2004

Effect of Organic Matter Addition to the Pen Surface and Pen Cleaning Frequency on Nitrogen Mass Balance in Open Feedlots

J. R. Adams
University of Nebraska-Lincoln

T. B. Farran
University of Nebraska-Lincoln

Galen Erickson
University of Nebraska-Lincoln, gerickson4@unl.edu

Terry Klopfenstein
University of Nebraska-Lincoln, tklopfenstein1@unl.edu

C. N. Macken
University of Nebraska-Lincoln

See next page for additional authors

Effect of organic matter addition to the pen surface and pen cleaning frequency on nitrogen mass balance in open feedlots[1]

J. R. Adams, T. B. Farran, G. E. Erickson[2], T. J. Klopfenstein, C. N. Macken, and C. B. Wilson

Department of Animal Science, University of Nebraska, Lincoln 68583-0908

ABSTRACT: Three finishing trials were conducted to determine the effects of dietary manipulation and management on N losses from open feedlots. In each experiment, 96 steers were assigned randomly to 12 nutrient balance pens. In Trial 1, calves were fed for 180 d during the winter/spring months; in Trial 2, yearlings were fed for 132 d in the summer. In Trials 1 and 2, N losses from pens were compared directly by adding OM to the pen surface or indirectly by feeding digestible ingredients designed to increase OM excretion. The dietary treatment (BRAN) included 30% corn bran (DM basis) replacing dry-rolled corn. Pens where OM was directly added received sawdust applications (SAWDUST) at a rate to match OM excretion from the BRAN diet. These two treatments were compared with a conventional, 75% dry-rolled corn diet (CON). Because CON and SAWDUST diets were identical, performance for both treatments was similar during Trials 1 and 2. The BRAN diet decreased ($P < 0.10$) gain efficiency during Trials 1 and 2 by 9.5% relative to CON. Fecal N excretion was greater ($P < 0.01$) for calves and yearlings when BRAN was fed compared with CON. Adding OM to the pen surface increased ($P < 0.01$) the amount of N in manure removed from pens and reduced ($P < 0.10$) N losses in Trial 1. Nitrogen losses were not significantly different among treatments in Trial 2. In Trial 3, calves were fed for 166 d during the winter/spring months. A 2 × 2 factorial design was used to evaluate pen cleaning frequency and diets similar to CON and BRAN. Pens were either cleaned monthly or once at the end of the feeding period. Daily DMI was greater ($P = 0.01$) and ADG was lower ($P < 0.01$) when cattle were fed BRAN compared with CON. Responses from all three trials indicate a negative effect of BRAN on gain efficiency. Dietary treatment and cleaning frequency interacted for N balance in the feedlot. Nitrogen losses decreased and manure N increased ($P < 0.10$) for cattle fed BRAN compared with CON when pens were cleaned monthly. Feeding BRAN did not affect total manure N, but resulted in higher N losses when pens were cleaned only once. For all trials, BRAN increased the amount of N remaining in composted manure. Adding OM to pen surfaces and/or cleaning pens more frequently may decrease N losses from open feedlot pens and from compost, although responses seem influenced by ambient temperature or season.

Key Words: Beef Cattle, Cattle Manure, Feedlots, Nitrogen Balance, Organic Matter

 J. Anim. Sci. 2004. 82:2153–2163

Introduction

As environmental regulations become more stringent, feedlot producers will need cost-effective alternatives to comply with air and water quality regulations. One of the most logical alternatives is to decrease N intake. Protein intake above the requirement increases the amount of N excreted and lost (Bierman et al., 1999; James et al., 1999; Erickson and Klopfenstein 2001a) and can subsequently affect air and water quality.

An alternative to decreasing N losses is the manipulation of manure C:N ratio. The C:N ratio can be manipulated by direct C application to manure or through dietary manipulations. Lory et al. (2002) evaluated the effect of sawdust applications to the pen surface on N losses and concluded that C additions were effective at reducing N losses during the summer months. Erickson and Klopfenstein (2001b) observed that feeding corn bran to reduce dietary digestibility decreased N losses during the winter/spring months. A comparison of these alternatives to decrease N losses has not been conducted.

Losses of N with these methods have not been consistent throughout the year. Erickson and Klopfenstein

[1]A contribution of the Univ. of Nebraska Agric. Res. Div., Lincoln. Journal Series No. 14163. This research was supported in part by funds provided through the Hatch Act.

[2]Correspondence: C220 Animal Science (phone: 402 472-6402; fax: 402 472-6362; e-mail: geericks@unlnotes.unl.edu).

Received September 17, 2003.
Accepted March 24, 2004.

(2001b) reduced N losses by decreasing diet digestibility in the winter/spring months; however, this method was ineffective during the summer months. A separate alternative to reduce N losses may be waste management strategies such as pen cleaning frequency. This may provide less exposure of manure N to surrounding air and subsequent losses.

Our hypothesis is that increasing the C:N ratio of manure by adding OM will decrease N losses and that pen cleaning frequency may reduce N losses even further. The objectives of this research were to 1) compare the effects of OM addition by feeding less digestible diets or adding sawdust on N losses, 2) determine the interaction between OM on the pen surface and pen cleaning frequency on N losses, and 3) determine whether increasing pen cleaning frequency of open feedlot pens would decrease N losses from pen surfaces.

Materials and Methods

Feedlot Performance

Trial 1. Ninety-six steer calves (325 ± 13 kg BW) were fed for 180 d from November to May (winter/spring months) to evaluate the effects of applying additional OM to the pen surface on N losses in open feedlots. Steers were weighed initially on two consecutive days after being limit fed (2% BW) for 5 d to minimize gastrointestinal fill differences. Steers were stratified by weight and assigned randomly to pens (eight steers/pen; four pens/treatment) in a completely randomized design.

The control (**CON**) was designed to represent a "typical" feedlot diet and environmental management. A dietary treatment (**BRAN**) was designed to increase OM excretion onto the pen surface by decreasing diet DM digestibility (Table 1). In this diet, dry-rolled corn (**DRC**) was replaced with 30% corn bran (DM basis). Dry-matter digestibility values for calves fed the CON diet were measured previously (Erickson and Klopfenstein 2001b). The authors observed that DM digestibility of a diet containing 30% corn bran (DM basis) was 71.7%, whereas a diet containing 0% corn bran (similar to CON) had a DM digestibility of 75.8%. However, Bierman et al. (1999) reported a digestibility value that was 9.1 units lower for a diet containing 41.5% wet corn gluten feed (**WCGF**) than for a diet containing DRC and 7.5% roughage (5% alfalfa hay and 5% corn silage). This WCGF diet contained approximately 30% corn bran, a component of WCGF. The DM digestibility values determined by Bierman et al. (1999) were arrived at using total fecal collection, whereas Erickson and Klopfenstein (2001b) used an external marker technique (Cr_2O_3; Merchen, 1988). Therefore, diets were evaluated using digestibilities of 75.8% for CON and both 71.7 and 66.7% for BRAN. The digestibility of 66.7% was derived by taking 75.8 (Erickson and Klopfenstein, 2001b) minus 9.1, the difference observed by Bierman et al. (1999). Data are presented with both methods.

A third treatment evaluated OM addition directly to the pen surface instead of through the diet (SAWDUST). Cattle assigned to the SAWDUST treatment were fed the CON diet and sawdust was applied weekly to the pen surface (6.4 kg of DM/steer weekly). Sawdust was added to the pen surface just behind the feed bunk on the cement aprons because cattle spend much of their time and excrete the most feces/urine in this area. The SAWDUST application was adjusted to match the OM excretion by cattle fed BRAN above CON using a DM digestibility of 66.7% for the BRAN diet (Bierman, et al., 1999). The sawdust was a by-product from pallet manufacturing using cottonwood trees (Trade Well Pallet Co., Gretna, NE).

On d 1, steer calves were implanted initially with Synovex-S (Fort Dodge Animal Health, Overland Park, KS) followed by Revalor-S (Intervet, Inc., Somerville, NJ) on d 90. Steers were adapted to finishing diets by replacing alfalfa hay with DRC. Alfalfa hay concentration during the adaptation period was 37.5, 27.5, 17.5, and 7.5% for 4, 3, 7, and 7 d, respectively. Finishing diets were formulated to meet metabolizable protein requirements, thereby reducing the amount of N excreted and subsequently lost through volatilization (NRC, 1996; Table 1). Calves received two protein supplements (Phase I and II). During Phase I, feather meal and blood meal were fed to meet undegradable intake protein (**UIP**) requirements. When animals weighed 488 kg, the Phase II supplement was initiated. During Phase II, finely ground corn replaced feather meal and blood meal to decrease UIP content of the diet. Dietary degradable intake protein (**DIP**) concentrations were 7.8 and 9.2% (dietary DM) for CON and BRAN, respectively. Calves fed BRAN were fed more DIP due to greater microbial efficiency when corn bran replaced DRC (NRC, 1996).

When cattle were visually appraised as being finished (e.g., 1.2 cm fat depth) they were marketed at a commercial abattoir (IBP, West Point, NE). At harvest, hot carcass weights were recorded. Final weights were calculated using a common dressing percent (63%). Following a 24-h chill, 12th-rib fat thickness and LM area were collected along with yield grade and marbling score as determined by a USDA grader.

Trial 2. Ninety-six yearling steers (376 ± 14 kg BW) were fed for 132 d from May to September to evaluate treatments identical to those used in Trial 1, but during summer months. Steers were implanted on d 1 with Synovex-C (Fort Dodge Animal Health, Overland Park, KS) and reimplanted on d 35 with Revalor-S.

Diets were similar to those in Trial 1, with supplemental protein changed to meet the requirements of yearling steers (Table 1). Steers received only one protein supplement. Steers fed CON received 6.6% DIP (dietary DM), whereas BRAN steers received 8.9% DIP. Diets were formulated to meet metabolizable protein requirements (NRC, 1996) similar to Trial 1. Adaptation to finishing diets, diet digestibility calculations,

Table 1. Composition of finishing diets (%, DM basis) for three trials evaluating performance and nitrogen mass balance in feedlots[a]

	Trial 1			Trial 2			Trial 3	
Ingredient	CON	BRAN	SAWDUST	CON	BRAN	SAWDUST	CON	BRAN
Dry-rolled corn	74	44	74	74	44	74	30	—
High-moisture corn							45	45
Corn silage	15	15	15	15	15	15	15	15
Corn bran	—	30	—	—	30	—	—	30
Molasses	5	5	5	5	5	5	5	5
Supplement[b]	6	6	6	6	6	6	5	5
Urea	1.05	0.77	1.05	0.70	1.13	0.70	0.83	0.61
Feather meal	1.13	1.00	1.13	2.70	—	2.70	0.33	0.29
Blood meal	0.14	0.12	0.14	—	—	—	0.04	0.03
Nutrient composition[c]								
CP	12.9	13.1	12.9	13.8	13.8	13.8	12.7	12.8
DIP	7.8	9.2	7.8	6.6	8.9	6.6	7.9	8.9
P	0.26	0.20	0.26	0.27	0.27	0.27	0.32	0.26
K	0.65	0.65	0.65	0.65	0.65	0.65	0.60	0.60
Ca	0.70	0.70	0.70	0.70	0.70	0.70	0.65	0.65

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet; SAWDUST = sawdust application to pen surface.

[b]Weighted average of two phases of finishing supplements for Trial 1 and Trial 3. Supplement provided 33 mg of monensin and 11 mg of tylosin/kg of diet DM, a vitamin premix containing 30,000 IU of vitamin A, 4,000 IU of vitamin D, and 7.5 IU of vitamin E/g, and a mineral premix containing 12% Zn, 10.0% Fe, 8% Mn, 1.5% Cu, 0.2% I, and 0.10% Co.

[c]CP and P were analyzed, other nutrients were calculated. DIP = degraded intake protein.

and carcass data collection were similar to those in Trial 1.

Trial 3. Ninety-six steer calves (336 ± 13.5 kg BW) were fed diets similar to CON and BRAN for 166 d from November to May. In addition to diets, two pen-cleaning frequency treatments were imposed to evaluate N losses when pens were cleaned monthly or at the end of the feeding period. Therefore, the treatment design was a 2 × 2 factorial with factors of diet and pen cleaning frequency. Pens were assigned randomly to one of the four treatments (eight steers/pen, three pens/treatment). Pens were cleaned five times and consisted of four pen cleanings (monthly) during the feeding period and one at the end after cattle removal. Pens that were cleaned once at the end were cleaned immediately after cattle removal upon termination of the study.

Dietary treatments fed to calves in Trial 3 were similar to those fed in Trials 1 and 2 in that corn bran replaced DRC to increase OM excretion (Table 1); however, the predominant grain fed to calves in Trial 3 was high-moisture corn. Corn bran replaced DRC (30% diet DM) in BRAN diets. High-moisture corn was added to improve performance of calves fed BRAN. Dry matter digestibility was calculated similar to Trials 1 and 2, with a base digestibility of 75.8% for CON and both 71.7 and 66.7% for BRAN; however, the addition of high-moisture corn increased total diet digestibility. Cooper et al. (2002) determined that total-tract digestibility of high-moisture corn was 3.8% greater than DRC. A review by Huntington (1997) agreed with this finding. Therefore, we calculated diet digestibility of the CON and BRAN diets based on the digestibility work by Erickson and Klopfenstein (2001b) and Bierman et al. (1999) with an adjustment to account for the increase in digestibility of diets due to high-moisture corn. This adjustment factor was a 1.7% (45% DM high-moisture corn multiplied by a 3.8% improvement in digestibility) increase in total diet digestibility applied to both the CON and BRAN diets. This resulted in a DM digestibility of 77.5% for CON, and both 73.4 and 68.4% for BRAN.

Steer calves were weighed initially on two consecutive days after being limit fed (2% BW) for 5 d to minimize gastrointestinal fill differences. Steers were stratified by weight and assigned randomly to pens within weight strata. Steers were adapted to final finishing diets over a 21-d adaptation period as previously outlined. On d 1, calves were initially implanted with Synovex-S and reimplanted with Revalor-S on d 69. The final diet was formulated to meet metabolizable protein requirements to minimize total N excreted (NRC, 1996). Calves received two protein supplements. Phase 1 was fed for the first 60 d and Phase II was fed for the final 106 d. Fine ground milo replaced blood meal and feather meal in Phase II supplements to decrease UIP content of the diet. Carcass data were collected in a manner similar to that of Trials 1 and 2. Procedures for all trials were reviewed and accepted by the University of Nebraska Institutional Animal Care and Use Committee.

Nutrient Balance

A nutrient balance, as defined by Erickson and Klopfenstein (2001b), was conducted for all three trials in 12 open feedlot pens previously used and diagrammed

by Bierman et al. (1999). Pen sizes and stocking densities were similar to those of previous experiments and typical industry averages of 29.6 m^2 and 61 cm of linear bunk space/steer (Erickson and Klopfenstein, 2001b). Throughout each feeding period, feed refusals were collected when present. On completion of each feeding period or during monthly pen cleaning (Trial 3), cattle were removed from pens and manure was scraped and piled on the pen surface. As the manure was removed from one central pile, manure samples were taken. Total manure was weighed on an as-is basis and transported to the University of Nebraska compost yard. The manure was composted for 3 to 4 mo.

Six earthen retention ponds collected runoff from the 12 pens. In the case of a runoff event, effluent was collected in retention ponds, drained through a PVC pipe, sampled, and quantified using an ISCO model 4230 air-bubble flow meter (ISCO, Lincoln, NE). To account for inherent differences in cleaning from pen to pen, soil in clean pens was sampled before each experiment and again following cleaning. Soil core samples were used to correct for variation in cleaning from pen to pen and manure/soil mixing by cattle activity during the experiments. Pen core samples account for either N addition or loss from pen soil. Core locations were evenly spaced throughout each pen on a grid pattern to account for sampling variation. Sixteen soil cores (15-cm-long, 2.5-cm-wide soil probe) were obtained from each pen and each core represented 15.3 m^2.

Composting was done in windrows during the summer months (May to October) for all three trials. One compost windrow was formed for all manure removed from pens allotted to the same experimental treatments. Compost was considered finished when windrows no longer produced heat 2 to 7 d after turning. After the composting process was complete, one random sample within each 3 m of windrow was taken on both sides of a compost windrow. Samples were mixed and sub-sampled to obtain one representative sample for each compost windrow. Samples were analyzed for DM, OM, N, P, and ash content. Using ash as an internal marker, compost N and OM recoveries were calculated by dividing the N and OM in manure after composting by the N or OM that was removed from the pen at cleaning.

Once collected, all samples were frozen at –4°C until analysis. To avoid N losses during the drying process, manure samples were freeze-dried using a Virtis Freezemobile model 25 SL (Virtis, Gardiner, NY). All other samples were oven-dried for 48 h at 60°C. All samples were ground through a Wiley Mill (1-mm screen) and ashed at 600°C for 6 h. Feed refusal and manure samples were composited by pen. Feed samples were collected weekly and composited by month. Soil cores were separated into initial and final samples and composited by pen. Runoff was composited by pond using a weighted average. Total N was analyzed by combustion method using a N analyzer (Leco FP428, LEco Corp., St. Joseph, MI) for all composites.

Nitrogen intake was calculated using analyzed N content of individual dietary ingredients multiplied by DMI and corrected for N content of feed refusals. Net protein and net energy equations established by the NRC (1996) were used to calculate steer N retention. Nitrogen excreted (urine plus feces) was determined by subtracting N retention from N intake. Manure N was determined by multiplying manure N concentration by kilograms of manure removed (DM) from the pen surface and corrected for soil core N before and after trials. Runoff N was calculated as N concentration in runoff multiplied by the total amount drained. Total N lost (kg/steer) was calculated by subtracting soil corrected manure N and runoff N from N excreted. All N values were reported on a kilogram per steer basis. Percentage of N lost was calculated as N lost divided by N excretion. The manure C:N ratio was calculated by taking the amount of manure OM multiplied by 0.49 (assuming OM contains 49% C), divided by the amount of N in the manure.

Performance, carcass, and nutrient data from Trials 1 and 2 were analyzed as a completely randomized design using the GLM procedures of SAS (SAS Inst., Inc., Cary, NC). Pen was considered the experimental unit. A protected F-test was used to evaluate treatment differences. The Bonferroni t-test was used for separation of least squares means. Data from Trial 3 were analyzed as a completely randomized design using the MIXED procedure of SAS. Pen was the experimental unit. Model effects were dietary treatment, pen cleaning frequency, and the interaction of the two. If dietary treatment × pen cleaning frequency interaction was detected ($P < 0.10$), simple effects were presented and separated using least significant difference method. If no interaction was detected between diet and cleaning frequency, then main effects of treatment and pen cleaning frequency were presented and separated using least significant difference method.

Results and Discussion

Trial 1

Performance of steers (ADG, DMI, and gain efficiency) assigned to CON and SAWDUST treatments was not different (Table 2). Steers consuming BRAN tended to have lower ADG than those fed CON or when SAWDUST was applied ($P = 0.11$); however, DMI was similar among all treatments, causing a reduction in G:F ($P < 0.01$) for steers fed BRAN. Subtle differences were observed across treatments consistent with the performance data (Table 2).

All nitrogen balance results are reported on a per-steer basis (Table 2). Nitrogen intake was similar among treatments. Nitrogen retention was based on total weight gained and final weight; therefore, due to lower ADG and final weights, BRAN calves retained less N than CON and SAWDUST (24 and 26 $g \cdot steer^{-1} \cdot d^{-1}$ for BRAN and CON or SAWDUST, respectively;

Table 2. Performance, carcass characteristics, and N mass balance of calves fed 180 d during the winter/spring[a]

Item	CON	BRAN	SAWDUST	SEM	*F*-test[b]
Performance					
Initial BW, kg	324	325	326	1	0.62
Final BW, kg	613[i]	591[j]	610[i]	8	0.14
DMI, kg/d	10.3	10.5	10.4	0.2	0.61
ADG, kg	1.60[i]	1.47[j]	1.58[i]	0.04	0.11
G:F	0.156[k]	0.140[l]	0.152[k]	0.003	0.01
Carcass characteristics					
Hot carcass weight, kg	386	372	385	5	0.14
Marbling score[c]	5.28[i,j]	4.95[i]	5.44[j]	0.15	0.11
12th-rib fat thickness, cm	1.21[i]	0.97[j]	1.17[i]	0.08	0.10
LM area, cm^2	93.6	93.8	93.9	2.1	0.99
Nitrogen balance					
N intake, kg/steer	37.9	39.7	38.4	0.6	0.15
N retention, kg/steer[d]	4.7[i]	4.3[j]	4.7[i]	0.1	0.09
N excretion, kg/steer[e]	33.2[i]	35.4[j]	33.7[i]	0.5	0.03
Manure N, kg/steer[f]	16.3[k]	24.8[l]	24.4[l]	1.6	0.01
Runoff N, kg/steer	0.4	0.3	0.3	0.1	0.10
N lost, kg/steer[g]	16.5[i]	10.3[j]	9.0[j]	1.7	0.03
N loss, % of excreted[h]	49.4[k]	29.1[l]	26.8[l]	4.7	0.01

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet; SAWDUST = sawdust application to pen surface.
[b]Analyzed using a protected *F*-test where numbers represent *P*-value for variation due to treatment; four pens per treatment.
[c]Marbling score: 4.50 = Slight[50]; 5.00 = Small[00]; 5.50 = Small[50].
[d]Calculated using NRC (1996) net protein and net energy equations.
[e]Calculated as N intake minus N retention.
[f]Corrected for soil N concentration before and after trial.
[g]Calculated as N excretion minus manure N (corrected for soil) minus runoff N.
[h]Calculated as N lost/N excretion.
[i,j]Means within a row with different superscripts differ ($P < 0.10$).
[k,l]Means within a row with different superscripts differ ($P < 0.01$).

$P < 0.10$). The slight numeric increase in N intake and decreased N retention resulted in BRAN calves excreting more N than CON and SAWDUST ($P < 0.05$). Although OM intake was similar between diets (due to similar DMI and dietary OM content), feeding BRAN resulted in a reduction in diet digestibility and an increase in OM excretion compared with CON and SAWDUST groups ($P < 0.01$).

Manure (corrected for soil contamination) from the BRAN and SAWDUST treatments contained 20% more N than CON (Table 2; $P < 0.01$). Approximately 49% of N excreted by CON cattle was removed in manure. Approximately 70% of the N excreted was removed in manure at pen cleaning from BRAN and SAWDUST pens. All N unaccounted for is presumed to be lost through volatilization because other forms of excreted N are presumed to be accounted for (manure removal, and runoff). The BRAN and SAWDUST treatments resulted in 6.2 and 7.5 kg/steer less N lost to volatilization, respectively, when compared with CON ($P < 0.05$). Relative to CON, BRAN decreased the amount of N lost by 38%, whereas SAWDUST decreased kilograms of N lost by 45%.

Trial 2

Performance of steers assigned to CON and SAWDUST treatments was similar (Table 3). Yearlings fed BRAN had higher DMI and similar ADG, causing lower G:F ($P < 0.01$). Due to greater DMI, BRAN fed cattle consumed more OM than CON or SAWDUST ($P < 0.01$; data not shown). Carcass characteristics were not different among treatments ($P > 0.13$; Table 3).

Nitrogen balance results are reported in Table 3. Nitrogen intake was similar among treatments. Average N retention was approximately 27 g N·steer^{-1}·d^{-1} and was similar among treatments. Nitrogen excretion was similar among treatments because N intakes and retentions were comparable. Organic matter excretion was greatest for cattle fed BRAN due to increased OM intake and reduced diet digestibility ($P < 0.01$; data not shown). Excreted N that was recovered in manure averaged 38, 43, and 35% for CON, BRAN, and SAWDUST, respectively.

In contrast to Trial 1, BRAN and SAWDUST treatments imposed during the summer months did not significantly reduce N loss compared with CON. Numerically, feeding BRAN resulted in the least amount of N lost and lowest percentage loss of N excreted.

Trial 3

No interaction between dietary treatment and pen cleaning frequency was detected for G:F ($P > 0.60$); therefore, only main effects of dietary treatment are

Table 3. Performance, carcass characteristics, and N mass balance of yearlings fed 132 d during the summer[a]

Item	CON	BRAN	SAWDUST	SEM	*F*-test[b]
Performance					
Initial BW, kg	376	376	376	1	0.97
Final BW, kg	574	569	580	4	0.19
DMI, kg/d	10.7[i]	11.4[j]	10.7[i]	0.1	0.01
ADG, kg	1.49	1.46	1.55	0.03	0.24
G:F	0.139[k]	0.128[l]	0.144[k]	0.002	<0.01
Carcass characteristics					
Hot carcass weight, kg	360[k,l]	359[k]	366[l]	2	0.13
Marbling score[c]	5.05	4.70	4.83	0.14	0.27
12th-rib fat thickness, cm	1.13	1.17	1.09	0.07	0.70
LM area, cm^2	87.6	90.4	90.1	1.82	0.55
Nitrogen balance					
N intake, kg/steer	31.2	31.5	31.3	1.0	0.99
N retention, kg/steer[d]	3.6	3.6	3.7	0.1	0.36
N excretion, kg/steer[e]	27.6	27.9	27.5	1.0	0.96
Manure N, kg/steer[f]	10.4	12.0	9.7	1.3	0.45
Runoff N, kg/steer	0.92[k]	0.85[k]	0.75[l]	0.04	0.03
N lost, kg/steer[g]	16.3	15.1	17.2	1.8	0.71
N loss, % of excreted[h]	58.9	53.3	62.1	5.3	0.52

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet; SAWDUST = sawdust application to pen surface.
[b]Analyzed using a protected *F*-test where numbers represent *P*-value for variation due to treatment; four pens per treatment.
[c]Marbling score: 4.50 = Slight^{50}; 5.00 = Small^{00}; 5.50 = Small^{50}.
[d]Calculated using NRC (1996) net protein and net energy equations.
[e]Calculated as N intake minus N retention.
[f]Corrected for soil N concentration before and after trial.
[g]Calculated as N excretion minus manure N (corrected for soil) minus runoff N.
[h]Calculated as N lost/N excretion.
[i,j]Means within a row with different superscripts differ ($P < 0.01$).
[k,l]Means within a row with different superscripts differ ($P < 0.10$).

presented (Table 4). Feeding BRAN increased DMI and decreased ADG compared with CON. Steers fed BRAN were less efficient than those fed CON, which was consistent with results from Trials 1 and 2. Subtle differences were observed in carcass traits (Table 4).

Nitrogen intake was similar among treatments except that calves fed CON with pens cleaned at the end consumed less total N than the other treatments (Table 5). Nitrogen retention was greatest for calves fed CON with pens cleaned monthly. However, N retention was relatively small when expressed as a percentage of N intake, averaging 16.3 and 15.0% retained N for CON and BRAN, respectively. As a result of a lower N intake, excretion of N was lowest for calves fed CON ($P < 0.05$) with pens cleaned at the end. Total manure N was highest when calves were fed BRAN and pens were

Table 4. Mean performance, and carcass characteristics of calves fed one of two diets for 166 d in Trial 3[a]

Item	CON	BRAN	SEM	*P*-value[b]
Performance				
Initial BW, kg	335	337	1.0	0.27
Final BW, kg	627	616	2.3	<0.01
DMI, kg/d	10.4	10.8	0.08	0.01
ADG, kg	1.76	1.68	0.01	<0.01
G:F	0.169	0.156	0.001	<0.01
Carcass characteristics				
Hot carcass weight, kg	395	388	1.4	<0.01
Marbling score[c]	5.20	5.01	6.7	0.09
12th-rib fat thickness, cm	1.23	1.18	0.07	0.57
LM area, cm^2	92.4	92.7	1.1	0.84

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet.
[b]Six pens per treatment for main effect of diet.
[c]Marbling score: 4.50 = Slight^{50}; 5.00 = Small^{0}; 5.50 = Small^{50}.

Table 5. Mean N mass balance measurements for diet within pen cleaning frequency groupings of calves in Trial 3 (values are expressed as kg/steer over the 166-d winter/spring period)[a]

	Monthly cleaning		End cleaning			
Item	CON	BRAN	CON	BRAN	SEM	*F*-test[b]
N intake	36.4[h]	36.9[h]	34.7[i]	37.1[h]	0.4	0.04
N retention[c]	5.9[h]	5.6[i]	5.6[i]	5.5[i]	0.06	0.08
N excretion[d]	30.4[h]	31.3[h]	29.1[i]	31.6[h]	0.4	0.05
Manure N[e]	16.2[h]	22.9[i]	16.9[h]	16.1[h]	0.8	<0.01
Runoff N	0.52	0.46	0.61	0.40	0.04	0.14
N lost[f]	13.7[hi]	7.9[j]	11.6[i]	15.1[h]	0.8	<0.01
N loss, %[g]	45.1[hi]	25.2[j]	39.8[i]	47.9[h]	2.6	<0.01

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet, n = three pens/treatment within cleaning frequency.
[b]*P*-value for interaction between cleaning frequency and dietary treatment.
[c]Calculated using NRC (1996) net protein and net energy equations.
[d]Calculated as N intake minus N retention.
[e]Corrected for soil N concentration before and after trial.
[f]Calculated as N excretion minus manure N (corrected for soil) minus runoff N.
[g]Calculated as N lost/N excretion.
[h,i,j]Means within a row with different superscripts differ ($P < 0.10$).

cleaned monthly ($P < 0.05$), indicative of the greatest potential in "trapping" N.

An interaction was observed between diet and pen cleaning frequency on N losses from open feedlot pens in Trial 3 (Table 5). When the management factor of cleaning pens was imposed, feeding BRAN resulted in a marked reduction ($P < 0.01$) in N losses through volatilization. However, N losses were greater for cattle fed BRAN compared with CON ($P < 0.05$) when pens were cleaned once at the end. These results indicate that more frequent cleaning of pens housing cattle fed BRAN decreased N losses as opposed to allowing manure to collect on the pen surface during the entire feeding period. Nitrogen losses were reduced by 44% ($P < 0.05$) when pens were cleaned monthly and BRAN was fed compared with CON.

In all three trials, feed efficiency was depressed due to feeding BRAN compared with the CON diet (CON and SAWDUST treatments). These data are consistent with those of Erickson and Klopfenstein (2001b), who observed lower feed efficiencies when corn bran was substituted at 30% of diet DM vs. a typical, corn-based feedlot diet. Milton et al. (2000) reported reduced ADG and feed efficiency when corn bran with different moistures was fed to yearlings at 40% of diet DM, fed in combination with high-moisture corn, DRC, and steep liquor. The authors reported the energy value of corn bran to be 65% that of corn. Macken et al. (2002) also reported reduced feed efficiency in yearlings fed corn bran in place of corn. Corn bran was estimated to have 68% the net energy of DRC in Trial 1 and approximately 60% that in Trial 2, the difference likely due to feeding calves vs. yearlings. When included in diets with 45% high-moisture corn (Trial 3), corn bran had 73.2% the net energy of DRC. These estimates were based on cattle performance and dietary ingredient composition (NRC, 1996; Owens et al., 2002).

Data from Trial 1 agree with N retention data compiled by Erickson and Klopfenstein (2001a) and Bierman et al. (1999). Differences in N retention are minimal and calculated N retentions are often quite low. Steers fed BRAN retained 11, 12, and 15% of N intake for Trials 1, 2, and 3, respectively. Steers fed CON diets retained 12% of fed N in Trials 1 and 2 and 16% in Trial 3.

The N concentration of feces was similar within treatments for all trials; however, cattle fed BRAN excreted more fecal N ($P < 0.01$) than those fed the corn-based diets (data not shown). Approximately 32% of N was excreted in the feces from steers fed the CON diet, whereas up to 44% was excreted in the feces of cattle fed BRAN in all trials. Our results would agree with those of Bierman et al. (1999), who reported increased fecal OM and N excretion in cattle fed 41.5% WCGF compared with cattle fed 7.5% roughage. Feeding a highly digestible fiber source, such as corn bran, to feedlot steers causes a shift in N excretion from less urinary to more fecal N, presumably due to hindgut fermentation (Giger-Reverdin et al., 1991; Bierman et al., 1999).

Bierman et al. (1999) reported a linear relationship ($r^2 = 0.90$) between the amount of OM contained in the manure and the amount of N preserved in the manure at the time of pen cleaning. Erickson and Klopfenstein (2001a) also reported a linear relationship between N in manure and OM in manure. These authors determined that as OM increases, N removed in manure increases. When more N is removed in manure, less N is volatilized to the atmosphere (i.e., Trial 1). During Trial 1, there were greater amounts of OM in manure when comparing BRAN and SAWDUST to CON. Also, there was a greater amount of N recovered in the manure at pen cleaning, which would support the findings of Bierman et al. (1999). However, during Trial 2, SAW-

Table 6. Manure and compost nutrient composition for Trials 1 and 2[a]

Item	Trial 1 CON	Trial 1 BRAN	Trial 1 SAWDUST	Trial 1 SEM	Trial 1 *F*-test[b]	Trial 2 CON	Trial 2 BRAN	Trial 2 SAWDUST	Trial 2 SEM	Trial 2 *F*-test[b]
Manure[c]										
DM removed, kg/steer	1,522	1,906	1,920	165	0.21	472[f]	575[g]	500[f]	31	0.10
DM, %	72.4[d]	65.7[e]	65.5[e]	1.3	0.01	61.0[f]	56.2[g]	54.4[g]	2.0	0.05
N removed, kg/steer	14.6[d]	21.9[e]	21.1[e]	1.5	0.01	7.0[d]	9.1[e]	7.2[d]	0.5	0.02
OM, %	18.8[d]	26.2[e]	28.6[e]	1.1	<0.01	23.5[f]	25.5[f]	31.7[g]	3	0.09
OM removed, kg/steer	284[d]	498[e]	544[e]	35	<0.01	111[d]	146[e]	156[e]	8	0.01
C:N ratio	9.3[d]	11.3[e]	12.5[e]	0.3	<0.01	8.0[d]	8.1[d]	11.0[e]	0.5	<0.01
Compost										
N weight, kg/steer	8.2	11.3	9.7	—	—	3.4	5.5	3.2	—	—
N recovery, %	55.9	51.6	45.9	—	—	47.9	60.3	43.3	—	—
OM weight, kg/steer	122	180	182	—	—	58	88	60	—	—
OM recovery, %	43.0	36.2	33.4	—	—	52.3	60.3	38.5	—	—

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet; SAWDUST = sawdust application to pen surface.
[b]Data were analyzed using a protected *F*-test where numbers represent *P*-value for variation due to treatment; four pens per treatment.
[c]Based on actual manure removal unadjusted for soil cores before and after trial.
[d,e]Means within row with different superscripts differ ($P < 0.05$).
[f,g]Means within row with different superscripts differ ($P < 0.10$).

DUST had a greater amount of OM recovered in manure than CON, yet contained approximately as much manure N as CON. Feeding BRAN also resulted in more OM in manure than CON, which coincided with a numeric increase in manure N at pen cleaning. This may suggest that the OM contained in SAWDUST may not be as available for microbial N immobilization during periods of rapid volatilization, such as during the warm summer months. In addition, BRAN alters route of N excretion from less urinary to more fecal, thereby decreasing urinary N excretion as urea. Less urinary N excretion may contribute to less N volatilization (greater manure N) because urine is the predominant contributor to volatilization when feces and urine are compared (Kellems et al., 1979), and presumably less N remains in manure collecting on the pen when more N is excreted in urine compared with feces.

For all trials, runoff N accounted for less than 3.3% of N excreted; therefore, it seems that runoff is not a large contributor to N loss. These data agree with previous research indicating that less than 5 to 10% of N is lost in precipitation runoff (Gilbertson, et al., 1971; Bierman et al., 1999; Erickson and Klopfenstein, 2001a). This is plausible because all rainstorms do not produce runoff and generally only one-third of the rainfall ends up as runoff when rainfall exceeds 1 cm (Clark et al., 1975). Rainfall totals were 28.3, 30.0, and 20.4 cm for Trials 1, 2, and 3, respectively.

Manure C:N Ratio

Concentration of OM in manure was greater ($P < 0.01$) for BRAN and SAWDUST than for CON in Trial 1 (Table 6). Although the amount of manure DM removed from pens was not different, the greater OM concentration in manure by feeding BRAN and applying SAWDUST increased manure OM removal from pens by 175 and 192%, respectively, compared with CON. Feeding BRAN and hauling SAWDUST into pens caused an increase in the amount of OM removed, presumably because the additional OM did not degrade completely before it was removed in the form of manure. The greater OM removal increased manure C:N ratio and manure N removal compared with CON ($P < 0.01$). Manure DM percentage was reduced with additional OM (BRAN or SAWDUST) to pen surfaces ($P < 0.01$).

In Trial 2, pens housing BRAN-fed steers had the greatest amount of manure DM removed from the pen surface (Table 6). Organic matter content of manure from pens receiving SAWDUST was greater than that of CON and BRAN ($P < 0.10$). Similar to Trial 1, feeding BRAN and applying SAWDUST resulted in more OM (kg/steer) recovered in manure than CON ($P < 0.01$). However, manure OM removed during the summer (Trial 2) was substantially lower than that of the winter/spring feeding months (Trial 1). Manure N removal was higher for BRAN than for CON or SAWDUST ($P < 0.05$). The C:N ratio increased with the addition of SAWDUST ($P < 0.01$); however, BRAN did not increase the C:N ratio when compared with CON because of the greater N removal in manure.

In Trial 1, the lower N losses found in pens housing steers fed BRAN and applied with SAWDUST are likely a result of increasing the manure C:N ratio. Although SAWDUST increased the C:N ratio of manure in Trial 2, a decrease in N loss was not observed, presumably due to C in SAWDUST being less available. It is unclear why the C:N ratio was not increased by feeding BRAN during Trial 2, albeit N removed in manure was numerically greater than CON or SAWDUST. Perhaps OM in feces excreted by steers consuming BRAN was degraded on the pen surface before final C and N measures were conducted. Previous research (Dewes, 1996; Sørenson, 1998; Erickson and Klopfenstein, 2001b) demonstrates that increasing the C:N ratio decreases N losses. Our results suggest that feeding diets higher in OM digest-

Table 7. Manure and compost nutrient composition for Trial 3[a]

	Monthly cleaning		End cleaning			*P*-values[b]		
Item	CON	BRAN	CON	BRAN	SEM	Diet × clean	Diet	Clean
Manure[c]								
DM removed, kg/steer	1,142[d]	1,566[e]	984[d]	957[d]	86	0.03	0.05	<0.01
DM, %	64.8[d]	60.6[e]	64.9[d]	52.4[e]	1.8	0.06	<0.01	0.06
N removed, kg/steer	14.1[d]	18.9[e]	14.2[d]	14.4[d]	1.2	0.08	0.07	0.10
OM, %	26.6	29.6	27.8	35.4	3.0	0.47	0.11	0.28
OM removed, kg/steer	303	464	272	337	38	0.24	0.02	0.07
C:N ratio	10.5	12.0	9.4	11.4	0.3	0.40	<0.01	0.04
Compost								
N weight, kg/steer	7.1	9.0	5.8	9.1	—	—	—	—
N recovery, %	50.4	47.6	40.9	63.2	—	—	—	—
OM weight, kg/steer	125	149	100	151	—	—	—	—
OM recovery, %	41.1	32.4	36.6	44.7	—	—	—	—

[a]CON = conventional, 75% corn diet; BRAN = 30% corn bran diet; n = three pens/treatment within cleaning frequency.
[b]Diet × clean = interaction between pen cleaning frequency and dietary treatment; diet = main effect of dietary treatment; clean = main effect of pen cleaning frequency.
[c]Based on actual manure removal unadjusted for soil cores before and after trial.
[d,e]Means in a row with different superscripts are different ($P < 0.05$).

ibility (i.e., CON) may actually increase N losses from feedlot pen surfaces.

Effects of diet and pen cleaning frequency on DM, OM, and C:N ratios of manure removed during Trial 3 from the pen surface are presented in Table 7. Interactions existed between diets and pen cleaning frequency for the amount of DM and N removed from pens. Similar to results from Trials 1 and 2, adding additional OM to the pen surface reduced DM concentration of manure. Manure from steers fed BRAN tended ($P = 0.11$) to have a greater percentage of OM compared with those fed CON. Feeding BRAN and monthly cleaning resulted in the greatest amount of DM and N removed from pens, likely as a result of the combination of reduced diet digestibility and less time for degradation on the pen surface. More manure OM was removed from pens housing steers fed BRAN ($P = 0.02$) and when pens were cleaned monthly ($P = 0.07$). Feeding BRAN and end cleaning did not result in more DM removal compared with CON, but did result in more OM removed due to a greater percent OM in manure. Regardless of pen cleaning frequency, feeding BRAN increased the C:N ratio of manure ($P < 0.01$) due to an increase in OM excretion. Organic matter is more indicative of manure because DM amounts will be a combination of OM and ash. Dry matter may be misleading if more ash (soil contamination) is hauled in manure.

Presumably, an increase in the C:N ratio leads to increased N stabilization in manure. In a study conducted by Erickson and Klopfenstein (2001b), 30% dietary corn bran fed during the fall and spring months reduced N volatilization by 27% when compared with a DRC-based diet. Interestingly, Erickson and Klopfenstein (2001b) found no impact on N loss when comparing corn bran to control diets when fed during the summer months, agreeing with findings from Trial 2. Nitrogen volatilization is enhanced by warm, moist conditions, such as those observed during the summer months (Dewes, 1996). These conditions cause the nitrogen pool to be lost at a greater rate and would suggest that summer climates promote rapid volatilization before the pool has a chance to be immobilized. Therefore, increasing the C:N ratio was less effective during Trial 2 vs. Trial 1. Furthermore, OM from corn bran is likely more available for microbial metabolism on the pen surface than sawdust, allowing more N to be conserved. Additional OM introduced into the pen increases the amount of OM to be hauled out of the pen and may increase the cost of manure handling. However, manure greater in OM and N would be of greater value when applied to cropland.

In contrast to Trial 1, feeding BRAN in Trial 3 only resulted in reduced N volatilization when pens were cleaned monthly. Feeding BRAN and waiting to clean pens until the end of the feeding period resulted in a 20% increase in N volatilization from pens compared with CON. However, the extra OM excretion by feeding BRAN resulted in a greater N recovery in finished compost.

To validate our assumption that most of the N lost is volatilized NH_3, we compared our results to those of Hutchinson et al. (1982). Using an average stocking rate of 359 steers/ha, with two cattle turns per year, N losses from pens housing steers fed CON were approximately 12,000 kg N emitted for each ha in one year, or 1.4 kg of $N \cdot ha^{-1} \cdot h^{-1}$. This estimate agrees with Hutchinson et al. (1982), who reported 1.4 kg of $N \cdot ha^{-1} \cdot h^{-1}$ using changes in air concentration surrounding a commercial feedlot. This would indicate our assumption to be correct for volatilized NH_3, despite differences in methodology among studies. The BRAN and SAWDUST treatments lost 0.8 kg of $N \cdot ha^{-1} \cdot h^{-1}$ for Trial 1. These estimates are lower, presumably because more N was retained in manure (less volatilization) compared with

cattle fed CON and manure from Hutchinson et al. (1982). Differences in N emissions were not as pronounced during Trial 2, presumably due to warm summer temperatures. Results from Trial 3 would agree with those of Trial 1 when pens were cleaned monthly.

Compost Nutrient Recovery

At least 45% of N from initial manure input was recovered following composting of manure from Trial 1 (Table 6). The initial manure N quantities were greater for BRAN and SAWDUST than for CON, resulting in more N remaining in finished compost for BRAN and SAWDUST treatments. As a percentage of N excretion, 25, 32, and 29% N was recovered in compost generated from CON, BRAN, and SAWDUST treatments, respectively. Finished compost from BRAN-fed steers and SAWDUST-applied pens contained approximately 48% more OM than CON compost.

Feeding BRAN resulted in the highest N recovery and the greatest N weight retained in compost in Trial 2 (Table 6). Feeding BRAN resulted in 20% of excreted N recovered in compost, whereas SAWDUST and CON retained only 12%. The BRAN and SAWDUST treatments contained the greatest amounts of OM after composting due to greater amounts of initial OM in manure. Feeding corn bran appears to be a more effective method of retaining N in compost than applying sawdust to the pen surface.

The percentage of N recovery in compost was similar between CON and BRAN within monthly pen cleaning frequency during Trial 3 (Table 7). However, manure N from BRAN-fed calves was higher than from CON calves before composting, resulting in 27% greater total N retention in finished compost from steers fed BRAN. When pens were cleaned at the end, BRAN compost had a 55% greater N recovery than CON compost, resulting in 57% more N in finished compost, although manure N prior to compost was not different. This latter observation would indicate that the additional OM excreted was effective in lowering N losses during the composting process. The N in composted manure from BRAN-fed cattle was similar between the two cleaning frequencies despite greater losses from pens cleaned only once at the end during the feeding period. This suggests that available N was not converted to organic N until the composting process for pens of steers fed BRAN that were cleaned at the end.

The compost N recovery data collected in these trials are in agreement with data collected by Eghball et al. (1997). Nitrogen losses from compost occur through volatilization, runoff, and leaching (Eghball and Gilley, 1999). However, as with raw manure, most N is lost through volatilization. Lory et al. (2002) reported 67% N recovered in compost from manure that had been amended with sawdust throughout the feeding period. These data suggest that additional OM excretion has value in "trapping" N during composting. Although composting does result in loss of nutrients, the overall quality of the compost is greater than that of raw manure. Nitrogen in compost becomes more stable, allowing for less volatilization once it is applied to the field. The handling characteristics of compost are also improved compared with manure due to lower moisture and the fine particle size that is achieved during the composting process (DeLuca and DeLuca, 1997). Another critical consideration is the form of N lost during composting compared with the feedlot manure on the pen surface. In the future, the form of N lost as well as mass balance should be evaluated with manure in feedlot pens and during the composting process. Based on transformations of N in soil, it is plausible that NH_3 undergoes nitrification to NO_3^- (Norton, 2000) and may be denitrified to N_2 (Robertson, 2000). More research is needed to adequately characterize the form of N losses, particularly benign forms such as N_2.

Literature Cited

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

Clark, R. N., A. D. Schneider, and B. A. Stewart. 1975. Analysis of runoff from southern great plains feedlots. Trans. ASAE. 18:319–322.

Cooper, R. J., C. T. Milton, T. J. Klopfenstein, T. L. Scott, C. B. Wilson, and R. A. Mass. 2002. Effect of corn processing on starch digestion and bacterial crude protein flow in finishing cattle. J. Anim. Sci. 80:797–804.

DeLuca, T. H., and D. K. DeLuca. 1997. Composting for feedlot manure management and soil quality. J. Prod. Agric. 10:235–241.

Dewes T. 1996. Effect of pH, temperature, amount of litter and storage density on ammonia emissions from stable manure. J. Agric. Sci. 127:501–509.

Eghball, B., and J. E. Gilley. 1999. Phosphorus and nitrogen runoff following beef cattle manure or compost application. J. Environ. Qual. 28:1201–1210.

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

Erickson, G. E., and T. J. Klopfenstein. 2001a. Managing N inputs and the effect on N losses following excretion in open-dirt feedlots in Nebraska. The Scientific World JOURNAL 1(Suppl. S2):830–835.

Erickson, G. E., and T. J. Klopfenstein. 2001b. Nutritional methods to decrease N losses from open-dirt feedlots in Nebraska. The Scientific World JOURNAL 1(Suppl. S2):836–843.

Giger-Reverdin, S., D. Suvant, J. Hervieu, and M. Dorleans. 1991. Fecal and urinary nitrogen losses as influenced by the diet carbohydrate and protein fractions in goats. Pages 358–360 in Proc. 6th Int. Symp. Protein Metab. and Nutr., Herning, Denmark.

Gilbertson, C. B., T. M. McCalla, J. R. Ellis, O. E. Cross, and W. R. Woods. 1971. Runoff, solid wastes, and nitrate movement in beef feedlots. J. Water Pollution Control Fed. 43:483–493.

Huntington, G. B. 1997. Starch utilization by ruminants: from basics to the bunk. J. Anim. Sci. 75:852–867.

Hutchinson, G. L., A. R. Mosier, and C. E. Andre. 1982. Ammonia and amine emissions from a large cattle feedlot. J. Environ. Qual. 11:288–293.

James, T., D. Meyer, E. Esparza, E. J. Depeters, and H. Perez-Monti. 1999. Effect of dietary nitrogen manipulation on ammonia volatilization from manure from Holstein heifers. J. Dairy Sci. 82:2430–2439.

Kellems, R., J. R. Miner, and D. C. Church. 1979. Effect of ration on waste composition and length of storage on the volatilization of ammonia, hydrogen sulfide, and odors from cattle waste. J. Anim. Sci. 48:436–445.

Lory, J., J. Adams, B. Eghball, T. Klopfenstein, and J. Powers. 2002. Effect of sawdust or acid application to pen surfaces on nitrogen losses from open-dirt feedlots. Neb. Beef Cattle Rep. MP 79-A:52–53.

Macken, C., T. Klopfenstein, G. Erickson, and R. Stock. 2002. Type of corn bran and corn processing method in beef finishing diets. Neb. Beef Cattle Rep. MP 79-A:72–73.

Merchen, N. R. 1988. Digestion, absorption, and excretion in ruminants. In The Ruminant Animal. Digestive Physiology and Nutrition. D.C. Church, ed. Waveland Press, Inc. Prospect Hills, IL.

Milton, T. T., T. Klopfenstein, D. Jordan, R. Cooper, and R. Stock. 2000. Effect of dry, wet, or rehydrated corn bran on performance of finishing yearling steers. Neb. Beef Cattle Rep. MP 73-A:61–62.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Norton, J. M. 2000. Nitrification, nitrogen transformations. In Handbook of Soil Science. M. E. Sumner, ed. CRC Press, Boca Raton, FL.

Owens, F. N., M. A. Hinds, and D. W. Rice. 2002. Methods for calculating diet energy values from feedlot performance of cattle. J. Anim. Sci. 80(Suppl. 1):273.

Robertson, G. P. 2000. Denitrification, nitrogen transformations. In Handbook of Soil Science. M. E. Sumner, ed. CRC Press, Boca Raton, FL.

Sørenson, P. 1998. Effects of storage time and straw content of cattle slurry on the mineralization of nitrogen and carbon in soil. Biol. Fertil. Soils 27:85–91.