THE NITROGEN CYCLE IN RUMINANT FEEDING OPERATIONS

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Introduction

Nitrogen (N) use, or abuse, in ruminant feeding operations is continuing to be at the center of a growing concern for potential pollution problems. Nitrogen that is lost from feeding operations in the form of ammonia facilitates vegetative growth in waterways and can be toxic to fish. Additionally, N that is lost to the atmosphere can contribute to particulate pollution of the atmosphere. Proposed Environmental Protection Agency (EPA) regulations target both N and P. Specific to pollution sources, the EPA states that "Livestock operations can cause environmental degradation of surface and ground waters unless their manure is collected, stored, and utilized/disposed of in an environmentally sound manner. Animal manure typically contains nutrients (i.e., nitrogen and phosphorus), pathogens, salts, and heavy metals (e.g., copper). However, animal manure properly spread and used on agricultural lands has many beneficial uses and can provide environmental benefits". Additionally, the EPA states that National Effluent Limitation Guidelines are technology-based effluent limitations that establish a minimum standard of performance for certain categories and classes of point sources. These standards are imposed on facilities through NPDES permits. The effluent limitation guideline for feedlots appears at 40 CFR part 412. These guidelines establish a standard of "zero discharge" to the waters of the U.S. for feedlots to which the guidelines apply".

On the other hand, cattle and sheep feeding systems rely on the competitive advantage of the ruminant—its ability to utilize non-protein N as a source of protein for maintenance and production of foods and fiber. It is this internal N management system that permits ruminants to manipulate the source and amount of N that is presented to the lower gastro-intestinal (GI) tract for survival or production processes. However, the complex processes of N metabolism in the ruminant, and the inherent difficulty in predicting DMI in ruminants, also prevent formulation of simple, straightforward N requirements of ruminants for maintenance, growth, reproduction, and production. The authors have attempted to summarize the state of knowledge on the fate of N in feedlots, and to advance current or futuristic perspectives for managing N in ruminant feeding operations.

State of Knowledge on the Fate of Nitrogen in Feedlots

Nitrogen utilization in the ruminant

Nitrogen is consumed by the ruminant, both as a component of pre-formed protein, and as non-protein N. Depending on the rumen degradability of pre-formed protein, microbial activity may transform up to 80% of rumen degradable protein to microbial protein. Pre-formed protein not degraded by microbial activity may be digested and absorbed in the small intestine in the form it was consumed. Regardless of source, digestion and absorption of protein that bypasses or results from microbial activity in the small intestine are relatively high (80%, NRC, 1996).

Therefore, quality of protein reaching the small intestine determines the fate of absorbed amino acids in the body.

Nitrogen arising from de-amination of pre-formed protein in the rumen, or from intake or recycled N (in the form of ammonia) is largely absorbed by the liver, and, to a great extent, converted to urea (Reynolds, 1995). Alterations in energy, rather than N, intake, organic matter digestion, microbial protein synthesis, and tissue metabolism are detected at the level of the liver, whereby the liver manipulates absorption and release of ammonia (Reynolds, 1995). For instance, liver urea N production resulting from a 5-day continuous infusion of ammonia was twice greater than liver ammonia removal from the gut (Lobley et al., 1995). Therefore, it is the liver that integrates N metabolism and determines the fate of N in the ruminant body. Ammonia incorporated into urea that is not required by the ruminant body is released in the urine. It is largely this ammonia that is the source of concern for potential pollution, as it is highly water-soluble and volatile at most environmental conditions.

Nitrogen released back into the environment via urine and feces (fecal N represents undigested intake or microbial protein, and protein sloughed off from GI tissues) may be transferred to various environmental pools (soil, water or air). Depending on environmental conditions and manure handling and storage, manure (the composite of fresh and old feces and urine, moisture from precipitation, bedding, and wasted feed) N can either be retained in the manure for land application, released into the atmosphere as ammonia, or lost in liquid runoff or leaching into the ground.

From a systems perspective, other N sources must be accounted for in a feeding operation: N in bedding, N in soils (unsurfaced lots), N deposited by wind or precipitation. However, outside of N in bedding and quantifying N in unsurfaced lots (as a baseline measurement between feeding groups), contributions by the other sources are relatively small (1.4% of N in the system; Miller et al., unpublished data).

Nitrogen retention by ruminants

Although a detailed description of N partitioning and processes by which metabolic N is used for maintenance or productive processes is beyond the scope of this paper, it is necessary to remember that maintenance of tissue function may be the single greatest expenditure of N in the body (Geay, 1984). In a ruminant, this need is exacerbated as the vital organ mass is proportionately larger than in the non-ruminant (Geay, 1984). This partially explains why non-ruminant animals are more efficient at retaining intake N. The other reason for this difference in efficiency was alluded to previously.

For the purpose of accounting for N in a feeding system, N retained in the body or in the carcass of ruminants relative to that consumed during a feeding period is a measurement of greater value. From a simple accounting perspective, N not retained in the body must be excreted via urine and feces and dealt with by existing manure management methods or lost to the environment.

In practice, feedlot managers and nutrition consultants formulate diets to meet requirements based on nutritional standards (NRC, 1996) or modifications thereof. Usually, a small "cushion" is either built into the formulation program or added on when making the feeding recommendation. Requirements are derived from complex nutritional studies that have taken years to accumulate and interpret. However, formulating and feeding N to requirements specified in nutritional standards does not guarantee N efficiency, it merely permits achieving some of the potential efficiency of N retention.

Determining what is the upper limit for efficiency of N retention is not easy. Multiple factors make extrapolation of results from studies to the feeding operation difficult. These may include, but are not limited to, age and weight of the animal, plane of nutrition, forage:concentrate ratio, length of determination, energy, protein, and mineral content, form of diet and frequency of feed delivery, previous plane of nutrition, and use of anabolic growth promotants or ionophores.

A statistical analysis of results from metabolism and feedlot balance studies was conducted by the authors. Data included in the initial regression analysis incorporated results from 15 studies where beef calves or yearlings (average BW during study ranging from 400 to 1000 lb) fed diets containing between 42 and 65 Mcal NE_g/cwt. Steers involved in feedlot balance studies were implanted with anabolic steroids. Because of difficulties with conducting metabolism studies, data are inherently confounded with methodology: results from studies with lightweight cattle are from metabolism studies, and those from studies with heavyweight cattle are from feedlot studies. However, N retention and excretion data fitted well across light- or heavyweight cattle (or methodology). Nitrogen retention is not (R^2 = .04; P = .46) related to BW while N excretion is highly correlated with BW (Figure 1). This reveals that the efficiency of N retention decreases with BW (e.g., a relatively similar amount of N is deposited at a greater N intake). Although data used to derive these observations are influenced largely by diet and intake achieved in each study, the trend for increased N excretion appears to be independent of the study plotted (Figure 1).

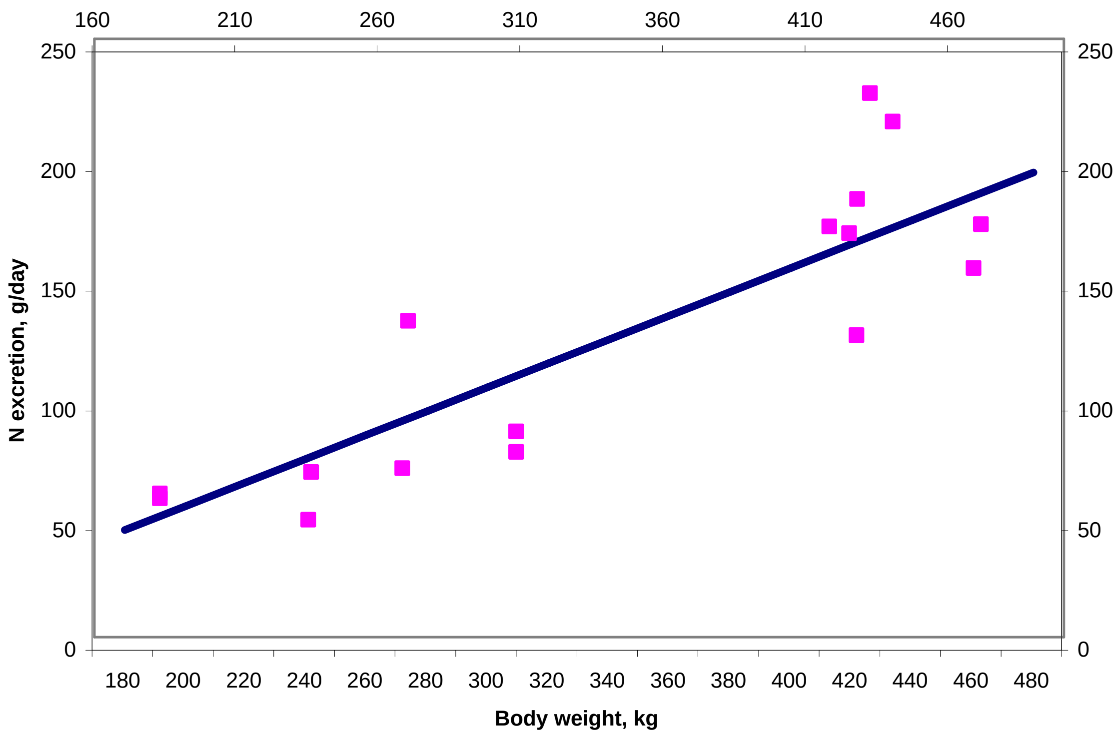

Figure 1. Regression of N Excretion on BW (N excretion, grams/day = -45.00 + .4983BW, kg; R^2 = .76; P < .05) is Depicted with a Scatter Plot of N Excretion at Various BW Obtained from Data Reported in the Literature

Interpolating these results to BW commonly observed in feedlots demonstrated that N excretion for a calf (188 days on feed, DOF) or yearling (153 DOF) averaged 70 or 63 lb/head during the entire feeding period. Values obtained by applying Model I of the NRC (1996) nutrient requirements for beef cattle model for the same interpolation were 73 or 61 lb/head, respectively for calves or yearlings. Thus, regardless of method, N excretion from ruminant feeding systems is a significant contributor to N pools in the environment (approximately 80% to 90% of N intake). Therefore, efforts to optimize N intake relative to productive processes within the context of a system and to manage N excreted in the environment must become areas of focus for nutritionists, environmental engineers, soil scientists, and agronomists.

A discrepancy was identified between estimates of N retention based on metabolism studies and those based on feedlot balance studies. Nitrogen retention measured in metabolism studies using diets containing > 42 Mcal NE_g/cwt and DMI greater than 2% of BW ranged between 16.3% and 40.9% of N intake while that obtained in feedlot balance studies ranged between 10.3% and 12.8% of N intake, respectively. Four factors differed between these studies: methodology to determine N retention, age, BW and duration of study. Without feedlot balance studies conducted in young calves, or metabolism studies conducted with cattle of feedlot age and BW, it is impossible to determine if methodology to determine N retention is a significant factor in observed differences. However, Miller et al. (2001a) conducted a feedlot balance study with steer-calves weighing an average of 941 lb for the duration of a 144-day finishing study. Nitrogen balance was measured either using DM digestibility, and urinary N output (at 56 and 126 DOF) or a model that predicted protein deposition (Owens et. al., 1995) from BW and ADG. Nitrogen retention as a percentage of N intake was 30.3% or 19.5% using the metabolism study or modeling approach, respectively. On the other hand, when applying the NRC (1996) model to predict N retention of steers for which N retention (51.3 grams/head/day) was measured in a metabolism study (Cecava and Hancock, 1994), N retention (34 grams/head/day) as a percentage of N intake was calculated to be 24.8% instead of 37.4% as measured in the metabolism study. Thus, it appears that application of the NRC (1996) model to predict N retention of feedlot steers may, in some instances, underestimate this value. Further studies to devise nutrition or management practices to reduce N load on the environment must be based on determining actual values of N retention to facilitate evaluation of these practices, and to establish application of manure management practices consistent with actual N excretion values.

An attempt to compare values calculated by an N retention model (NRC, 1985, 1996) or measured directly in a sheep feedlot model was recently made (Miller et al., 2001b). Nitrogen intake, N retention, N in manure, N volatilization, and N in runoff were measured directly on 12 pens of sheep (initial BW, 57 lb) fed for a 133-day period. Dry matter intake and CP content of the diet measured on weekly samples were used to determine N intake. Serial slaughter of one sheep/pen at the beginning, middle and end of the study was used to measure N retention. Nitrogen in manure was measured as the difference in N content between all clay hauled in clean before the trial began and all clay hauled out when the study ended. Nitrogen in runoff was measured after each significant precipitation episode using a catch basin. Nitrogen deposited by wind erosion or precipitation was measured on blank portions of the pen inaccessible to sheep. Nitrogen volatilized into the atmosphere was estimated by subtracting all other pools of N from N intake and N in the original clay. Using these procedures, N retention (13.7% vs 14.2%) and excretion (86.3% vs 85.8%) as percentage of intake were similar between direct measurements and modeled results. Therefore, at least for estimating sheep N use the NRC (1985, 1996) model appears to be accurate.

The fate of excreted nitrogen

Manure management can have a large impact on the amount of nutrients that are retained in the manure and utilized in other production systems. The element that is lost the easiest and to the greatest extent is N (Koelsch and Lesoing, 1998). Nitrogen can be made unavailable to cropping systems via volatilization of ammonia, nitrate leaching or runoff. Factors that affect N loss include temperature, moisture, pH, aeration status, rainfall, and C:N ratio, along with amount of time between application of the manure and incorporation into the soil.

Manure can be a valuable resource for crop production if managed and marketed properly. This is because manure is a good source of organic matter, N, P, K, Zn, Mg, S, Na, Cu, and other minor nutrients (Eghball and Power, 1994; Deluca and Deluca, 1997). Annual or biennial manure or compost application resulted in corn grain yields similar to those obtained with chemical fertilizer application (Eghball, 2001).

However, manure and associated wastes can also be a source of water, air, and land pollution. Along with the beneficial nutrients, manure can also contain excess concentrations of nitrates, microorganisms, salts, pathogens, and greenhouse gases. A study of nutrient balances in Nebraska feedlots (Koelsch and Lesoing, 1998) demonstrated that size of livestock operation (greater N and P imbalance with greater animal units) provided only limited explanation for N imbalances (N inputs from feed, animals, fertilizer, legumes, and irrigation, and managed outputs from cattle, crops and manure). Degree of integration of the livestock operation (expressed as crop acres/animal unit) did not explain differences in N imbalance. The authors suggested that other farm characteristics or management practices must be further investigated to determine what farm/feedlot factors affect nutrient (especially N) imbalances. Seasonality may account for some differences in N volatilization. Nitrogen recovered in manure was greater (lower N volatilization occurred) during winter than summer feeding periods (Erickson et al., 1999, 2000; Zehnder et al., 2000).

Approximately 50% of the N excreted by the animal in the feedlot will be gone before that manure leaves the feedlot (Eghball and Power, 1994). Then, by the time the manure is spread and incorporated it can lose another 50% of the remaining N (Eghball and Power, 1994). Therefore, as little as 25% of the N excreted by the feedlot animal is available for use in the field by the growing crop. This value was confirmed by preliminary data from Miller et al. (2001b). In their calculations on feedlot mass balance, Koelsch and Lesoing (1998) reported N losses from farming systems with 540 to 20,650 animal units ranged from 47% to 77%. Volatilization of N after manure is applied to cropland will increase as soil pH increases above 7.0, soil and/or atmospheric temperature increases, wind velocity increases, depth of incorporation into the soil decreases, rate of N applied increases, and soils contain a higher amount of calcium carbonate.

Nitrogen contents of beef manure were 3.1%, 4.2%, 2.7%, and 1.9% of total solids when collected from scraping under slotted floors, in pits or tanks, bedded units, and open feedlots, respectively (Eghball and Power, 1994). This finding indicates that the greatest amount of N is lost to the environment from open feedlots and bedded feedlots while the least amount of N is lost from slotted floor units and pits or tanks. Thus, management of manure for cattle housed in open lots is essential. A manure-soil seal is formed within a short time after pens are stocked. For as long as cattle occupy the pens, this seal prevents N leaching into the ground. Therefore, when open lots are scraped care must be taken not to break this seal. Also when pens are abandoned or unoccupied for an extended period of time, it is important to remove this layer to prevent N leaching into the ground (Harrison, 2000).

Demmers et al. (1997) reported variations in annual ammonia emission for various types of cattle in several housing types. Ammonia emission from beef cattle bedded on straw was lower than that from beef cattle housed on a slurry-based system (6.6 vs 10.3 lb NH_3/animal unit/year). In the same study, ammonia emission factors were also reported for dairy in slurry-based housing with either a scraped solid floor or a fully slatted floor of 13.2 and 18.3 lb NH_3 /animal unit/year.

<u>Integration of nitrogen use and transfer in ruminant feeding operations</u>

Feedlot mass balance studies conducted at the University of Nebraska and the University of Minnesota have demonstrated with cattle and sheep that N retention over a finishing period vary between 10% and 15% of N intake. A simulated cattle feedlot using sheep fed to slaughter weight (133 d) was used to determine values for each N input, transfer and output. Application of these results to a cattle feedlot is shown (Figure 2).

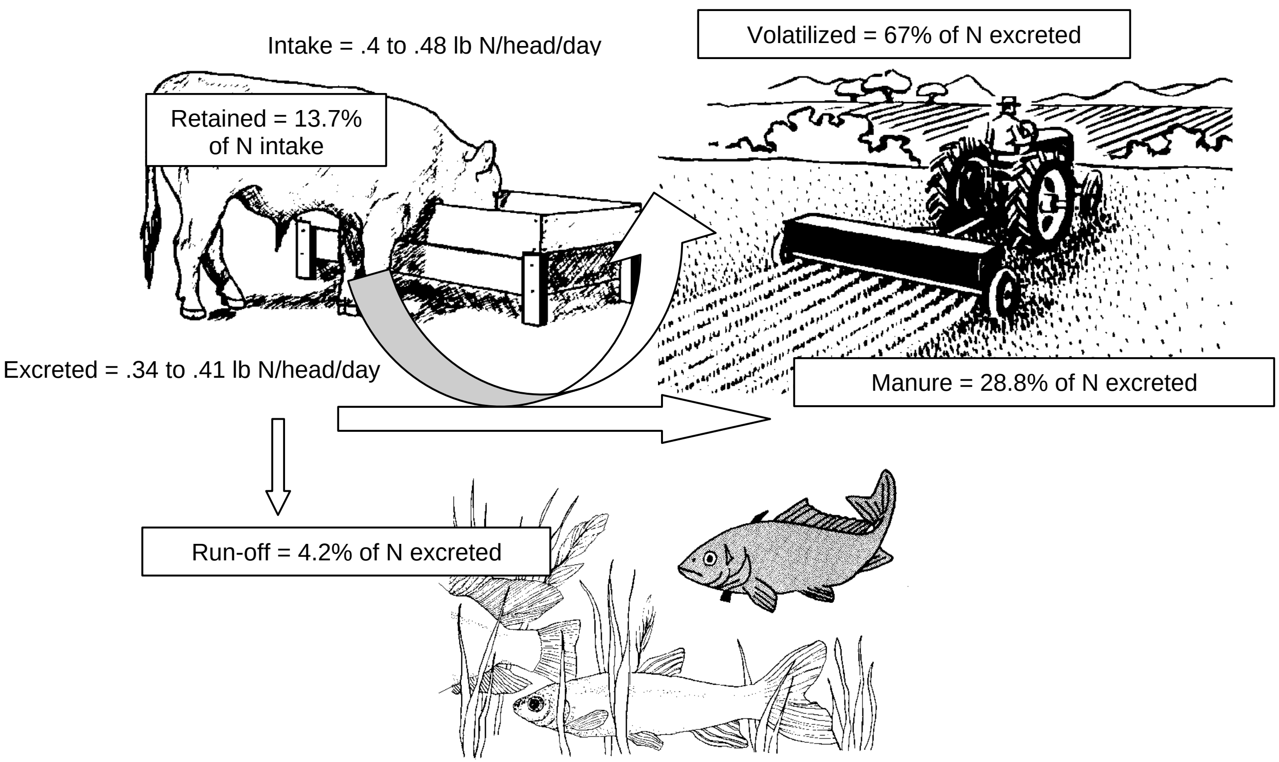

Figure 2. Proposed Fate of Nitrogen in a Feeding Operation (Miller et al., 2001b)

Efforts to improve retention so that it reaches the higher end of this range, or higher, are underway at various universities. However, of the excreted N (85% to 90% of N intake), between 60% and 80% is likely lost to the environment—mostly through volatilization (65% to 75% of N excreted) and runoff (3% to 5% of N excreted).

Managing Nitrogen in Ruminant Feeding Operations

Managing N inputs into a feedlot system have not been areas of focus for feedlot managers or consulting nutritionists. However, as pressure to become environmentally accountable mounts, feedlot managers, nutritionists and researchers are evaluating ways that N can be managed in the feedlot for reduced environmental impact. From a ruminant metabolism perspective, managing N input is inherently dependent on managing nutrient (energy and protein) content, use and frequency of bedding, DMI, DOF, ionophore and growth promotant use; therefore, day-to-day decisions made by feedlot managers and consulting nutritionists have a large impact on N presented to the animal. Another obvious aspect of managing N in the feedlot is to manage N output from the animal and system.

Managing N inputs

As indicated earlier, decisions to purchase feeds, balance rations for a certain performance, feed at a determined DMI level for a certain length of time while using certain ionophores or growth promotants inherently determine a level of managing N input into the system. Thus, astute feedlot manager and consulting nutritionists recognize that they can manipulate these factors even in small increments and have a great impact on the amount of N excreted into the environment.

Today, the feedlot industry is largely dependent on use of high quality grains and byproducts, health management products, implants and ionophores, and an advanced knowledge of the interactions between nutrient content, nutrient level and performance of each diet fed. This approach has allowed the industry to enhance N retention and reduce N excretion, even when that was not the primary goal. Improvements in N retention and excretion relative to control diets are listed in Table 1.

Table 1. Impact of Various Factors that Affect N Utilization in Feedlot Cattle

Factor tested	Average (% of control) impact on: N retention	N excretion	References
Protein sources	7.3	-4.4	Cecava and Hancock, 1994
Growth promotants	23.4	-5.1	Various[a]
High-energy diets	3.4	-6.6	Various[c]
Protein balance	-.2	-15.1	Various[b]

[a]Griffiths, 1982; Lapierre et al., 1992; Hunter et al., 1998.
[b]Erickson et al., 1998, 1999; Cooper et al., 2000; Miller et al., 2001a.
[c]Bierman et al., 1996; Erickson et al., 2000.

Improvements in N retention and excretion due to use of high-energy diets ranged from 1% to 5% and .4% to 17%. Use of growth promotants had a larger impact on N retention and excretion. Improvements in N retention and excretion due to the use of growth promotants averaged 23% and 5%, respectively. In a climate of increased, yet misguided, public concern for the use of grains, feed additives and growth promotants in the feedlot industry, it is perhaps necessary to highlight the impact these animal production practices have had on N utilization by U.S. feedlots. On the other hand, if public perception prevails, and ruminant feeding systems become free of conventionally available grains (or low-grain-based), and free from additives and growth promotants ("organic-based"), N excretion would likely increase by 20%. Therefore, the public debate on these issues must incorporate the absolute impact of conventional vs "organic" systems on the environment.

Recently, researchers at various universities have focused on alternative methods to reduce N output from feeding systems. With the advent of a model to predict protein requirements of feedlot cattle based on energy supply, degradable intake protein (DIP), and rumen metabolism (NRC, 1996), many research projects re-evaluated protein requirements of feedlot cattle and N utilization in feedlot systems. Application of methodology outlined in NRC (1996) to match undegradable intake protein (UIP) and DIP with metabolizable protein (MP) and DIP requirements resulted in little or no change in N retention while N excretion was reduced from 9% to 22% (Table 1).

Results from Cecava and Hancock (1994) confirmed that the value of protein provided to growing cattle determines to a great extent the efficiency of N retention. They observed that combinations of DIP and UIP led to greater (7.2%) efficiencies of N retention, and lower N excretion (4.4%) compared to urea-based supplements. Similarly, urea, as the sole supplemental protein source, was not as adequate to sustain growth and N retention as combinations of urea and soybean meal, blood meal, meat meal, or corn gluten meal, or a combination of corn gluten and meat or blood meal (Stock et al., 1981). Cattle in both these studies were < 310 kg.

Thus, feedlot managers and consulting nutritionists can utilize the NRC (1996) software to predict and match UIP and DIP over a feeding period. Urea addition to dry rolled corn diets improved DIP balance, thereby improving ADG and feed efficiency (Lardy et al., 1998). A slight deficiency in DIP was detected in the diet containing urea to bring overall diet CP to 12%, yet no additional improvements on gain or feed efficiency were demonstrated when urea was added to the diet so that overall CP increased to 13.5% or 15%. These authors outlined a procedure to utilize NRC (1996) to formulate diets for feedlot cattle to meet MP and DIP requirements.

Effective application of results of modeled MP and DIP requirements under practical conditions is not easy and requires some knowledge of historic DMI and performance of cattle for which applications are being made. Additionally, feedlot managers may be required to closely monitor intake and CP content of diets so that determinations may be made to alter CP content and UIP and DIP supply according to stage of growth.

Various methods have been applied, most of them successfully, to limit CP intake in accordance to MP and DIP requirements while conducting these initial studies. However, limiting N intake to match requirements may be an easier task than attempting to limit P intake. Studies with yearlings conducted in Nebraska have used high-moisture corn to reduce the possibility of overfeeding UIP (the need for UIP in yearlings is lower) while those with calves have used dry rolled corn to begin with, switching over to high-moisture corn as cattle matured (Erickson et. al., 1998; 1999; Cooper et al., 2000). In these studies, diet composition was fixed once cattle reached a certain BW or DOF. In studies by Cooper et al. (2000) or Miller et al. (2001a) diet or supplement offered were phase-fed to meet NRC (1996) requirements for UIP and DIP or a set CP intake (2.75 lb/head/day), respectively. The hypothesis tested in the latter study was that a CP supply of 2.75 lb/head/day was sufficient to permit maximum growth and efficiency in steers under an aggressive implant strategy. In both studies, phase-feeding resulted in gains and feed efficiencies equal to, or superior to control diets balanced for > 12.7% CP—N excretion was reduced 8% to 22% of N intake. Phase-feeding of diets or supplements will be necessary to achieve N intakes consistent with N requirements; yet, knowledge of cattle and their DMI are also required to effect diet or supplement changes in a timely fashion.

Managing N outputs

Current manure management options for an open-lot feedlot system are outlined in Figure 3 (Ritter and Scaraborough, 1995). When reviewing this flow chart, management practices that are conducive for greater N captures involve use of lined basins or tanks, roofed manure storage, and incorporation of manure into ground. Nitrogen capture is also greatest from slurry and liquid manure fractions. Anaerobic digestion is also presented as an alternative to enhance N capture.

Several ideas have been devised to utilize more of the N that is produced by the feedlot animal. Composting can be an economical alternative that reduces biomass in the manure, but retains most of the N, therefore, increasing the concentration of N that can be used as fertilizer or mulch. The amount of N captured while composting can be variable and is dependent on the conditions during the decomposition of the material. Increasing composting period and duration of anaerobic activity will increase N loss, while pH, and material bulk have little effect on N capture in compost (Eghball and Power, 1994; Deluca and Deluca, 1997). The moisture content of the composting manure had little effect on N loss; excessive moisture will reduce oxygen and increase the potential for anaerobic decomposition and runoff (Lesoing et al., 1996). Under these conditions, runoff from the composting pile may increase N loss. Dry material prevents initiation of composting. Ideal material for composting should range from 40% to 65% moisture, have a carbon to N (C:N) ratio of 20:1 to 40:1, and a temperature range of 110 to 150 °F (Lesoing et al., 1996). Low C:N ratio leads to ammonia loss as the carbon is consumed before the N is stabilized (Lesoing et al., 1996). Losses of N from compost range from 15% to 40% of manure N. Results from a study where manure from cattle fed diets formulated using 41.5% wet corn gluten feed, 7.5% roughage, or 0% roughage (Lesoing et al., 1996) was composted indicated that 23.5% to 36.1% of the manure N was lost during composting.

Research has been conducted to develop practices to reduce N loses (Eghball and Power, 1994). However, there has yet to be substantial research on whether these practices are practical in reducing N loses in beef cattle feeding operations. Some of the ideas tried have been to increase frequency of pen cleanings, adjusting bedding level or type, and use of additives to reduce volatilization and de-nitrification. De-nitrification inhibitors, acidifying materials such as phosphoric acid, pyrite, ferrous sulfate, and sulfur and precipitants or stabilizers have been some of the additives used.

Advanced manure management systems retain manure in closed systems for biogas, protein, and fish production. The system contains an anaerobic digester, a facultative lagoon, and several aerobic lagoons. Anaerobic digestion of cattle waste is facilitated for biogas production for use as an energy source. A facultative lagoon permits production of micro-algae and of single-cell protein. Aerobic lagoons are used for development of micro-algae and other aquatic plants to be harvested as protein, or for culture of finfish (Harrison, 2000).

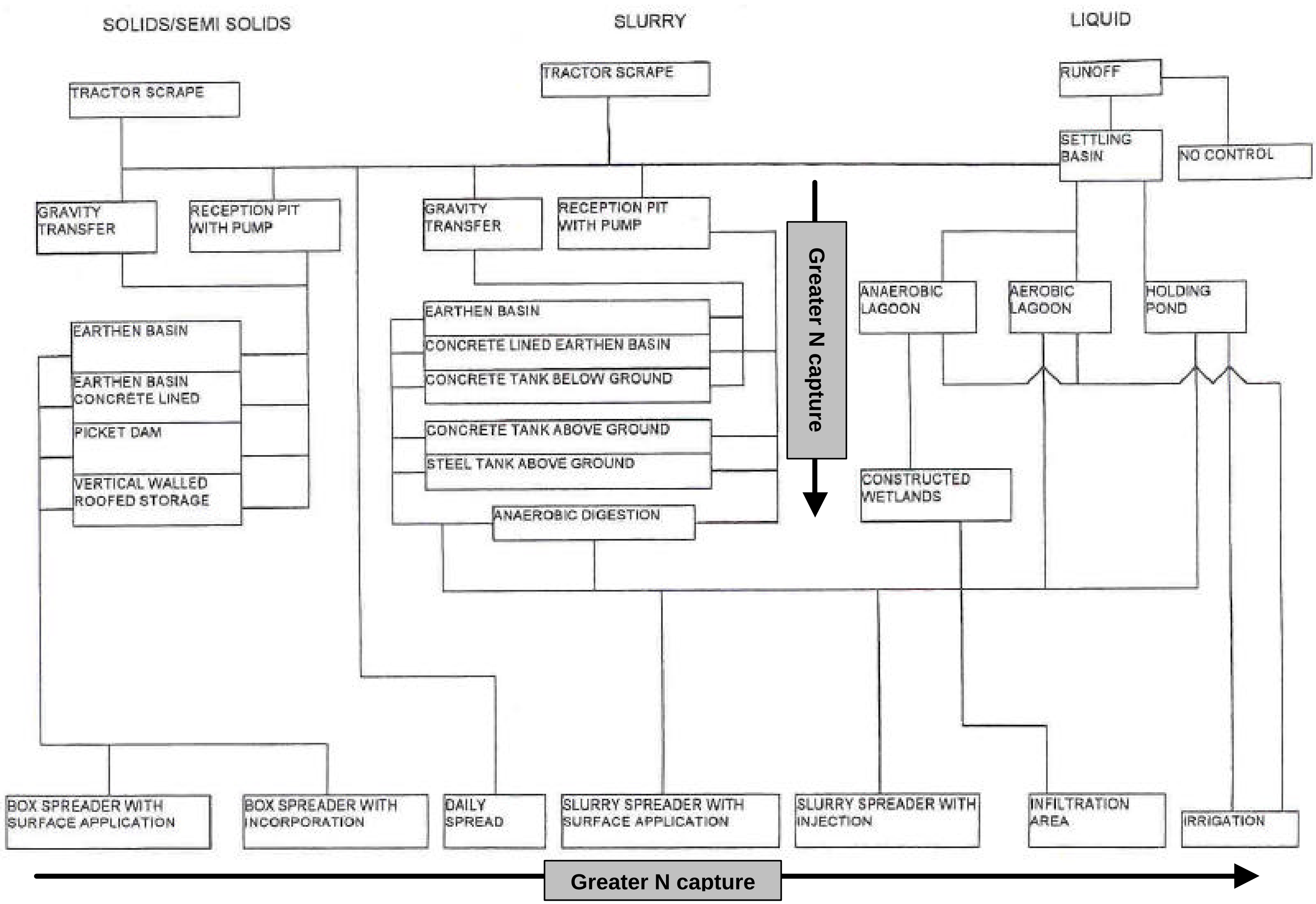

Figure 3. Manure Management Alternatives for Beef Cattle fed on Open Feedlots (Ritter and Scarborough, 1995)

Conclusions

Nitrogen retention by ruminant feeding systems accounts for a relatively small proportion of N intake. Therefore, ruminant feeding systems excrete large amounts of N that must be managed so that either 1) lower N enters the system or 2) a greater amount of N is captured from that which is excreted, or both. Increased regulations to reduce nutrient loss from feeding operations will pressure feedlot managers and consulting nutritionists to manage N intake by reducing or matching N intake to N requirements, and by managing manure so that the greatest amount of N is captured from that which is excreted. Public debate over the use of growth promotants and feed additives must include the fact that these technological advances have permitted up to 20% reduction in N output from cattle feeding operations. Further research to devise methods by which efficiency of N retention in the animal or capture by manure management systems is required immediately to facilitate sustainability of animal feeding operations.

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