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Effects of Manipulating Protein and Phosphorus Nutrition of Feedlot Cattle on Nutrient Management and the Environment

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Effects of manipulating protein and phosphorus nutrition of feedlot cattle on nutrient management and the environment[1]

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ABSTRACT: Feedlot nutrition will play a role in meeting challenges such as nutrient management. Nitrogen and phosphorus are two nutrients that are currently studied in this context. One nutritional method is formulating diets not to exceed requirements for nitrogen and phosphorus. Requirements are different for calves and yearlings. The requirements also change during the finishing period. Phosphorus requirements have not been extensively studied for feedlot cattle between 270 and 600 kg. Therefore, P requirements studies were conducted to determine the P requirement of calves (265 kg) and yearlings (385 kg). The requirement was not detected with P levels as low as 0.14 (yearlings) and 0.16% (calves) of diet DM based on performance and bone ash. Compared to NRC-predicted P requirements, P intakes ranged from 76 to 190% (calves) and 71 to 162% (yearlings). In separate nutrient balance experiments, decreasing dietary P to NRC-predicted requirements (0.22 to 0.28%) did not influence gain but decreased P input by 33 to 45% and excretion by 40 to 50% compared to the industry average (0.35% P). The metabolizable protein (MP) system was recently adopted and may allow more accurate diet formulation for protein, thereby decreasing N excretion. Compared to the industry average (13.5% CP) and formulation with the CP system, using the NRC model and phase-feeding not to exceed MP requirements over the feeding period decreased N inputs by 10 to 20% for calves and yearlings without affecting ADG. Decreasing N inputs led to a concomitant decrease in N excretion (12 to 21%) and volatilization (15 to 33%) in open-dirt feedlot pens. Nitrogen losses are variable with time of year, with averages of 60 to 70% of excreted N lost during the summer months and 40% lost from November to May feeding periods. Protein requirements are continually being refined as more research data are collected. However, formulation to meet and not exceed protein requirements and removal of P supplements are important nutritional management options to help feedlots become more environmentally sustainable.

Key Words: Nitrogen, Phosphorus, Cattle Feeding, Nutrient Requirements, Waste Management

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Introduction

Cattle feedlots continue to increase in size. This concentrates manure and the nutrients contained therein. For example, a feedlot with a 50,000-animal capacity will feed over 5×10^6 bushels of corn per year. This requires over 12,141 ha (30,000 acres) of corn to meet the needs of the cattle. In order to be environmentally sustainable, the manure from that feedlot should be spread back on that 12,141 ha. That is a radius of about 6.4 km. So what is the problem?

There are many problems relating to manure distribution. Locally, one problem is that most corn is raised in a rotation with soybeans, which may increase the area needed in our example. Further, many crop producers do not want to use manure for various reasons. An estimate in Nebraska is that only 30% of crop producers are willing to accept manure as a fertilizer. In other situations, the feedlot may be surrounded by land that is not cropland, such as pasture land.

Probably a bigger problem is the regional or national problem of grain/manure distribution. For example, if Iowa or Nebraska corn is shipped to Texas for feeding to cattle there, the manure produced from those cattle should logically be shipped back to the Iowa or Nebraska cornfields.

There are two basic problems we face with feedlot manure. First is the distribution problem mentioned above. The second problem is the volatilization of nitrogen in the form of ammonia from feedlot surfaces. If we minimize nutrients fed to feedlot cattle, then logically we minimize the nutrients excreted and minimize the environmental impact.

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Table 1. Effect of dietary P concentrations on finishing performance (Erickson et al., 1999)

	Phosphorus, % of DM					
Item	0.14	0.19	0.24	0.29	0.34	SE
P intake, g/d	15.9	19.7	27.6	32.1	36.4	0.7
Initial wt, kg[a]	385	384	390	385	385	11
Final wt, kg[ab]	567	553	568	566	545	15
DMI, kg/d[a]	11.4	10.4	11.4	11.1	10.7	0.3
ADG, kg/d[a]	1.76	1.62	1.71	1.75	1.53	0.09
ADG:DMI[a]	0.154	0.157	0.149	0.158	0.142	0.007

[a]No significant linear, quadratic, or cubic effects due to P ($P > 0.10$).
[b]Determined as hot carcass weight divided by 62% dress.

Results and Discussion

Phosphorus

Phosphorus does not volatilize from the pen surface, so whatever is excreted must be distributed to crop land. In order to minimize the amount fed, it is absolutely necessary to know the requirements for phosphorus. The NRC (1996) requirements are calculated using the factorial approach. For feedlot cattle, it is the total of P for maintenance and gain. The requirement for maintenance was determined with animals at maintenance and may be less per kilogram of BW for fatter cattle. The requirement for gain is based on 50-yr-old data on dairy cattle. It is based on the P content of protein gain. Further, the requirement assumes 68% true absorption of P, which is difficult to measure and may be higher or lower and may depend on the diet (forage vs grain).

Erickson et al. (1999) attempted to determine the P requirement of yearling cattle in the feedlot. We are unaware of other reports in which P requirement was determined using a dose response in feedlot cattle. Because corn is the primary ingredient in feedlot diets and because it contains about 0.32% P, it was difficult to develop diets deficient in P that still gave performance comparable to commercial feedlot cattle. Two products were used from corn milling industries: corn bran and brewers grits. Neither contains the germ, which has much of the P. A control diet was developed that contained 0.14% P and produced 1.76 kg/d gain and 0.154 feed efficiency.

Phosphorus was added to the control diet as monosodium phosphate. There was no response in cattle performance to P additions (Table 1). Further, there was no effect of P level on bone ash or bone breaking strength. This is strong evidence that yearling cattle (385 kg initial weight) have a P requirement of 0.14% or less. The NRC (1996) requirement for these cattle (avg wt = 476 kg) was 0.2% of diet dry matter.

These data were somewhat surprising, and it was believed that younger and lighter cattle might (should) have higher requirements. A second experiment was conducted (Erickson et al., 2002) with calves of 265 kg initial weight. The control diet contained 0.16% P and graded levels of P were added as monosodium phosphate. There was no response in calf performance to levels of P above 0.16% (Table 2). The NRC (1996) requirement for this average weight (418 kg) is 0.21% of diet dry matter.

We conclude that the P requirement is far below the 0.32% P found in corn and that supplemental P should never be added to corn-based feedlot diets. The problem is that corn contains too much P and there does not seem to be a logical way to overcome that problem. Perhaps corn hybrids can be selected or genetically engineered to be lower in P.

By-product feeding accentuates the problem of overfeeding P. For example, in the production of distillers grains from corn, the starch is fermented to alcohol and CO_2. This concentrates the remaining nutrients, including P, by about three times. The resulting distillers grains have about 0.9% P. Because of increases in numbers of fuel alcohol plants, wet distillers grains are plentiful and can be fed up to 40% of the diet (Larson et al. 1993). The resulting diet will contain about 0.55% P, which is three to four times the requirement. This emphasizes the manure distribution issue raised previously. Because 75% of the corn now goes through the alcohol plant before the by-product is fed to the cattle, the land area needed to produce the corn has doubled and the area upon which to spread the manure has doubled.

Nitrogen

The metabolizable protein (**MP**) system presented in the 1996 NRC allows us to more accurately balance feedlot diets so that requirements are met but protein is not oversupplied. Protein fed above the requirement may be expensive and may lead to environmental problems. The MP system separates protein needs into degradable intake protein (**DIP**) needs by the rumen microorganisms and MP needs by the animal. The MP is the sum of digestible microbial true protein and digestible undegraded intake protein (**UIP**). The challenge is to just meet both requirements without overfeeding.

Table 2. Effects of dietary P on finishing performance for calves fed varying levels of P (Erickson et al., 2002)

	Phosphorus, % of DM							
Item	0.16	0.22	0.28	0.34	0.40	SE	Linear	Quadratic
P intake, g/d	14.2	20.2	23.4	31.7	35.5	0.7	0.01	—
Initial wt, kg	268	265	264	264	264	6	0.61	0.75
Final wt, kg[a]	579	578	538	592	564	11	0.69	0.33
DMI, kg/d	8.9	9.0	8.2	9.3	8.8	0.2	0.92	0.32
ADG, kg/d	1.52	1.53	1.34	1.61	1.47	0.04	0.86	0.28
ADG:DMI	0.171	0.171	0.163	0.174	0.166	0.004	0.65	0.79

[a]Determined as hot carcass weight divided by 62% dress.

DIP Requirements

Level 1 of the NRC (1996) model sets the dietary DIP requirement equal to bacterial crude protein (**BCP**) production. Bacterial CP is calculated with the equation BCP = 0.13 (eNDFadj) (TDN; where 0.13 equals microbial N efficiency, eNDFadj is an adjustment factor that lowers microbial N efficiency for diets that cause low ruminal pH because of low roughage levels, and TDN equals the total digestible nutrient content of the diet [g/d]). Adjusted microbial N efficiency values for typical 90%-concentrate finishing diets are usually between 0.08 and 0.09 of TDN, depending on the roughage source.

Carbohydrate digestion in the rumen is likely the most accurate predictor of BCP synthesis and is used in Level 2 of the NRC (1996) model. However, few data are currently available for the rates of passage and digestion of various carbohydrate fractions in feedstuffs commonly fed in feedlot diets. Therefore, dietary TDN is used in Level 1 of the NRC (1996) model because it is currently the most accurate and readily available estimate of energy value for a diet. However, because Level 1 of the NRC (1996) model uses TDN to predict the dietary DIP requirement, factors that shift the site of digestion of the dietary nutrients, such as grain processing, are not appropriately accounted for.

We have conducted several trials evaluating the effect of corn processing method on the dietary DIP requirement of finishing steers. Shain et al. (1998) conducted two finishing trials with a total of 304 yearling steers. Steers were fed 92.5%-concentrate, dry-rolled corn-based diets that were supplemented with 0, 0.88, 1.34, and 1.96% urea (DM basis). Steers did not respond to dietary urea levels above 0.88%, indicating that the dietary DIP requirement for a dry-rolled corn-based diet was met at 6.4% of DM.

Cooper et al. (2001) conducted three trials to evaluate the effect of corn processing on the dietary DIP requirement of finishing steers. In Trial 1, 252 steers were fed 90%-concentrate, high-moisture corn-based diets that contained 0, 0.4, 0.8, or 1.2% urea (DM basis). Nonlinear analysis predicted maximal feed efficiency at 1.09% urea, which provided a dietary DIP value of 10.2% of DM. In Trial 2, 264 steers were fed 90%-concentrate steam-flaked corn-based diets that contained 0, 0.4, 0.8, 1.2, 1.6, or 2.0% urea (DM basis). Nonlinear analysis predicted maximal feed efficiency at 0.83% urea, which provided a dietary DIP value of 7.1% of DM. In Trial 3, 90 individually fed steers were fed 90%-concentrate dry-rolled, high-moisture, or steam-flaked corn-based diets. Urea was factored across diets at 0, 0.5, 1.0, or 2.0% of DM. Dietary CP, DIP, and finishing steer performance are shown in Table 3. For the dry-rolled corn-based diet, nonlinear analysis could not predict a requirement because feed efficiency was not improved beyond the first increment of urea, suggesting that the DIP requirement was met at 6.3% of DM. For the high-moisture corn-based diet, nonlinear analysis predicted maximal feed efficiency at 1.14% urea, which provided a dietary DIP value of 10.0% of DM. For the steam-flaked corn-based diet, nonlinear analysis predicted maximal feed efficiency at 1.64% urea, which provided a dietary DIP value of 9.5% of DM.

These data suggest that dietary DIP requirements for dry-rolled, high-moisture, and steam-flaked corn-based diets are approximately 6.3, 10.0, and 8.3% of DM, respectively. Level 1 of the NRC (1996) model predicts that the dietary DIP requirement for a 90%-concentrate dry-rolled corn-based diet is approximately 6.8% of DM. The value of 6.3% is in close agreement with the predicted value. Milton et al. (1997), in two separate finishing trials, found dietary DIP requirements of 6.9 and 7.1% of DM for 90%-concentrate dry-rolled corn-based diets. Therefore, it appears Level 1 of the NRC (1996) model is relatively accurate in predicting the dietary DIP requirement for dry-rolled corn-based diets. However, Level 1 does not appropriately account for the increased ruminal starch digestion, and thus BCP production, in high-moisture and steam-flaked corn-based diets. These data suggest that high-moisture and steam-flaked corn-based diets require up to 50% more dietary DIP than a comparable dry-rolled corn-based diet.

UIP Requirements

Dietary UIP requirements are equal to the MP requirement of the animal minus MP supplied from BCP. Often, typical corn-based finishing diets do not need to

Table 3. Dietary protein composition and finishing performance for steers fed dry-rolled, high-moisture, and steam-flaked corn-based diets (Cooper et al., 2001)[a]

	Urea, % of DM				
Treatment	0	0.5	1.0	1.5	2.0
Crude protein, % of DM[b]	9.5	10.9	12.4	13.8	15.3
DIP, % of DM[b]					
DRC	4.8	6.3	7.7	9.2	10.6
HMC	6.7	8.1	9.6	11.0	12.5
SFC	4.7	6.1	7.6	9.0	10.5
DM intake, kg/d					
DRC	9.9	9.6	10.0	10.6	10.4
HMC	10.5	9.6	9.7	9.9	9.5
SFC	8.1	10.1	9.5	10.0	8.5
Daily gain, kg/d					
DRC	1.54	1.64	1.54	1.80	1.68
HMC	1.68	1.57	1.60	1.70	1.51
SFC	1.36	1.72	1.62	1.85	1.57
Gain/feed					
DRC[c]	0.156	0.172	0.154	0.170	0.162
HMC[c]	0.161	0.163	0.165	0.172	0.160
SFC[c]	0.168	0.171	0.179	0.186	0.186

[a] DRC = dry-rolled corn, HMC = high-moisture corn, SFC = steam-flaked corn.

[b] Based on NRC tabular values.

[c] NLIN predicts 6.3, 10.1, and 9.5% DIP requirement for DRC, HMC, and SFC, respectively.

be supplemented with additional UIP because base-diet UIP and MP from BCP are sufficient to meet the needs of the animal. Corn usually contains between 8 and 10% CP, with up to approximately 60% of the CP as UIP. In diets containing 85% corn, this results in 4.1 to 5.1% of the diet being UIP (NRC, 1996). We have found that 4.6% UIP in addition to BCP is sufficient to meet the MP needs of finishing yearling steers (Shain et al., 1994; Sindt et al., 1994), indicating supplemental UIP would not be needed in this case. However, supplemental UIP may be needed in diets with lower inherent UIP such as high-moisture corn, or in animals with high MP needs such as rapidly growing, lightweight calves.

A good example of the difficulty in balancing for MP, without overfeeding, is shown in Table 4. This diet contained 25% wet corn gluten feed and 60% steam-flaked corn. The UIP value of steam-flaked corn is at least as high as that of dry-rolled corn. As indicated previously, the site of starch digestion is shifted to the rumen when steam-flaked corn is fed. This increases BCP production and increases DIP requirement. The wet corn gluten feed increases rumen pH (Krehbiel et al., 1995) and thereby increases microbial efficiency, further increasing BCP production and the DIP requirement.

Crude protein level was increased from 13% to 13.7% and to 14.4% by addition of urea. Gains and gain:feed increased with added protein and we estimate the crude protein requirement to meet the DIP requirement is about 14%. When these values are put into the NRC (1996) model, the supply of MP is much greater than that required by the cattle (Table 5). These were calf-fed steers and were about 318 kg when they reached the finisher diet following appropriate step-up diets. At that point the model predicts a surplus of 53 g/d of MP. This is equivalent to 0.58 percentage units of CP in the diet. At the midpoint of the feeding period, the calves were getting 105 g/d more MP than they needed, which was equivalent to 1.12 percentage units of CP in the diet. At market weight (590 kg), the cattle were getting 190 g/d more MP than they required, which was equiva-

Table 4. Effect of level of CP in feedlot diets containing corn gluten feed and steam-flaked corn[a]

	CP level[b]			
Item	13.0%	13.7%	14.4%	SE
Initial wt, kg	288	288	287	—
ADG, kg[c]	1.59	1.69	1.69	0.04
DMI, kg[c]	9.23	9.51	9.47	0.14
Gain:feed[c]	0.172	0.178	0.178	0.003

[a] Block et al., 2002, average of 25% corn gluten feed in diet DM.

[b] Supplemental protein supplied by urea.

[c] Linear effect of CP level ($P < 0.05$).

Table 5. Metabolizable protein supplies to calf-fed steers fed corn gluten feed and steam-flaked corn[a]

	Body weight, kg		
Item	318	443	590
Degradable intake protein			
Supply/required, g/d	830	874	916
Metabolizable protein			
Supply, g/d	843	911	966
Required, g/d	790	806	776
Excess protein, g/d	53	105	190
Excess protein, % DM	0.58	1.12	1.90

[a] NRC (1996).

lent to 1.90 percentage units of CP. It appears that it was necessary to meet the DIP requirement even though MP was is excess.

MP Requirements

Level 1 of the NRC (1996) model predicts large changes in protein requirements throughout the feeding period due to changes in intake, body weight, and composition of gain. The DIP requirement increases due to a gradual increase in intake as body weight increases (Figure 1). The UIP requirement decreases as body weight increases due to both a larger supply of BCP and from a lower requirement because the composition of gain is increasingly more fat and less lean (Figure 1). The overall MP requirement for the animal does not change significantly with time on feed because as the MP needed for gain decreases, the MP needed for maintenance increases. Figure 1 was developed with performance parameters described in Table 6, which will be discussed later, and assumes a 90%-concentrate dry-rolled corn-based diet with alfalfa as the roughage source. Because the type of protein needed (DIP vs UIP) to meet the MP requirement changes with days on feed, a single finishing diet fed through the feeding period is inadequate, being deficient up to body weight for which it was balanced and excessive from that point on. Therefore, a series of finishing diets fed in sequential order in order to meet, but not exceed, both the DIP and UIP requirements throughout the feeding period (phase-feeding) should be beneficial.

There are several reasons for feeding protein levels at, but not above, requirements. If UIP is supplemented to meet the MP requirements of finishing calves early in the feeding period, it is economically beneficial to remove this costly form of protein supplementation when it is no longer needed to maintain maximum performance. However, we feel the primary reason for feeding protein levels at, but not above, the requirement is pending environmental regulations. In trials conducted at the University of Nebraska (Erickson and Klopfenstein, 2001) yearling steers were fed finishing diets containing 13.5% crude protein, which was approximately 123% of the predicted requirement. During the 137-d feeding period from May to September, each steer excreted approximately 29 kg of nitrogen onto the pen surface, of which approximately 71% volatilized into the air. In 192-d calf-finishing trials conducted from October to May, steers excreted approximately 32 kg of nitrogen onto the pen surface, of which approximately 41% volatilized into the air.

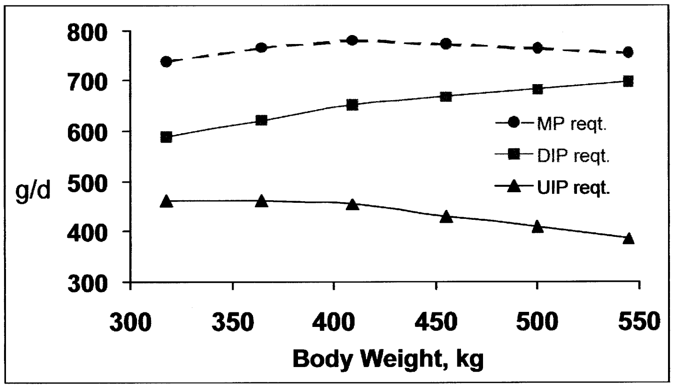

Figure 1. Metabolizable protein (MP), degradable intake protein (DIP), and undergradable intake protein (UIP) requirements of calf-fed steers predicted by NRC (1996).

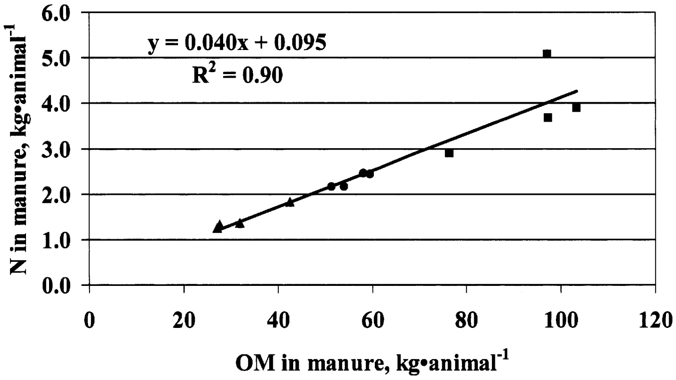

Figure 2. Relationship of N in manure to OM in manure (Bierman et al., 1999).

Table 6. University of Nebraska ARDC Beef Feedlot performance parameters for finishing calves

Body weight, kg	DM intake, kg	DM intake, % of body weight	Daily gain, kg	Gain/feed
272	8.2	3.00	1.6	0.200
318	8.6	2.71	1.6	0.189
363	9.1	2.50	1.6	0.179
408	9.5	2.33	1.6	0.172
454	9.8	2.15	1.6	0.167
499	10.0	2.00	1.6	0.164
544	10.2	1.88	1.6	0.159
590	10.4	1.77	1.6	0.156
431[a]	9.5[a]	2.29[a]	1.6[a]	0.172[a]

[a]Values in this row are averages.

It is important to note that in order to utilize phase-feeding as a nutrient management strategy without adversely affecting performance, one must know or be able to accurately predict the performance of a given group of cattle. Past feeding history is likely the best indication of future performance. We have summarized the performance of finishing calves at the University of Nebraska ARDC Beef Feedlot (Table 6). This summary contains approximately 640 animals fed as calves from 1994 to 1997 on a high-concentrate corn-based diet. All animals were implanted with at least one trenbolone acetate-combination implant and did not have a significant treatment effect in their respective trial. Intermediate performance was based on intake records and intermediate weights that were pencil-shrunk 4%. The 1996 NRC model does not predict intake and NE requirement very well early and late in the feeding because the equations are based on feeding period averages.

Erickson and Klopfenstein (2001) conducted four finishing trials, two with calf-feds and two with yearlings, to evaluate phase-feeding diets in order to minimize N excretion vs feeding a typical high-concentrate finishing diet that was formulated to industry standards and fed throughout the feeding period. The standard diet was 92.5% concentrate and formulated to contain 13.5% CP. Phase-fed diets were also 92.5% concentrate and formulated to match DIP, UIP, and MP requirements throughout the feeding period. For yearlings, three phase-fed finishing diets were used that were fed for 28, 28, and 54 d. For calves, eight phase-fed finishing diets were used that were switched every 14 d, the eighth diet being fed for 73 d. Finishing performance and N balance are shown in Table 7. In yearlings, phase-feeding diets to match protein requirements improved feed/gain by 5% compared to the standard 13.5% CP diet. Nitrogen excretion to the pen surface was reduced by 22% and total N volatilized into the atmosphere was reduced by 32% for the phase-fed diets compared to the standard diet. In finishing calves, phase-feeding reduced feed efficiency by approximately 4% compared to the standard diet. Nitrogen excretion to the pen surface was reduced by 13% and total N volatilized into the atmosphere was reduced by 15% for the phase-fed diets compared to the standard diet. Differences in N volatilization between the yearlings and

Table 7. Performance of finishing yearlings and calves fed either a standard finishing diet or phase-fed multiple finishing diets in order to match protein requirements (Erickson and Klopfenstein, 2001)

	Treatment[a]		
Urea, % of DM	Conventional	Phase-fed	*P*-value
Yearlings			
DM intake, kg	11.4[b]	11.1[c]	0.03
Daily gain, kg	1.81	1.85	0.27
Gain/feed	0.158[b]	0.166[c]	0.01
N intake, kg/steer	33.1	27.0	0.01
Calves			
DM intake, kg	9.2	9.4	0.21
Daily gain, kg	1.56	1.54	0.43
Gain/feed	0.170[b]	0.164[c]	0.04
N intake, kg/steer	37.0	32.8	0.01

[a]Standard diet balanced to contain 13.5% CP; phase-fed diets were fed in sequential order and were balanced to match MP requirements throughout the feeding period.

[b,c]$P < 0.05$.

Table 8. Organic matter (OM) balance in the feedlot for the yearling and calf experiments separated by dietary treatment (all values expressed as kg/steer over the entire feeding period) (Erickson and Klopfenstein, 2001)

	Yearlings (132 d)				Calves (183 d)			
Item	Control	Phase	SE	*P*-value	Control	Phase	SE	*P*-value
Intake	1,463	1,399	12	0.01	1,508	1,595	17	0.01
Excreted[a]	302	418	3	0.01	339	425	4	0.01
Manure	110	180	6	0.01	367	396	24	0.38
Soil[b]	19	−34	14	0.02	−34	−39	17	0.83
Runoff	20	15	2	0.08	8	13	1	0.02
Volatilized[c]	153	257	16	0.01	−2	55	26	0.13
Manure + soil[d]	129	146	15	0.43	333	358	25	0.50

[a] OM excretion calculated from digestibility data from corn and corn bran diets.

[b] Soil is core balance on pen surface before and after each experiment; negative values suggest removal of nutrient present before the experiment.

[c] Volatilized calculated as excretion minus manure minus soil minus runoff.

[d] Manure + soil corrects what was hauled at cleaning by soil nutrients remaining or removed from pen surface.

calves are likely due to cooler temperatures during the calf-finishing studies (November to May) compared to the yearling-finishing studies (May to October).

Bierman et al. (1999) studied the effect of level and source of dietary fiber on mass balance of nutrients on feedlot pens. They fed an all-concentrate diet to minimize organic matter excreted. A 7.5% roughage addition increased fecal output, and adding 41.5% wet corn gluten feed further increased fecal output.

The authors hypothesized that fiber digestion in the hindgut would shift nitrogen excretion from urine to feces. Only 19% of the nitrogen was excreted in the feces by cattle fed the all-concentrate diet, whereas 31% was excreted by cattle fed the wet corn gluten feed diet.

The all-concentrate cattle produced about 88 kg organic matter that was available for removal as manure. The cattle fed wet corn gluten feed produced about 189 kg organic matter available for cleaning. The all-concentrate diet has appeared as "good news" in the past because less manure was available for "disposal." However, Bierman et al. (1999) showed that in order to be able remove more nitrogen in the manure, it was necessary to remove more organic matter as well (Figure 2).

Mass Balance in the Feedlot

The majority, but certainly not all, of the cattle are fed in the plains states of the United States. These feedlots are nearly all outside dirt pens. Typically, pens are cleaned (manure removed) when cattle within the pens are sold and prior to a new lot of cattle being placed in the pen. That means that it is normal for manure to accumulate over a 120- to 140-d period.

Table 9. Nitrogen (N) balance in the feedlot for the yearling and calf experiments separated by dietary treatment (all values expressed as kg/steer over the entire feeding period) (Erickson and Klopfenstein, 2001)

	Yearlings (132 d)				Calves (183 d)			
Item	Control	Phase	SE	*P*-value	Control	Phase	SE	*P*-value
Intake	33.1	27.0	0.3	0.01	37.0	32.8	0.4	0.01
Retention[a]	3.6	3.6	0.02	0.80	4.6	4.6	0.03	0.28
Excretion[b]	29.5	23.4	0.3	0.01	32.4	28.2	0.4	0.01
Manure	5.9	8.9	0.3	0.01	19.8	18.9	1.2	0.60
Soil[c]	1.7	0.4	0.6	0.03	−1.7	−2.9	0.8	0.28
Runoff	1.0	0.7	0.1	0.07	1.0	1.0	0.1	0.74
Volatilized[d]	20.9	14.2	0.7	0.01	13.3	11.3	1.4	0.32
% volatilized	70.9	60.7	—	—	41.1	40.1	—	—
Manure + soil[e]	7.6	8.5	0.7	0.39	18.1	15.9	1.3	0.24

[a] N retention based on ADG, NRC equation for retained energy and retained protein.

[b] N excretion calculated as intake minus retention.

[c] Soil is core balance on pen surface before and after each experiment; negative values suggest removal of nutrient present before initiation of experiment.

[d] Volatilized calculated as excretion minus manure minus soil minus runoff.

[e] Manure + soil corrects what was hauled at cleaning by soil nutrients remaining or removed from pen surface when compared with nutrients on the pen surface before the experiment.

Table 10. Phosphorus (P) balance in the feedlot for the yearling and calf experiments combined across both years (values expressed as kg/steer; 132 d for yearlings and 183 d for calves) (Erickson et al., 2000)

	Yearlings				Calves			
Item	Control	Phase	SE	*P*-value	Control	Phase	SE	*P*-value
Intake	5.83	3.28	0.05	0.01	6.81	4.50	0.07	0.01
Retention[a]	0.87	0.88	0.01	0.82	1.12	1.11	0.01	0.24
Excretion[b]	4.95	2.40	0.05	0.01	5.69	3.39	0.07	0.01
Manure	2.36	2.48	0.13	0.54	6.61	5.55	0.54	0.24
Runoff	0.22	0.11	0.03	0.04	0.06	0.11	0.02	0.28
Soil[c]	0.26	−1.40	0.15	0.01	−1.48	−2.36	0.15	0.02
Difference[d]	2.12	1.21	0.11	0.01	0.50	0.10	0.41	0.52
Manure + core	2.62	1.08	0.15	0.01	5.13	3.19	0.41	0.03

[a] P retention based on ADG, NRC equation for retained energy, retained protein and P.

[b] P excretion calculated as intake minus retention.

[c] Soil is core balance on pen surface before and after each experiment; negative values suggest removal of phosphorus present before the experiment.

[d] Difference calculated as excretion minus manure minus soil minus runoff. These values indicate that not all the P that was excreted is being recovered.

Erickson et al. (2000) and Erickson and Klopfenstein (2001) have conducted mass balance studies to determine the fate of the N and P prior to manure removal. The cattle used were referred to previously in the discussion on phase-feeding. The cattle were fed conventional diets with 13.5% CP and 0.35% P. The phase-fed cattle were fed 11.6% CP and 0.23% P. Calves were fed from November to May and yearlings were fed May to October over 2 yr. Pens had eight steers each and there were 12 pens for each yearlings and calves over the 2 yr.

Excretion of OM by the cattle was calculated from measured DMI and indigestibility measured in digestion trials. Retention of N and P was estimated from actual steer gains and NRC (1996) equations. Runoff was quantified and analyzed for N and P. Soil core samples were taken from the pen surface prior to and at the conclusion of studies (after manure removal). The cores were analyzed for N and P to account for N and P not removed or for soil removal with the manure. Finally, manure was sampled, weighed, and composted.

More OM was excreted by phase-fed than by control cattle (Table 8). About 57% of the OM was volatilized during the summer (yearlings), whereas only 6% was volatilized in the winter (calves).

Phase-fed steers excreted less N than control steers (Table 9). Volatilization was greater (60 to 70%) in the summer than in the winter (40%). When weighted for time of year and cattle on feed at different times of the year, we calculated the average volatilization loss to be 50.8% of the N excreted for both control and phase-fed diets (Erickson and Klopfenstein, 2001). In the summer, phase feeding reduced N intake by 18%, which reduced excretion by 21%. Because more OM was produced and removed as manure, a greater percentage of N was also removed in the manure and volatilization losses expressed as total weight were reduced 32% by phase feeding.

Phase feeding reduced P intake by 51% for the yearlings and 41% for the calves (Table 10). Because the P is not volatilized, it is all recovered in the manure or runoff. Phase feeding reduced P removal in the manure by 59% for yearlings and 38% for the calves. If P had been fed at 0.16% of the diet, which is the level we propose is the requirement, then the reduction in P excretion would have been 65 to 70% compared to the control diet.

Conclusions

The phosphorus requirement for feedlot cattle is low (0.14 to 0.20%). Because corn and corn by-products contain more P than the cattle require, and because all of the P is recovered in runoff and manure, P becomes a distribution problem for cattle feedlots. With current technology, it is not clear how to practically reduce P excretion in feedlot cattle below that provided from corn alone. The current best management practice is to remove all supplemental P.

The excretion of N can be reduced from current levels if the MP system is utilized. There may be too much UIP in corn and corn by-products so that MP is overfed, excess N is excreted, and all of the excess is lost as ammonia from dirt feedlots. Because the protein in high-moisture corn or barley is more degradable, these energy sources can be used to reduce MP supplied and therefore N excreted and ammonia volatilized. Conversely, steam-flaked corn and some by-products increase MP supplies, N excretion, and N volatilization. There is a limit to how much we can reduce ammonia emissions through nutrition. Other means such as alternative waste handling systems may be necessary in order to further reduce ammonia emissions.

Implications

Phosphorus and nitrogen present distribution problems for concentrated cattle feedlots and nitrogen volatilization as ammonia is an air-quality concern. The P requirement is lower than previously believed, but corn and corn by-products have more P than is required, making it difficult to reduce P excretion. The metabolizable protein system allows us to minimize N (protein) fed in many situations but not all. Ammonia volatilization can be reduced through nutrition, but further technology is needed to minimize losses.

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