site was located 13 km south of the town of La Broquerie in southern Manitoba. The site was originally seeded to alfalfa (*Medicago sativa* L), timothy (*Phleum pratense* L) and meadow bromegrass (*Bromus biebersteinii*) approximately 10 yr prior to the start of this trial. However, by the start of this trial, the pastures had naturalized to primarily Kentucky bluegrass (*Poa pratensis* L) and quackgrass [*Elytrigia repens* (L.) Nevski]. Prior to the onset of this study, the site had been used for hay production. The selected area (32 ha) was divided into six paddocks, two of which were assigned to each of three treatments.

Soil at the study site had a Canadian agricultural capability class of 3m, which is marginal for annual crop production due to lack of summer soil moisture on the coarse-texture soil. The soil series present at the site are Berlo loamy fine sand (70%) and Kergwenan loamy sand to gravel (30%) with the former being a Gleyed Dark Gray Luvisol and the latter a Dark Gray Chernozem (Hopkins 1985). The topography of the site was very gently sloping to level. Soil drainage was rapid, though imperfect at times due to a high water table during snowmelt and prolonged heavy rainfall. Background soil nutrient concentrations (0–5 cm) in the fall of 2003 for all plots prior to start of the trial were total organic carbon 21.3 g kg^{-1} , total N 1.6 g kg^{-1} , extractable $\text{NH}_4\text{-N}$ 4.1 mg kg^{-1} , $\text{NO}_3\text{-N}$ 1.3 mg kg^{-1} and NaHCO_3 -extractable P 10.8 mg kg^{-1} soil.

Pasture Treatments

Three manure treatments were evaluated in this study, namely: no manure (Control), liquid hog manure

applied as a split application (70 ± 6 kg available N ha^{-1}) in the spring and fall (Split), and a single application of liquid hog manure applied at a rate of 142 ± 20 kg available N ha^{-1} each spring (Single). Liquid hog manure was surface-applied by drag lines (fall 2003) and splash-plate tanker (remaining applications) from the primary cell of a nearby earthen manure storage of a feeder hog operation. Application rate was based on available N content assuming the following: a 25% volatilization loss of ammonia N, 100% availability of the remaining ammonia N, and a 25% availability of added organic-N in the year of application to grass (Prairie Provinces' Committee on Livestock Development and Manure Management 2006). The liquid hog manure had an average pH of 7.0 ± 0.3 , a DM content of $6.4 \pm 3.3\%$ and contained $0.5 \pm 0.1\%$ total N (% fresh weight), $0.3 \pm 0.04\%$ $\text{NH}_3\text{-N}$ (% fresh weight), 2142 ± 143 mg K L^{-1} , 1207 ± 637 mg P L^{-1} , and 1115 ± 404 mg Mg L^{-1} over the study period. Pastures receiving liquid hog manure were 4 ha and untreated (Control) pastures were 8 ha in size to ensure adequate forage availability for steers assigned to each pasture.

Pasture Management

The study extended over 3 yr from 2004 to 2006. Each year, yearling steers were turned onto a continuously grazed pasture in late May or early June, when standing forage biomass was estimated to be 1.0 t DM ha^{-1} . The grazing season was divided into three, 28-d periods. Standing forage biomass of each pasture was determined at the beginning of each 28-d period by clipping nine, 0.25-m^2 quadrats in a W-pattern to a height of 3.75 cm. "Put and take" steers, as described by Kopp et al. (2003), were used in an attempt to maintain standing forage biomass between 1.0 and 1.5 t DM ha^{-1} and to maintain plant growth in the vegetative stage. When not used, "put and take" steers were maintained on an adjacent pasture, similar in botanical composition to the test pastures. To collect an accurate sample of consumed forage material, animal grazing activity was observed and similar swards were hand-plucked to the height grazed. Hand-plucked samples from each pasture were collected in each period concurrent with enteric CH_4 collections. Growing cattle were removed from pastures when animals achieved a minimum BW of 340 kg or when pasture forage biomass was less than 400 kg ha^{-1} .

Botanical Composition

Botanical composition of the pastures was estimated by identifying 10 transects along the diagonal of each pasture. Each transect (approximately 300 cm) had 10 points below which the nearest plant was recorded. Another transect, parallel to the first, was used to take a duplicate sample, thus a total of 200 plants were identified in each pasture. Measurements were taken in mid-July of each year.

Animal Management

Ten British-continental cross yearling beef steers (338 ± 32 kg) were assigned to each pasture at the beginning of each grazing season such that steer weight entering pastures was uniform. Steers were treated with Spoton[®] pour-on solution (Bayer Inc., Toronto, ON), vaccinated with Bovi-Shield 4[®] (Pfizer Animal Health, Exton, PA) and One Shot[®] (Pfizer Animal Health, Exton, PA), and Valbazen[®] oral suspension (Pfizer Animal Health, Kirkland, QC) was administered. Steers also received Revlar-G[®] implants (Intervet Canada Ltd, Whitby, ON) immediately prior to introduction to the pasture. On pasture, steers were sprayed with Ectiban[®] (Durvet Animal Health Inc, Bluesprings, MO) to protect against biting flies and mosquitoes when flies were observed settling on animals. Fresh water and trace minerals (Rancher's Choice 8:4:50 Interlake Beef Pasture Premix, Puratone Feeds, Niverville, MB) were available ad libitum in each pasture. Steers were weighed upon entry to the pasture at the start of each trial year and also at removal at the end of the grazing season in early or mid-August. Steers were also weighed on day 1 of each sampling period and again at the end of the gas sample collection period. Animal handling and care procedures in this study were approved by the University of Manitoba Animal Care Committee according to guidelines of the Canadian Council on Animal Care.

Animal Measurements

Dry Matter Intake

Dry matter intake for each test animal in each grazing period was determined using n-alkane controlled-release capsules (MCM Alkane, Auckland, New Zealand) as described by Moshtaghi-Nia and Wittenberg (2002). The capsules were administered orally at least 11 d prior to faecal sampling to allow capsules sufficient time to reach a steady release rate in the rumen. Forage n-alkane content was determined from duplicate hand-plucked pasture forage samples collected on the same day as a faecal grab sample was taken from each steer. Methods of n-alkane extraction and analysis, as well as equations used to calculate dry matter intake (DMI), were similar to those described by Moshtaghi-Nia and Wittenberg (2002). Manufacturer's release rates of n-alkanes from controlled release capsules were verified in a separate trial using three rumen-fistulated steers grazing the same test pastures (Undi et al. 2008).

Enteric Methane Emissions

In each 28-d period, enteric CH_4 emissions were measured in a 24-h period using the sulphur hexafluoride (SF_6) technique as described by Boadi et al. (2002). Methods of CH_4 and SF_6 collection and analysis were similar to those described by Boadi and Wittenberg (2002) and Boadi et al. (2002). Enteric CH_4 emissions were calculated using an equation described by Johnson et al. (1994).

Blood Samples

Blood samples were collected from the tail vein of steers once per 28-d period at the time of weighing. Samples were placed on ice immediately after collection and were refrigerated prior to analysis. Blood metabolites were analyzed by Manitoba Agriculture, Food and Rural Initiatives Veterinary Services Branch, (Winnipeg, MB), using colorimetric tests with a Vitros 250 (Ortho Clinical Diagnostics Inc., Pub. No. MP2-9, Rochester, NY).

Chemical Analyses

Forage and faecal samples were dried for 48 h at 60°C in a forced-air oven to determine DM content. After drying, samples were ground to pass through a 1-mm screen (Cyclotec Tecator 1093 Sample Mill, Foss Analytical, Denmark). Forage samples were analyzed for CP using a LECO NS 2000 analyzer (LECO Corporation, St. Joseph, MI). Gross energy was determined using a Par 6300 Automatic Isoperibol Calorimeter (Moline, IL). Forage acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using an ANKOM 200 fiber analyzer (Fairport, NY) as described by Komarek (1993). Forage ash was determined by combustion in a furnace (Association of Official Analytical Chemists (AOAC) 1990, method no. 942.05). Forage Ca, P, K, and Mg concentrations were determined by inductively-coupled plasma emission spectroscopy (Vista MPX ICP, Varian Canada Inc., Mississauga, ON; AOAC 2005, method no. 985.01).

Statistical Analyses

Standing pasture biomass and forage nutrient concentrations were analyzed using the MIXED procedure of SAS Software (Version 9.1, SAS Institute, Inc. 2003) with pasture as the experimental unit. Average daily gain (ADG), DMI, enteric CH₄ and blood profile data were also analyzed using the MIXED procedure of SAS software with animal as the experimental unit. Both models used a repeated measures design with period as the unit of time. The fixed effects in the models were treatment, period, and treatment × period interaction. Year and replicate were considered random factors. Grazing days, liveweight gain, and botanical composition data were analyzed using the MIXED procedure of SAS software with replicate as the random factor. Least squares means were calculated and, where appropriate, mean separation was performed using Bonferroni's multiple comparison tests.

RESULTS AND DISCUSSION

Weather Conditions

Precipitation, measured from April/May through to November in each year, averaged 521, 578 and 281 mm for 2004, 2005 and 2006, respectively. In 2004 and 2005, precipitation exceeded the historical average for the area (Steinbach Airport; Canadian Climate Normal Period 1961–1990). Air temperatures did not vary

among study years as much as precipitation and ranged from approximately –2 to 28°C during the growing period. Heavy snowfall interrupted manure application in the spring of 2004.

Pasture Yield

Manure treatment ($P=0.13$) and grazing period ($P=0.22$) did not influence standing forage biomass (Table 1) because “put and take” animals were used in an attempt to maintain standing forage biomass at 1.0 to 1.5 t DM ha⁻¹. However, rapid growth response to precipitation made it challenging to maintain standing forage biomass at 1.0 to 1.5 t DM ha⁻¹ for manured pastures. Pasture stocking rates ranged from 0.7 to 2.4 animals ha⁻¹ for Control pastures and from 1.2 to 5.6 animals ha⁻¹ for manured pastures over the course of the study. Based on biomass accumulation, stocking rates employed in manured pastures may have been too low at times, a reflection of difficulty to predict forage growth response to environmental conditions such as temperature and precipitation.

Pasture Quality

Botanical Composition

Liquid hog manure treatment influenced proportions of Kentucky bluegrass ($P=0.030$) and quackgrass ($P=0.026$) in grass pastures over 3 yr. Control pastures contained an equal proportion of Kentucky bluegrass and quackgrass, each making up $40 \pm 6.9\%$ and $41 \pm 8.0\%$ of the pasture plants, respectively. A significantly lower ($P=0.030$) proportion of Kentucky bluegrass was observed in manured pastures. In Split and Single pastures, Kentucky bluegrass made up approximately 22 and $27 \pm 6.9\%$ of the pasture plants, respectively. Quackgrass was the predominant grass in Split and Single pastures, making up 63 and $58 \pm 8.0\%$ of the pasture plants, respectively. Manure application did not influence ($P=0.71$) the proportion of other grass species such as timothy. The proportion of these grass species (Fig. 1) was higher ($P=0.053$) in all pastures in year 1 ($25 \pm 9.6\%$) relative to years 2 ($7.8 \pm 9.6\%$) and 3 ($5.7 \pm 9.6\%$). The initiation of grazing reduced the proportion of these grass species. Legumes represented a small proportion of the pasture plants, $3 \pm 1.4\%$ in Control pastures and $1 \pm 1.4\%$ in manured pastures and were not influenced ($P=0.12$) by manure treatment. The proportion of forbs in Control pastures, $7 \pm 1.3\%$, was higher ($P=0.004$) than in manured pastures, where forbs made up $1 \pm 1.3\%$ of the pasture plants.

The greatest species diversity over the course of the study was observed in the Control pastures where Kentucky bluegrass and quackgrass occurred in equal proportions and legumes and other forbs made up approximately 10% of the pasture composition. Conversely, grasses made up approximately 98% of the plants in manured pastures, the remaining 2% being primarily forbs.

Table 1. Standing forage biomass and nutrient profile^z (DM basis) of forages in pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study ($N=48$)

| | Treatment (T) | | | | Period (P) | | | | P value | | |
|--|-------------------|-------------------|-------------------|------|-------------------|-------------------|-------------------|------|---------|-------|-------|
| | Control | Split | Single | SE | 1 | 2 | 3 | SE | T | P | T × P |
| Standing forage biomass (t DM ha ⁻¹) | 1.2 | 2.6 | 2.0 | 0.59 | 1.5 | 2.5 | 1.8 | 0.50 | 0.13 | 0.22 | 0.60 |
| Crude protein (g kg ⁻¹) | 95 ^b | 162 ^{ab} | 178 ^a | 15.5 | 159 | 132 | 144 | 15.0 | 0.027 | 0.26 | 0.62 |
| Neutral detergent fibre (g kg ⁻¹) | 604 | 594 | 569 | 14.8 | 578 | 608 | 581 | 16.0 | 0.19 | 0.30 | 0.09 |
| Acid detergent fibre (g kg ⁻¹) | 335 ^a | 321 ^{ab} | 300 ^b | 9.3 | 299 ^b | 335 ^a | 322 ^{ab} | 8.4 | 0.015 | 0.001 | 0.022 |
| Gross energy (kJ kg ⁻¹) | 18.7 | 18.9 | 19.1 | 0.14 | 19.2 | 18.8 | 18.8 | 0.12 | 0.18 | 0.08 | 0.40 |
| Ash (g kg ⁻¹) | 64.7 ^b | 70.2 ^a | 72.0 ^a | 0.22 | 64.0 ^b | 69.2 ^a | 73.7 ^a | 0.22 | 0.002 | 0.003 | 0.09 |
| Calcium (g kg ⁻¹) | 4.1 | 3.7 | 3.7 | 0.40 | 3.0 | 4.1 | 4.3 | 0.52 | 0.55 | 0.24 | 0.33 |
| Phosphorus (g kg ⁻¹) | 1.9 ^b | 2.9 ^a | 3.2 ^a | 0.25 | 2.6 | 2.5 | 2.8 | 0.38 | 0.001 | 0.88 | 0.39 |
| Potassium (g kg ⁻¹) | 10.6 ^b | 16.1 ^a | 18.6 ^a | 1.92 | 16.8 | 14.3 | 14.1 | 2.04 | 0.001 | 0.41 | 0.80 |
| Magnesium (g kg ⁻¹) | 1.5 ^b | 1.8 ^a | 1.9 ^a | 0.18 | 1.4 | 1.8 | 2.0 | 0.21 | 0.001 | 0.17 | 0.44 |
| Calcium to phosphorus ratio | 2.2 ^a | 1.3 ^b | 1.2 ^b | 0.10 | 1.2 ^b | 1.8 ^a | 1.6 ^a | 0.09 | 0.001 | 0.001 | 0.012 |
| Tetany ratio ^y | 0.9 ^b | 1.4 ^a | 1.4 ^a | 0.09 | 1.7 ^a | 1.1 ^b | 1.0 ^b | 0.11 | 0.002 | 0.014 | 0.43 |

^zNutrient profile of hand-plucked forage samples representative of grazed forage.

^yK/(Ca+Mg); Concentrations of K, Ca, and Mg were expressed in mEq kg⁻¹ DM.

a, b Means within factors in a row followed by a different letter differ ($P < 0.05$).

Forage Nutrient Composition

As might be expected, the CP content of manured pastures was 56% higher ($P=0.027$) than that of Control pastures (Table 1). The CP content of hand-plucked samples from Control pastures ranged from 59 to 131 g CP kg⁻¹ DM over the course of the study. By comparison, animals grazing manured pastures consumed forage that ranged from 97 to 282 g CP kg⁻¹ DM. The minimum CP requirement for a growing 325 kg steer gaining approximately 1 kg d⁻¹ is 97 to 170 g CP kg⁻¹ DMI [National Research Council (NRC) 1996]. Therefore, manure application ensured that

forage CP content always met or exceeded minimum CP requirements of growing steers.

Forage NDF content was not influenced ($P=0.19$) by manure treatment (Table 1). However, ADF content was influenced ($P=0.022$) by manure treatment as well as by grazing period (Table 1). Acid detergent fibre content of Control pastures steadily increased as the grazing season progressed. In contrast, peak forage ADF content in the Split pastures was observed following a flush of plant growth during the second period, when animal numbers were insufficient to maintain pasture forage in a vegetative state. As the grazing season progressed, the rate of growth was exceeded by the rate of biomass consumption, and ADF content declined. Forage ADF content of Single pastures remained almost constant over the three grazing periods and ranged from 287 to 292 g kg⁻¹ DM basis.

Forage GE was not influenced ($P=0.18$) by pasture treatment but tended ($P=0.08$) to be higher in the first period relative to the other grazing periods (Table 1). Forage ash content reflects the total mineral content of forage, and is negatively associated with forage energy and protein content (Hoffman 2005). Liquid hog manure application ($P=0.002$) and advanced grazing season ($P=0.003$) increased pasture ash content (Table 1).

Manure treatment increased forage K ($P=0.001$), P ($P=0.001$), and Mg ($P=0.001$) concentrations but had no influence ($P=0.55$) on Ca concentration (Table 1). Even without liquid hog manure treatment, forage K concentration (10.6 ± 1.92 g kg⁻¹ DM) exceeded animal K requirements. Dietary K requirement of growing cattle is 3 to 4 g kg⁻¹ DM (NRC 1996), with a maximum tolerable K concentration of approximately 30 g kg⁻¹ DM in ruminant diets (NRC 2001). Forage Mg concentrations of both Control (1.5 ± 0.18 g kg⁻¹) and manured (1.9 ± 0.18 g kg⁻¹) pastures were adequate to meet the Mg requirements of growing beef cattle

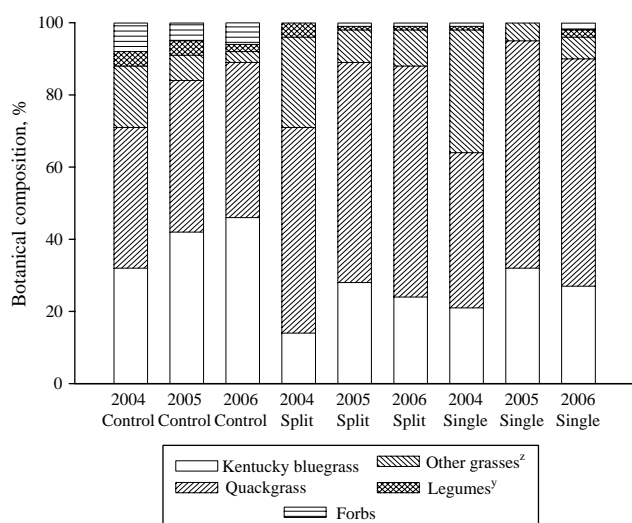


Fig. 1. Botanical composition of grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study ($N=18$). ^zTimothy made up approximately 43% of other grasses. ^yThe main legumes were alfalfa and red clover.

(NRC 1996). The increase in forage P concentration from $1.9 \pm 0.25 \text{ g kg}^{-1}$ DM in Control pastures to $3.0 \pm 0.25 \text{ g kg}^{-1}$ DM in manured pastures following liquid hog manure application (Table 1) suggests that the soils were deficient in P. Soils at the study site tested low to very low for NaHCO_3 -extractable P, averaging 10.8 mg kg^{-1} soil. In Manitoba, 25 to 30 mg kg^{-1} soil NaHCO_3 -extractable P is considered agronomically optimum for plant growth (Manitoba Phosphorus Expert Committee 2006).

The effect of pasture treatment on grass Ca to P ratio differed depending on grazing period ($P=0.012$). The Ca:P ratio of Control pastures ($1.7 \pm 0.19:1$) was higher than Split pastures ($1.0 \pm 0.19:1$) and Single pastures ($0.96 \pm 0.19:1$) in the first grazing period. This trend continued in all grazing periods. Also, the Ca to P ratio of Control pastures was highest in the second period ($2.8 \pm 0.14:1$) relative to the first ($1.7 \pm 0.19:1$) and third ($2.1 \pm 0.17:1$) grazing periods. The relatively higher forage Ca:P ratio of Control pastures was a result of lower pasture P concentration in these pastures relative to manured pastures. Calcium:P ratios of $2.2 \pm 0.10:1$, $1.3 \pm 0.10:1$, and $1.2 \pm 0.10:1$ for Control, Split and Single pastures (Table 1), respectively, were within tolerable ranges for ruminants. The most suitable Ca:P ratio for farm animals ranges from 1:1 to 2:1 although ruminants can tolerate higher ratios provided P requirements are met (McDonald et al. 1995).

Liquid hog manure application increased ($P=0.002$) the tetany ratios $[\text{K}/(\text{Ca}+\text{Mg})]$ of pasture forages (Table 1). Also, the tetany ratio was higher ($P=0.014$) in the first period relative to the other periods. Increasing tetany ratios with liquid hog manure application were a result of increasing pasture forage K content with no change in Ca content. However, liquid hog manure, at application rates used in this study, did not result in forages with tetany ratios above 2.2. Forages with a ratio greater than 2.2 will predispose cattle to grass tetany (Jefferson et al. 2001). Indeed, no cases of grass tetany were recorded in this study.

Animal Productivity

Dry Matter Intake

An aversion to forage growing on manured land was visually noted upon initial exposure to pastures in period 1 of the first grazing season as cattle exhibited preference for forage along fence lines and other areas that did not receive manure. This short-term aversion lasted for approximately 10 d, and did not reduce ($P=0.56$) DMI of steers grazing on manured pastures. Dry matter intake ranged from 6.1 to 6.7 kg d^{-1} among treatments and from 6.1 to 7.2 kg d^{-1} over the grazing season (Table 2). When expressed as a percentage of body weight (BW), DMI was not influenced ($P=0.85$) by treatment, with intakes of 1.9% in steers on Split pastures and 2.0% BW in steers on Single and Control pastures. Dry matter intakes (%BW) reported in this

study are typical for animals grazing grass pastures in western Canada (McCaughy et al. 1999; Chavez et al. 2006; Ominski et al. 2006). Steers grazing naturalized grass pastures typical of western Canada consumed less than 2% BW, DM basis (Ominski et al. 2006). Using n-alkanes to estimate DMI, Chavez et al. (2006) reported mean DMI of 1.7% BW for 380 kg heifers grazing grass pastures in three locations of western Canada.

Increased forage CP content resulted in higher ($P=0.005$) CP intake by steers on manured pastures (Table 2). Gross energy intake ($P=0.58$) and NDF intake ($P=0.79$), however, were not influenced by pasture manure treatment.

Average Daily Gain

Although steer ADG in the first and second periods were similar among treatments, steers on Split pastures showed a marked reduction in ADG in the third period relative to steers on the Control and Single pastures ($P=0.037$). In the third period, steers on Split pastures had an ADG of $0.2 \pm 0.59 \text{ kg d}^{-1}$, while those on Control and Single pastures gained 1.1 ± 0.59 and $1.2 \pm 0.59 \text{ kg d}^{-1}$, respectively. The low gains for steers on the Split treatment was related to poor weight gains in year 2 of the study, with gain in year 1 being similar to those observed for other treatments. The reduction in ADG of steers on Split pastures in period 3 is difficult to explain as changes in parameters such as DMI, crude protein intake (CPI), and serum urea nitrogen (SUN) were not apparent.

Enteric Methane Production

Enteric CH_4 emissions ranged from 152 to 172 L d^{-1} and were not influenced by pasture manure treatment although there was a tendency ($P=0.09$) for enteric CH_4 emissions to be lower for steers on Split pastures (Table 2). Among dietary factors that influence ruminant enteric CH_4 emissions, DMI has a significant influence on enteric CH_4 emissions (Boadi and Wittenberg 2002; Ellis et al. 2007). In a study by Boadi and Wittenberg (2002), DMI accounted for 64% of the variation in enteric CH_4 production. A recent study utilizing beef and dairy data obtained from multiple studies showed that DMI predicted enteric CH_4 production with an R^2 of 0.69 (Ellis et al. 2007). However, other factors such as NDF, ADF, lignin, and amount of forage in the diet were also useful dietary factors for predicting ruminant enteric CH_4 production (Ellis et al. 2007). In the current study, fertilization of grass pastures did not influence forage NDF content ($P=0.79$; Table 1) or DMI ($P=0.56$) of steers (Table 2), which might suggest that fertilization of grass pastures with liquid hog manure did not influence forage quality enough to alter DMI and influence ruminant enteric CH_4 production.

Differences in animal BW, DMI, pasture forage quality and quantity among western Canadian studies make comparisons of CH_4 emissions difficult. Enteric

Table 2. Dry matter intake, weight gain and methane production of steers grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study

| | N | Treatment (T) | | | SE | Period (P) | | | SE | P value | | |
|--|-----|------------------|------------------|------------------|-------|------------------|------------------|------------------|-------|---------|-------|-------|
| | | Control | Split | Single | | 1 | 2 | 3 | | T | P | T × P |
| Dry matter intake (kg d ⁻¹) | 420 | 6.6 | 6.1 | 6.7 | 0.64 | 6.2 | 6.1 | 7.2 | 0.94 | 0.56 | 0.68 | 0.46 |
| Dry matter intake (% BW) | 420 | 2.0 | 1.9 | 2.0 | 0.21 | 2.1 | 1.9 | 2.0 | 0.32 | 0.85 | 0.90 | 0.50 |
| CP intake (kg d ⁻¹) | 420 | 0.6 ^b | 1.0 ^a | 1.2 ^a | 0.14 | 1.0 | 0.8 | 1.1 | 0.22 | 0.005 | 0.39 | 0.47 |
| GE intake (MJ d ⁻¹) | 420 | 124.5 | 116.8 | 128.3 | 10.99 | 119.6 | 113.5 | 136.5 | 25.88 | 0.58 | 0.70 | 0.40 |
| NDF intake (kg d ⁻¹) | 420 | 3.9 | 3.7 | 3.9 | 0.39 | 3.6 | 3.7 | 4.1 | 0.85 | 0.79 | 0.84 | 0.65 |
| Average daily gain (kg d ⁻¹) | 469 | 1.2 | 0.8 | 1.1 | 0.31 | 1.1 | 1.2 | 0.8 | 0.50 | 0.16 | 0.87 | 0.037 |
| Methane (L d ⁻¹) | 340 | 172 | 152 | 163 | 18.5 | 160 | 167 | 160 | 18.5 | 0.09 | 0.54 | 0.06 |
| Methane (L kg BW ⁻¹ d ⁻¹) | 284 | 0.5 | 0.5 | 0.5 | 0.06 | 0.5 ^a | 0.5 ^a | 0.4 ^b | 0.06 | 0.33 | 0.001 | 0.024 |
| Methane (% GEI) | 284 | 6.4 | 6.1 | 6.0 | 0.78 | 6.4 | 6.3 | 5.7 | 0.90 | 0.89 | 0.83 | 0.68 |

a, b Means within factors in a row followed by a different letter differ ($P < 0.05$).

CH₄ emissions in the current study are similar to those reported by Ominski et al. (2006), where yearling steers consuming unimproved grass pastures in Manitoba produced 156 to 237 L CH₄ d⁻¹. Boadi and Wittenberg (2002) reported enteric CH₄ emission values of 238 L d⁻¹ for beef heifers fed forages.

Pasture treatment influenced enteric CH₄ emissions, expressed relative to BW, in the early part of the grazing season ($P = 0.024$). Enteric CH₄ emissions were lower in steers on Split (0.47 ± 0.06 L kg BW⁻¹ d⁻¹) pastures relative to steers on Control (0.59 ± 0.06 L kg BW⁻¹ d⁻¹) and Single (0.53 ± 0.06 L kg BW⁻¹ d⁻¹) pastures in the first grazing period (Fig. 2). In the last two periods, enteric CH₄ emissions averaged 0.47 ± 0.06 L kg BW⁻¹ d⁻¹ for all treatments. Enteric CH₄ emissions expressed relative to BW for cattle grazing grass pastures in western Canada range from 0.4 to 0.8 L kg BW⁻¹ d⁻¹ and are dependent on forage quality and quantity as well DMI (McCaughey et al. 1999; Ominski et al. 2006). On grass pastures, Ominski et al. (2006) reported CH₄ emissions

ranging from 0.5 to 0.7 L kg BW⁻¹ d⁻¹. In heifers grazing either alfalfa/grass or grass only pastures, CH₄ emissions were lower (0.74 L kg BW⁻¹ d⁻¹) on alfalfa/grass pastures than on grass pastures (0.81 L kg BW⁻¹ d⁻¹; McCaughey et al. 1999). Values reported in the current study fall within the range for western Canada and were not influenced by differences in forage quality.

When expressed as a percentage of energy lost, enteric CH₄ emissions ranged from 6.0 to 6.4% GEI and were not influenced by manure treatment ($P = 0.89$) or by grazing period ($P = 0.83$; Table 2). These values are similar to those reported by Chavez et al. (2006) for steers grazing alfalfa or grass pastures, but higher than values reported by McCaughey et al. (1997) for steers. Comparing steers (380 kg) kept on either alfalfa or grass pastures, Chavez et al. (2006) reported enteric CH₄ emissions with an energetic cost of 5.8 and 6.2% GEI for grass and alfalfa pastures, respectively. Steers grazing native pastures in Manitoba had an energetic loss of 6.9 to 11.3% GEI as CH₄ (Ominski et al. 2006). Ominski et al. (2006) suggested that energetic losses as a result of CH₄ production are a function of pasture forage availability and quality, where low levels of either resulted in higher enteric CH₄ losses per unit of feed consumed. Lower enteric CH₄ losses in the present study relative to those reported by Ominski et al. (2006) were likely a result of higher standing forage biomass, providing cattle with better opportunity to select higher quality forage. Results of the current study suggest that, for grass pastures containing CP ranging from 95 to 178 g kg⁻¹, methane conversion rates (Y_m) will average 6.2% GEI. This value is comparable with that recommended by the International Panel on Climate Change Tier 2 for steers and lower than that reported in other Canadian studies (Ominski et al. 2007).

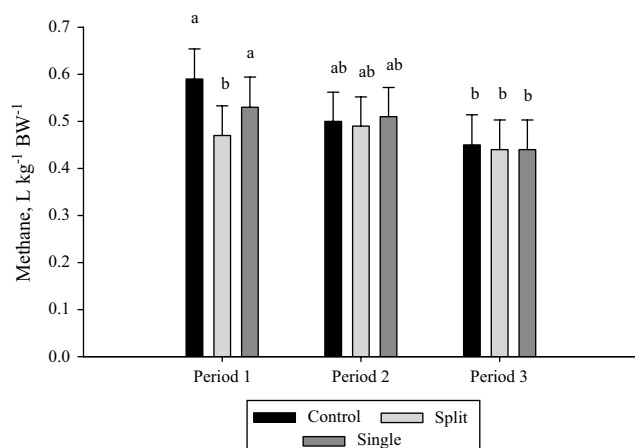


Fig. 2. Enteric CH₄ emissions of steers grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study ($N = 284$; $SE = 0.06$).

Blood Profile

Ninety-seven of the 469 blood samples (21%) collected from steers over the three grazing seasons were below normal SUN values for steers, which range from 2.8 to 8.8 mmol L⁻¹ (Boyd 1984). Of these, all but two

samples were from steers grazing Control pastures. Seventy-two percent of the low observations occurred in the first period, with the remainder observed in the second period (Fig. 3). It is apparent that serum urea N concentrations were lowest ($P=0.001$) in steers grazing Control pastures (Table 3), reflecting lower forage CP content as well as steer CPI for Control pastures. Serum urea N concentrations were correlated ($r=0.68$; $P=0.001$) with forage CP content. Although SUN was also correlated with CPI, this relationship was weaker ($r=0.41$; $P=0.001$) and may be attributed to similarities in DMI among treatments.

Manure treatment did not influence serum concentrations of Ca ($P=0.11$), P ($P=0.51$), K ($P=0.40$), Na ($P=0.08$), glucose ($P=0.31$), and creatinine ($P=0.40$) of steers grazing grass forages (Table 3). Serum creatinine concentrations were higher ($P=0.001$) in the second and third grazing periods relative to the first period. Serum Mg concentrations were influenced by both manure treatment and grazing period ($P=0.001$). Serum Mg concentrations were higher in steers on Split pastures in the first period (0.89 ± 0.03 mmol L⁻¹) relative to the third grazing period (0.85 ± 0.03 mmol L⁻¹). In Full pastures, serum Mg concentrations were higher in the first period (0.88 ± 0.03 mmol L⁻¹) relative to the second grazing period (0.80 ± 0.03 mmol L⁻¹). Serum Mg concentrations of steers on Control pastures did not change over the course of the grazing season, averaging 0.87 ± 0.03 mmol L⁻¹. Serum chloride concentrations were higher ($P=0.020$) in steers on Split pastures relative to those on Control pastures, and intermediate on Single pastures (Table 3). Ninety-six percent of the steers had normal chloride concentrations (96 to 104 mmol L⁻¹; MAFRI, Veterinary Services Branch, Winnipeg, MB). None of the steers demon-

strated signs of chlorine deficiency, which is characterised by anorexia, weight loss, lethargy, dehydration, mild polydipsia, and mild polyuria (Neathery et al. 1981). Despite observed differences in serum concentrations of creatinine and Mg associated with liquid hog manure application to grass forages, values were within normal ranges (MAFRI, Veterinary Services Branch, Winnipeg).

Blood enzymes were monitored to provide an assessment of the health status of grazing steers. Manure treatment did not influence ($P=0.44$) serum creatine kinase concentrations of grazing steers (Table 4) throughout the study. Serum alkaline phosphatase concentration was above the expected normal range (41 to 116 U L⁻¹; MAFRI, Veterinary Services Branch, Winnipeg, MB) and was higher ($P=0.001$) in steers grazing Control pastures relative to those on manured pastures. The implications of such high levels of alkaline phosphatase in steers on Control pastures are not immediately clear; however, alkaline phosphatase is generally used as an indicator of bone disease and liver failure (Padilla et al. 2000). Serum alkaline phosphatase concentration was negatively correlated with serum urea N ($r=-0.52$; $P=0.001$). Concentration of serum gamma-glutamyl transferase, an indicator of liver damage (Quintavalla et al. 2001), was higher ($P=0.006$) in steers on Split pastures, with no difference between steers on Control and Single pastures. Aspartate amino transferase is primarily used to diagnose and monitor the course of liver disease (Padilla et al. 2000). Serum aspartate amino transferase concentration was highest ($P=0.028$) in steers on Split pastures, lowest on Control pastures, with intermediate values in steers on Single pastures (Table 4). Mean serum enzyme concentrations, with the exception of alkaline phosphatase, suggest that the health of steers was not compromised and perhaps improved by consuming forages treated with liquid hog manure.

Pasture Productivity

Pasture Carrying Capacity

Liquid hog manure application increased ($P=0.001$) carrying capacity, as measured by grazing days ha⁻¹, from 89 grazing days ha⁻¹ in Control pastures to 340 and 308 grazing days ha⁻¹ in Split and Single pastures, respectively (Table 5). Timing of manure application was also important as the split application of liquid hog manure resulted in 32 more ($P=0.001$) grazing days per ha than the Single application. This increase in productivity of Split pastures over Single pastures may have been due to logistics of manure application. In 2004, the spring manure application was delayed for several weeks due to a late snowstorm. The Split application had received its initial half-rate application of liquid hog manure in the autumn of 2003 and responded to the available nutrients with a strong flush of plant growth the following spring. By the time steers were introduced

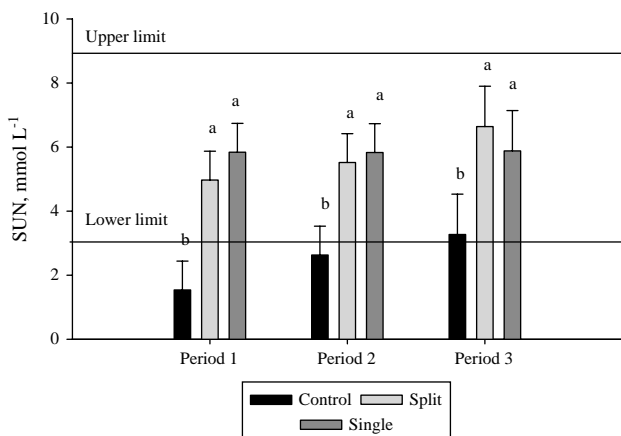


Fig. 3. Serum urea nitrogen (SUN)² concentrations of steers grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study ($N=469$; $SE=1.0$). ²Normal SUN values for steers range from 2.8 to 8.8 mmol L⁻¹ (Boyd 1984).

Table 3. Serum urea nitrogen ($N=469$) and mineral profiles ($N=294$) of steers grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over 2 yr of the study

| | Treatment (T) | | | | Period (P) | | | | P value | | |
|--|------------------|------------------|-------------------|------|-----------------|------------------|------------------|------|---------|-------|-------|
| | Control | Split | Single | SE | 1 | 2 | 3 | SE | T | P | T × P |
| Serum urea nitrogen ² (mmol L ⁻¹) | 2.5 ^b | 5.7 ^a | 5.9 ^a | 0.42 | 4.1 | 4.7 | 5.3 | 0.40 | 0.001 | 0.06 | 0.07 |
| Glucose (mmol L ⁻¹) | 3.3 | 3.0 | 3.2 | 0.21 | 3.6 | 2.4 | 3.5 | 1.29 | 0.31 | 0.59 | 0.26 |
| Creatinine (μmol L ⁻¹) | 103 | 106 | 101 | 3.9 | 91 ^b | 112 ^a | 107 ^a | 3.3 | 0.40 | 0.001 | 0.30 |
| Calcium (mmol L ⁻¹) | 2.4 | 2.3 | 2.3 | 0.04 | 2.4 | 2.3 | 2.4 | 0.03 | 0.11 | 0.35 | 0.50 |
| Phosphorus (mmol L ⁻¹) | 2.4 | 2.5 | 2.6 | 0.14 | 2.6 | 2.4 | 2.4 | 0.21 | 0.51 | 0.56 | 0.94 |
| Magnesium (mmol L ⁻¹) | 0.9 | 0.9 | 0.8 | 0.02 | 0.9 | 0.8 | 0.9 | 0.03 | 0.51 | 0.45 | 0.001 |
| Potassium (mmol L ⁻¹) | 5.2 | 5.3 | 5.4 | 0.12 | 5.4 | 5.5 | 4.9 | 0.22 | 0.40 | 0.37 | 0.73 |
| Sodium (mmol L ⁻¹) | 140 | 141 | 140 | 0.44 | 140 | 140 | 141 | 1.32 | 0.08 | 0.69 | 0.06 |
| Chloride ion (mmol L ⁻¹) | 98 ^b | 101 ^a | 100 ^{ab} | 0.77 | 99 | 99 | 101 | 0.55 | 0.020 | 0.12 | 0.052 |

²Data collected for 3 yr.

a, b Means within factors in a row followed by a different letter differ ($P < 0.05$).

to pasture in the spring of 2004, forage DM yields in the Split pastures were approximately three times more than Control or Single pastures. In an attempt to reduce standing forage biomass to 1.5 to 2.0 t ha⁻¹, more “put and take” steers were allotted to Split pastures. As a result, Split pastures averaged an additional 110 grazing days per hectare over Single pastures in 2004. In 2005 and 2006, carrying capacities between manured pastures were similar. These results show that nutrient application is most beneficial if the nutrient is applied when plants are able to utilize it most effectively for growth. Increasing grazing days is beneficial as it allows for increased stocking density or reduces the need to provide supplemental forage to animals.

Pasture Liveweight Gain

Liveweight gain per hectare of steers grazing Control (100 ± 16.7 kg ha⁻¹) pastures was lower ($P = 0.001$) than that of steers on either Split (319 ± 16.7 kg ha⁻¹) or Single (339 ± 16.7 kg ha⁻¹) pastures (Table 5). Pastures receiving liquid hog manure provided grazing animals with higher quality forage as well as increased standing forage biomass (Table 1). These pastures also were able to support more grazing animals. Comparable results have been reported by Cohen et al. (2004) in which the addition of up to 200 kg N ha⁻¹ to crested wheatgrass (*Agropyron cristatum* L) pastures improved pasture DM

yield and increased productivity (measured as liveweight gain) by up to 100%, but did not influence individual animal ADG.

IMPLICATIONS

Naturalized pastures can be very responsive to liquid hog manure application, with carrying capacity and pasture liveweight gains increasing as much as threefold with N application rates at agronomic levels. Grazing animal productivity and health status, as defined by DMI, ADG, SUN, and serum enzymes, were maintained or improved with liquid hog manure application. However, the expected benefits relative to enteric CH₄ emissions were not as great as expected. While split manure application demonstrated some advantages over a single application, there may not be enough benefit to justify the added costs of a second manure application.

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Table 4. Serum enzyme concentrations of steers ($N=294$) grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over 2 yr of the study

| | Treatment (T) | | | | Period (P) | | | | P value | | |
|---|-------------------|-------------------|-------------------|------|------------|------|------|------|---------|------|-------|
| | Control | Split | Single | SE | 1 | 2 | 3 | SE | T | P | T × P |
| Creatine kinase (U L ⁻¹) | 198 | 214 | 256 | 46.1 | 224 | 248 | 197 | 71.3 | 0.44 | 0.83 | 0.88 |
| Alkaline phosphatase (U L ⁻¹) | 164 ^a | 112 ^b | 112 ^b | 8.3 | 150 | 116 | 121 | 15.9 | 0.001 | 0.36 | 0.70 |
| Gamma-glutamyl transferase (U L ⁻¹) | 31.9 ^b | 36.2 ^a | 32.1 ^b | 1.47 | 34.0 | 33.8 | 32.4 | 1.48 | 0.006 | 0.69 | 0.19 |
| Aspartate aminotransferase (U L ⁻¹) | 121 ^b | 136 ^a | 126 ^{ab} | 4.6 | 123 | 131 | 129 | 5.6 | 0.028 | 0.59 | 0.11 |

a, b Means within factors in a row followed by a different letter differ ($P < 0.05$).

Table 5. Pasture carrying capacity and liveweight gain of steers grazing grass pastures receiving no manure (Control) or liquid hog manure in one (Single) or two (Split) applications over the 3-yr study ($N=18$)

| | Treatment | | | | <i>P</i> value |
|---|------------------|------------------|------------------|------|----------------|
| | Control | Split | Single | SE | |
| Grazing days ha ⁻¹ ^z | 89 ^c | 340 ^a | 308 ^b | 8.2 | 0.001 |
| Liveweight gain (kg ha ⁻¹) ^z | 100 ^b | 319 ^a | 339 ^a | 16.7 | 0.001 |

^zIncludes test and "put and take" steers.

a-c Means within a row followed by a different letter differ ($P < 0.05$).

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