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Nitrogen and Phosphorus Balance of Beef Cattle Feedyards

N. A. Cole and R. W. Todd
USDA-ARS-CPRL, Bushland, Texas
Email: Andy.Cole@ARS.USDA.GOV

ABSTRACT

Large quantities of nutrients enter beef cattle feedyards in feed ingredients. These nutrients subsequently *leave* the yard in finished cattle, manure, or through the atmosphere. A better understanding of the movement of these nutrients would be helpful in developing nutrient management plans and technologies to capture more of these nutrients in usable form. To that end, diet, fresh feces, and air dried manure samples were collected monthly at 2 commercial feedyards in the Texas Panhandle over a year. The feedyards provided data on cattle head counts, body weights, and feed consumption. Nitrogen (**N**) and phosphorus (**P**) retention were calculated using NRC (2000) equations. Diet digestibility was calculated using acid insoluble ash as an indigestible marker. Urinary N and P excretion were determined by difference and N volatilization losses were estimated via the change in the N:P ratio between the diet and air-dried manure, and as N unaccounted for in the total N balance. Daily N intake averaged 164.7 kg /1000 head and daily N retention averaged 23.3 kg/1000 head. Approximately 141.4 kg of N was excreted daily per 1000 head of which 51.0 kg (36 % of excreted) was in feces and 90.4 kg (64 %) was in urine. Approximately 66.9 kg (41 % of N intake) was subsequently captured in manure. Of the N intake, 25 % in winter to 58 % in summer (mean 44.3 %) was apparently lost via volatilization. When metabolizable protein (**MP**) intake exceeded animal requirements, N volatilization losses increased linearly ($r^2 = 0.53$: $P < 0.001$). Daily P intake averaged 28.9 kg /1,000 head and daily P retention averaged 5.7 kg/1,000 head. Approximately 23.1 kg of P was excreted daily per 1,000 head; 14.5 kg (63 % of excreted) in feces and 8.6 kg (37 % of excreted) in urine. Nitrogen excretion and volatilization losses were affected by feedyard diet and season.

INTRODUCTION

Appreciable quantities of nutrients enter beef cattle feeding operations in the form of feeder cattle and feed. These nutrients subsequently leave the operation in the form of finished animals, manure, or via atmospheric emissions. A better understanding of the movement of these nutrients would be helpful in developing nutrient management plans and technologies to capture more of these nutrients in usable form. A total nitrogen (**N**) balance is also useful to evaluate measurements of gaseous ammonia losses from feedyards. To that end, the objectives of this study were: 1) to determine a total N and phosphorus (**P**) balance for commercial beef cattle feedyards typical of those in the Southern Great Plains, 2) to evaluate dietary factors affecting nutrient balance, and 3) to compare calculated gaseous N losses to ammonia losses determined using a dispersion model.

MATERIALS AND METHODS

Diet, fresh feces, and air dried manure samples were collected monthly at 2 commercial feedyards in the Texas Panhandle over a 12-mo period. Each month, samples of the finishing ration at each yard were collected from the feedbunks of 5 pens immediately after feeding, but before cattle had an opportunity to disturb the feed. From the same 5 pens, 3 to 5 sub-samples of fresh feces and manure were collected and composited to provide 1 sample of fresh feces and 1 sample of air-dried manure per pen. Each month, the feedyard management provided data on the average number of cattle on feed, average in-weights and out-weights, average days-on-feed, dietary ingredient composition, and monthly feed consumption. Feedyard A also provided data on average daily gains (**ADG**) of the cattle that left the yard that month. Average daily gains at both yards were also calculated from net energy concentration of the finishing diet, average feed consumptions, and average animal body weight using NRC (2000) equations. The net energy values of the diets at Feedyard A were adjusted so that calculated ADG were within 5 % of actual ADG. Feedyard E did not provide animal performance data; therefore ADG were calculated using the same net energy adjustment factors as for Feedyard A.

Following wet digestion, diets, fresh feces, and air-dried manure were analyzed for N and P using a Flow Injection Analyzer (Lachet Instruments, Milwaukee, WI.). Samples were analyzed for dry matter (**DM**) by drying at 100 °C for 24 h. Diets and fresh feces were analyzed for acid insoluble ash (**AIA**) using the method of Van Kuelen and Young (1977). Manure pH was determined using a pH meter in a 1:5 (wt.:vol.) manure:deionized water mixture.

Daily nutrient intake was calculated as the product of dry matter intake (**DMI**) and dietary N and P concentration. Nitrogen and P retention by the animals were calculated using NRC (2000) equations (Cole et al., 2006). Dry matter and nutrient digestibilities were calculated using AIA as an indigestible marker. Fecal excretion of DM, N, and P were calculated from nutrient intake and digestibility as follows:

*Fecal Excretion (g/day) = Daily Intake(g/day) – (Daily intake * % digestibility/100).*

Urinary N and P excretion were determined by difference as follows:

Urinary Excretion (g/day) = Intake (g /day) – fecal excretion (g/day) – retained (g/day).

N volatilization losses were estimated via 2 methods:

1) as N unaccounted for in the total N balance (assuming 5 % runoff – Bierman et al., 1999), and
2) the change in the N:P ratio between the diet and air-dried manure, as follows:

*N Volatilization (% of intake) = (N:P of diet – N:P of air dry manure)/N:P of diet)*100.*

*N Volatilization (g/day) = ((N volatilization as % of intake)/100) * N intake(g/day).*

These calculations assumed the N:P ratio of the air-dried manure and runoff to the retention pond were similar. Because both methods gave similar values, only the values from the total N balance are presented.

Metabolizable protein (**MP**) is defined as the true protein absorbed by the intestine. In cattle it is comprised of microbial protein produced in the rumen and feed protein that escapes the stomach undigested. Metabolizable protein intakes and animal requirements were calculated using NRC (2000) equations. Metabolizable protein-N status (**MPN-status**: MPN = MP / 6.25) was then calculated as the difference between MPN intake and the MPN required for maintenance and growth. For comparison, the resulting data were divided into 4 approximately equal quadrants designated as Deficient, Adequate, High, or Excessive MPN-status. The relationship between MPN-status and N volatilization losses were determined using the PROC REG procedure of SAS (SAS Institute Inc., Cary, NC). The relationship between pen surface manure pH and N volatilization losses were also determined using the PROC REG procedure.

RESULTS AND DISCUSSION

Average monthly cattle numbers, DMI, and animal performance for the 2 feedyards are presented in Table 1. In general Feedyard E contained more cattle than Feedyard A and cattle in Feedyard E tended to have greater DMI. This greater DMI was most likely due to a higher roughage content of the finishing diets fed at Feedyard E (approximately 9 to 12 %) than at Feedyard A (approximately 6 to 8 %). A higher dietary roughage content would also account, in part, for the slightly greater fecal DM excretion and lower N volatilization losses (Bierman et al., 1999; Farran et al., 2006).

Seasonal effects and average chemical composition of the diets, fresh feces, and

Table 1. Cattle characteristics and average nutrient metabolism at Feedyards A and E over a 12-month period.

Item	Feedyard A		Feedyard E	
	Mean	Std. dev.	Mean	Std. dev.
Head count	12,462	1,982	20,345	1,345
Avg. body weight, kg	434.0	7.13	436.5	9.63
Day on feed	179.6	15.1	178.2	16.9
Calculated daily gain, kg	1.33	0.17	1.40	0.18
Daily DM intake, kg	7.12	0.62	7.99	0.58
Calculated DM:Gain	5.32	0.32	5.40	0.29
Daily fecal DM, g/head	1,617	652	1,950	1,204
Nitrogen metabolism				
Daily N intake, g/head	166.6	11.4	162.6	24.3
N digestion, %	67.3	17.2	69.9	12.4
Daily fecal N, g/head	53.8	28.1	47.8	18.2
Daily urine N, g/head	91.2	32.5	89.4	28.4
Urine N, % of excreted N	62.4	20.0	64.1	14.9
N volatilized, % of N intake	49.3	7.32	38.5	13.0
Manure N , % of N intake	37.8	7.61	45.7	11.6
P metabolism				
Daily P intake, g/head	23.2	4.24	29.7	3.00
Daily fecal P, g/head	14.8	9.62	13.8	6.52
Daily urine P, g/head	3.16	10.52	9.69	6.66
Urine P, % of excreted	14.8	5.21	40.9	26.8

Table 2. Seasonal effects on manure and feces composition and N and P metabolism.

Item	Fall	Winter	Spring	Summer	Overall mean	Std. deviation
Manure [1]						
pH	8.10	7.70	7.81	8.03	7.89	0.30
DM, %	79.7	59.2	76.2	72.9	72.3	5.72
N, %	2.59	3.34	3.12	2.80	2.91	0.36
P, %	0.88	0.80	0.76	0.89	0.80	0.14
N:P	3.03	4.20	4.16	3.22	3.77	0.85
Fresh feces[1]						
DM, %	23.4	23.9	26.4	24.8	25.8	3.68
N, %	2.62	3.41	3.11	3.09	2.96	0.50
P, %	0.87	0.83	0.78	0.88	0.82	0.28
N:P	3.37	5.00	4.28	3.78	3.98	1.40
Diets[1]						
DM, %	71.2	71.0	69.1	73.1	70.7	5.77
N, %	2.19	2.02	2.19	2.24	2.18	0.28
P, %	0.34	0.37	0.36	0.44	0.38	0.09
N:P	6.63	5.59	6.22	5.11	5.93	1.17
DMI, kg/d	7.88	7.40	7.58	8.23	7.75	0.76
Calc. ADG, kg	1.44	1.35	1.39	1.54	1.43	0.23
DMI / Calc. ADG	5.49	5.52	5.55	5.34	5.49	0.41
DM digestion, %	72.4	74.5	73.8	78.3	74.8	16.9
Daily N metabolism						
N Intake, g/head	172.8	150.6	164.5	185.2	164.7	22.1
N gain, % of N intake	13.9	16.4	14.0	14.0	14.8	2.24
N digestion, %	67.8	58.0	69.4	73.5	68.0	15.0
Fecal N, g/head	55.0	63.0	50.2	48.9	51.0	25.8
Urine N, g/head	92.7	63.7	89.9	110.5	90.4	31.3
Urine N, % of excreted	62.5	50.0	64.0	68.9	62.3	17.8
N volatilization loss, % of intake	53.9	24.9	31.9	51.1	44.3	12.8
N volatilization loss, g/head	93.1	37.0	52.7	87.3	62.6	25.2
N volatilization loss, % urine N	124.0	71.8	64.8	73.4	78.9	58.6
Manure N, % of intake	32.2	58.7	54.1	34.9	41.0	8.9
Daily P metabolism						
P intake, g/head	28.5	23.3	25.1	32.2	29.5	7.06
Fecal P, g/head	20.8	13.3	11.5	14.6	14.5	8.06
Urinary P, g/head	1.15	4.64	8.15	11.3	8.6	9.58

[1] All values, except dry matter, are on a dry matter basis.

air-dried pen manure are presented in Table 2. The mean values and ranges were similar to those reported in other studies (Cole et al., 2009a, b). In general, the N content and N:P ratio of the manure pack were greater in the winter and spring than in the summer and fall. The DM concentration of the air-dried manure was lower in the winter than the remaining seasons, due to considerable snow during the winter season.

Season effects and overall means for N and P metabolism are also presented in Table 2. Nitrogen intakes tended to be lower in the winter than the other seasons. This was due to a combination of lower dietary crude protein concentrations and lower DMI. The lower intake was likely due in part to the wet pen conditions caused by the very wet winter. Nitrogen and P

Table 3. Effects of metabolizable protein-nitrogen (MPN) intake status on N metabolism averaged over both feedyards.

Item	Deficient	Adequate	High	Excessive
MPN intake – MPN required	-10.70	8.87	19.26	27.65
Ration composition				
N, %	1.83	2.13	2.36	2.41
P, %	0.36	0.36	0.33	0.52
N:P ratio	5.02	6.10	7.36	5.85
Feces composition				
N, %	3.05	2.85	2.94	3.03
P, %	0.70	0.82	0.87	0.99
N:P ratio	4.71	4.04	3.72	3.05
Manure composition				
N, %	2.95	2.95	2.92	2.65
P, %	0.74	0.85	0.78	0.98
N:P ratio	4.02	3.59	3.92	2.69
Calc. ADG, kg	1.41	1.48	1.45	1.44
DMI, kg	7.72	7.90	7.88	8.01
DMI / Calc. ADG	5.51	5.36	5.42	5.46
N intake, g/d	140.2	168.6	178.3	191.3
N gain, g/d	24.3	25.5	24.7	24.6
N gain, % of N intake	17.3	15.1	14.0	12.8
N digestion, %	64.5	70.3	68.0	75.3
Fecal N, g/d	48.7	49.2	57.4	47.7
Urine N, g/d	67.3	93.9	96.2	119.0
Urine N, % of N excreted	57.3	65.0	63.3	71.6
N volatilization, % of N intake	21.0	41.2	45.0	53.9
N volatilization, g/head daily	29.8	69.5	79,9	103.1
N volatilization, % of urine N	46.6	89.8	104.9	93.3
Manure N, % of N intake	56.0	40.9	39.8	33.9

Table 4. Regression of metabolizable protein-nitrogen status (MPNstatus) and manure pH vs. N volatilization losses averaged over two feedyards.[1]

Dependent variable & Data set	Equation	R^2	RMSE	*P* <
N loss, g/head				
All	47.7 + 1.444 (MPNstatus)	0.59	17.85	0.001
MPNstatus negative	29.30 – 0.343 (MPNstatus)	0.03	12.50	0.500
MPNstatus positive	40.14 + 1.852(MPNstatus)	0.53	17.70	0.001
All	-261.96 + 41.30 (Manure pH)	0.26	24.64	0.001
N loss, % of N intake				
All	30.24 + 0.602 (MPNstatus)	0.43	10.17	0.001
MPNstatus negative	17.57 – 0.535 (MPNstatus)	0.12	8.47	0.131
MPNstatus positive	26.62 + 0.801(MPNstatus)	0.41	9.89	0.001
All	-132.18 + 21.41 (Manure pH)	0.29	11.73	0.001

[1] MPNstatus = Daily metabolizable protein-nitrogen intake – daily metabolizable protein- nitrogen required. RMSE = Root mean square error.

digestion and retention were similar to controlled studies in which diets, similar to those used in these feedyards, were fed (Cole et al., 2006; Vasconcelos et al., 2009).

Calculated N volatilization losses as a percentage of N intake during the winter and spring were approximately 50 to 60 % of those determined for the summer and fall. Similarly, Todd et al. (2008) reported that winter ammonia emissions were 53 % of summer emissions at a nearby feedyard. The lower winter emissions may have been due in part to the lower N intake and lower urinary N excretion during the winter and spring; but was also due to differences in temperature. This might also account for the greater N concentration of manure in the winter and spring and to the greater recovery of fed N in manure in winter (52.1 %) and spring (46.9 %) than in summer (35.2 %) or fall (28.9 %).

The primary source of ammonia losses from feedyards appears to be fresh urine spots (Cole et al., 2009a, b). Nitrogen volatilization losses, as a percentage of urinary N excretion ranged from 64 to 124 % of urinary N excretion in our study with an average of 78.9 %. Average N volatilization losses were 51.1% of N intake in the summer, 24.9% of N intake in the winter, and 44.3 % of N intake over the year. Ammonia emissions from the same feedyards measured using atmospheric ammonia concentrations coupled with a dispersion model, averaged 61 % of N intake in the summer and 38 % of N intake in the winter (see Todd et al., these proceedings). At another Southern Great Plains feedyard Todd et al. (2008) reported that summer ammonia-N emissions were 68 % of N intake, winter emissions were 36 % of N intake, and the annualized mean emissions were 53 % of fed N.

Phosphorus intake averaged 29.5 g/head daily. Approximately 67 % of excreted P was lost in feces and approximately 37 % was lost in the urine. In cattle fed high-roughage diets P is excreted almost exclusively in the feces. However, in high concentrate diets, urinary phosphate may serve to buffer the increased acid load produced during ruminal fermentation of high starch diets (Cole et al., 2006; Vasconcelos et al., 2009). Urinary P excretion also tends to increase with days on feed (Cole et al., 2006; Vasconcelos et al., 2009).

The effects of MPN-status on N metabolism are presented in Table 3. Calculated ADG tended to be lower in cattle on protein deficient diets due to slightly lower DMI. Nitrogen intake increased with increasing MPN-status as did urinary N excretion, total N excretion, and N volatilization losses. Nitrogen retention and fecal N excretion were similar for the 4 MPN-status categories. Based on previous controlled studies (Cole et al., 2005), these results would be expected. In cattle on MPN-deficient diets N volatilization was approximately 50 % of urinary N excretion; whereas when diets were adequate in MP, N volatilization losses were greater than 90 % of urinary N excretion. Nitrogen captured in manure, as a percentage of fed N, decreased with increasing MPN-status.

Regression analysis indicated that the relationship between MPN-status and N volatilization losses were best represented by 2 linear equations; 1 calculated for cattle on MPN-deficient diets and 1 for those on MPN-adequate to MPN-excessive diets (Table 4). When MP intake was less than required, N volatilization losses were not significantly affected by N intake (i.e. the slope of the regression line was not significantly different from 0). However, when MP intake was adequate to excessive, N volatilization losses increased linearly ($P < 0.001$). The intercepts for the regressions of MPN-status vs. N volatilization were 29.3 and 40.1 g/head daily for the MPN-deficient and MPN-adequate equations, respectively. This suggests that the minimum ammonia volatilization loss from cattle fed typical feedyard diets would be in this range.

Decreasing dietary crude protein concentrations in typical finishing diets in order to decrease ammonia emission can be risky, because of potential negative effects on animal performance and costs of gain. However, decreasing dietary protein concentrations of diets during the last 45 to 60 d on feed, when protein requirements are decreased, can potentially decrease ammonia losses without adversely affecting animal performance (Klopfenstein and Erickson, 2002; Cole et al., 2006).

As might be expected, N volatilization losses were positively correlated to the pH of the pen surface manure (Table 4). This relationship may be due to two factors: 1) at higher pH a greater proportion of the ammonia + ammonium molecules are in the gaseous ammonia form, and 2) application of urinary urea to the pen surface causes an increase in the pen surface pH and ammonia concentration (Cole et al., 2009a).

CONCLUSIONS

Results of this study suggest that N volatilization losses from typical Southern Great Plains beef cattle feedyards under similar dietary and environmental conditions will average approximately 44 % of fed N or 63 g / head daily. Factors such as diet and season will affect those losses. When protein was fed in excess of requirements, N volatilization losses increased linearly with increasing N intake; whereas, when protein intake was deficient, N volatilization losses appeared to be relatively constant at 29 g/head daily. The proportion of fed N captured in manure varied inversely with N volatilization losses and ranged from 29 to 52 % of fed N.

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