AMMONIA EMISSIONS FROM DAIRY PRODUCTION SYSTEMS

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Summary

Environmental increases in the reactive forms of N have occurred over the 20th century partly due to anthropomorphic activities associated with combustion of fossil fuels, urbanization, and intensification of agriculture. Increased reactive forms of N in aquatic systems has resulted in eutrophication and acidification. This has resulted in higher nitrate concentrations in ground water. Atmospheric ammonia has increased 2.5 μm particulates which increase haze, human health risks, and green house gasses. Increases in atmospheric ammonia lead to acid rain and subsequent impact on water systems and forests. The effects on plant and tree growth are not all negative, as increased deposition of ammonia can stimulate forest and plant growth. Environmental reactive N is a major concern of the U.S. Environmental Protection Agency (EPA) and three offices have major efforts underway to understand and control N: Water, Air and Research and Development.

Inventories accounting for sources of atmospheric N indicate that animal production systems are the primary source of atmospheric reactive N in the form of ammonia. Dairy production systems primarily contribute to ammonia emissions through excretion of waste N as urea in urine. Urease activity in feces is high and rapidly converts urea to ammonia after excretion. Conversion of urea to ammonia is temperature and pH dependent. Volatilization is also dependent on depth of fluid column and agitation of storage structures. With open lots and housing systems developed for improved ventilation for animal health, ammonia from urea is rapidly volatilized into the atmosphere from many housing systems. Furthermore, degradation of organic nitrogen in animal waste to ammonia can occur during storage. Ammonia may be also lost from storage structures and land application of slurry. Even during grazing, at least 8% of urinary nitrogen is volatilized.

A typical dairy cow producing 27 kg of milk may consume 417 g of N and excrete 127 g of N in urine, 30% of intake. Urea may comprise 86% to 90% of urinary nitrogen. Thus 109 g of N may volatilize daily from this cow. In dry cows and heifers, 39% to 50% of intake nitrogen may be lost each day in urine and be subject to volatilization. Erickson has estimated that 50 to 63% of intake N may be volatilized from beef feed lots. To control ammonia emissions, rations must be formulated to optimize rumen microbial capture of N in bacterial protein and reduce over feeding of protein. In addition, rapid collection of urine and separation from feces can minimize contact time and reduce ammonia losses from barns. Capping lagoons and pits and injection of slurry at time of land application at time of high crop uptake can reduce losses from field application of animal wastes. Acidification of slurries or alkalizing alley ways may also reduce ammonia volatilization. Ammonia losses from dairy and beef facilities cannot be reduced to zero, but they can be minimized and will need to be to meet EPA air quality standards.

Introduction. Nitrogen use in agriculture both as fertilizer in agronomic systems and as protein supplements in animal systems has increased productivity and benefited mankind over the last 150 years. However, forms of reactive N (ammonia – ammonium ions, nitric oxides, nitrates and nitrites, nitrous oxides) have increased in air, land and water systems with negative effects (Anon, 2002; Cowling et al. 2001). Increased loadings of N into aquatic systems has increased eutrophication and acidification, with negative effects on aquatic plants and fish. Atmospheric deposition of reactive N on land has stimulated tree and plant growth, but has also decreased biodiversity and acidified soils. Atmospheric loadings of reactive N increase haze, 2.5 μm particulate, green house gasses, and acid precipitation. Ammonia emissions are a major concern and there is international momentum to set policy measures to reduce these emissions (Cowling et al. 2001). According to US EPA national air pollutions emissions trends report, ammonia emissions come predominantly from agricultural sources, primarily from livestock.

Ammonia emissions primarily arise from animal waste. Nitrogen in excreta can be converted to ammonia through bacterial degradation, primarily the conversion of urea to ammonia (Muck, 1982). N content of dairy cattle excreta in directly influenced by N intake (Wilkerson et al., 1997). Historically, NRCS was the governmental agency with the primary responsibility to oversee the collection and land disposal of animal waste, and the USDA through the National Research Council was the agency responsible for suggesting feeding standards for dairy and beef cattle of all age classes. However, due to the intense concern over N pollution, the EPA is becoming the major agency with oversight on N in animal waste, and ultimately may have indirect control over N in animal feeding. The EPA is the coordinating agency establishing the national standards for nutrient management programs in concentrated animal feeding operations with cooperation from the NRCS and USDA. Therefore, dairy and beef operators need to be aware of factors within their operations that can contribute to ammonia emissions.

Protein Feeding Systems. Both the Beef and Dairy NRC publications (NRC, 1996; 2001) utilize metabolizable protein systems to define requirements for growing, and lactating cattle. Metabolizable protein is calculated as the sum of absorbed true protein from the small intestine which is derived from digestion of feed protein that has escaped rumen degradation and rumen bacterial cells that have passed from the rumen. Bacterial cells are produced from fermentation of organic matter in the rumen.

The core of metabolizable protein systems in ruminants is the prediction of the extent of rumen degradation of feed proteins and the amount of microbial protein produced for any given diet and feed intake. NRC Dairy (NRC, 2001) assumes the yield of bacterial crude protein (BCP) is 130 g/kg of TDN (discounted) intake. Dietary rumen degraded protein (RDP) is 1.18 x MCP yield. When RDP is less than 1.18 x RDP then BCP yield is calculated as .85 x RDP supply. The Beef NRC uses a value of 13 g/100 g of TDN to predict BCP synthesis when forage comprises over 40% of the diet. When forage is less than 40% of the diet, then BCP synthesis is reduced 2.2% for every 1 percent decrease in forage effective neutral detergent fiber (eNDF) less than 20%. The dairy NRC considers BCP to contain 80% true protein and 20% nucleic acid N. True protein is considered to be 80% digestible, thus 64% of BCP is absorbed by the cow.

Rumen degraded feed protein supplies N necessary to support BCP synthesis. Some N may be provided from urea recycling in saliva, thus it may be possible to slightly under feed RDP and still maintain BCP yields. However, RDP above that needed for BCP is absorbed as ammonia from the rumen and ultimately is converted to urea by the liver and excreted from the body in urine and milk.

Requirements for MP are the sum of protein necessary to support maintenance, lactation, growth and gestation. A factorial approach is used to determine requirement. Each physiologic process is associated with an efficiency of utilization. The conversion of MP to net protein in product releases N from tissue metabolism, which eventually is lost as urea in urine and milk. Provision of optimal blends of amino acids may enhance production efficiency. In dairy cows, the requirement for MP for production is milk true protein yield divided by 67%.

When supplies of RDP and rumen undegradable protein (RUP) are balanced for milk production, plasma urea will fall within a specific range for a group of cows (Roseler, et al. 1993). In addition milk urea was as useful as blood urea to monitor protein status (Baker, et al. 1992; Roseler, et al. 1993). Urea moves into milk via passive diffusion from blood and rapidly equilibrates with blood values (Baker et al., 1992). Based on work by Baker and Roseler, we have previously proposed that the mean optimal urea values for a group of cows would fall between 10 to 14 mg/dl and 95% of the individual cows in the group would range +/- six units from the mean milk urea nitrogen (MUN) value (DePeters and Ferguson, 1992). The minimum value of 10 mg/dl agrees with Hof et al., and represents the minimum MUN value below which rumen available N may impair performance (Hof et al., 1997). However, with wide spread use of MUN testing available from DHIA centers and milk processing plants, some very high producing herds are able to support production with mean MUN values between 8.0 to 10.0 mg/dl.

Higher values of MUN would be associated with reduced efficiency of protein utilization and would be wasteful. Jonker et al. (1998) proposed a model to assess N intake from MUN and provided guidelines for expected MUN values based on milk production and cattle grouping. Therefore, MUN serves as a useful tool to assess protein feeding efficiency (Hof et al., 1997; Jonker et al., 1998). In nonlactating cattle, particularly beef animals, blood samples would need to be used to assess urea-N concentrations, but the same principals would apply.

Urinary Nitrogen. Forms of N in urine include urea, creatinine, allantoin, uric acid, ammonia, α-amino nitrogen, peptide N and hippuric acid. The major N sources are urea, creatinine and purine derivatives, allantoin and uric acid. Of the purine derivatives, allantoin is the major constituent found in cattle urine. By far the major N component in urine is urea. In cattle consuming a similar ration the urinary urea-N concentration ranged from 185 mg/dl to 1250 mg/dl with a mean of 697 mg/dl (sd 252 mg/dl). Creatinine ranged from 11.0 to 78.2 mg/dl with a mean of 77.7 mg/dl (sd 35.2). Creatinine contains 33.6% N on a weight basis, therefore this represented 26 mg/dl N from creatinine. Nitrogen from urea in urine is about 25 times the amount of N from creatinine. Urine contains a small amount of ammonia, which is excreted as a urinary buffer. These cows had .10 mg/dl to 9.43 mg/dl ammonia in urine with a mean of 1.97 mg/dl (sd 1.95). Urea-N may be 92% of N in urine, creatinine 2% and other nitrogenous compounds including ammonia, 6% of urinary N. Diet will influence the urea excretion to a major extent. Creatinine excretion is relatively constant and is a function of body weight (Ganong, 1999).

We sampled 275 bloods and urines from 91 cows. Samples were collected monthly across one year. Cows were on different diets through out the year. Mean values for plasma urea –N and creatinine were 12.6 mg/dl (sd 4.2) and 1.05 mg/dl (sd .2), respectively. Urinary urea-N and creatinine were 705 mg/dl (sd 234) and 92.0 (sd 34.7), respectively. Urinary creatinine and urinary urea were inversely related ($r=-.276$, $p<.0001$). High concentrations of creatinine tended to occur later in lactation, when cows had lower urinary urea. Urinary creatinine was independent of dietary CP content but was associated with plasma creatinine ($r=.299$, $p<.0001$). Urinary urea was correlated with plasma urea ($r=.151$, $p<.01$) and dietary CP content ($r=.136$, $p<.05$). Our main interest in this trial was to monitor urea and assess its loss from the dairy barn through out the day.

Baker (1992) observed that as urea-N was infused intravenously, 95% of the infused dose was collected in urine and 5% in milk. MUN could serve as an indicator of urea-N excreted in urine. Jonker et al. (1998) observed a direct relationship between MUN and urinary output. Smits et al. 1995 found that urinary nitrogen excretion was dependent on protein in the diet. Urinary urea is rapidly broken down to ammonia nitrogen when in contact with bovine feces due to urease enzymes present in bacteria in feces (Muck , 1985). The rate of ammonia production was temperature and pH dependent. With temperatures above 15 ^{o}C most urea-N was converted to ammonia. At temperatures above 20 ^{o}C, additional organic N was converted to ammonia in manure. Therefore, urinary urea-N as a minimum represents what may lost from a dairy or beef facility as volatile ammonia. MUN would serve as a predicator of potential ammonia losses.

Ammonia Volatilization. Bovine feces is rich in urease (Muck, 1985). Urease activity was influenced by pH and temperature. Optimum activity was observed when pH was between 6.8 to 7.6 (Muck, 1985), which is typical for cattle feces. Warm weather increased the rate of ammonia production from urea, particularly with temperatures above 15 ^{o}C. This means substantial losses of ammonia may occur from a dairy facility and open beef feed lots in temperate months of the year.

Assuming all urinary nitrogen may volatilize, we (Ferguson et al., 2001) estimated potential losses from a typical Pennsylvania dairy farm using data from Dou et al. (2001). For a farm with 69 lactating cows, 4.62 tonne/year of ammonia would be volatilized. This would represent 30.9 kg/animal unit/year. This is 32% of N intake in feed. Voorburg and Kroodsman (1992) reported a value of 1 kg of N per month per cow lost from Dutch housing facilities, which would represent 12 kg/cow/year. This is lower than our estimate, possibly due to different protein feeding or manure handling in the Dutch situation.

To more closely assess these losses, we have monitored N flow at the Marshak Dairy over 2000 and 2001. Monthly samples of feed, milk, feces, urine, flush water, and blood were collected from cows at the Marshak Dairy, University of Pennsylvania, School of Veterinary Medicine dairy facility. The Marshak Dairy is a green house free stall barn, with space for 200 cows. Alleys are cleaned by twice daily flushing with recirculated lagoon water. Currently the herd is composed of 135 milking cows. Dry cows are housed in a separate facility. Cows are milked twice a day, housed usually in four to five groups, and fed a total mixed ration.

To monitor N flow, we collected samples of flush water from the top of each alley at start of flush and at the bottom of each alley and at the collection pit. Solids are separated by conveyor and these were sampled after separation. Urine and fecal samples were collected for three sequential days each week from a random sample of cows in each group and composited for daily analysis. Samples were acidified on collection. Feed and fecal samples were analyzed for DM, CP, ADF, NDF, starch, lignin, fat, and minerals. Ammonia content of feces was also analyzed. similarly analyzed for the Urine and blood samples were analyzed for ammonia, urea, creatinine and potassium and phosphorus.

Table 1 presents mean values on a dry matter basis for feed and feces for the main groups of cows in the barn over the year. Table two presents the values for volatile losses if all the urea-N and ammonia were volatilized from the dairy. Twenty four to 29% of feed N was lost as ammonia in the lactating groups and 46% from the heifer group. Table 3 presents the urine and flush data for each group. Despite high concentrations in urine, little urea-N was collected at the bottom of each alley after flushing. Ammonia concentrations increased in bottom flush fluid, representing some collection of ammonia from alleys. In June – October no urea was collected in flush liquid in bottom of alleys (data not shown) and ammonia concentrations increased. Months when mean temperature were above 15 ^{o}C urea at the bottom of flush collection was zero. This agrees with Muck (1985). The mean volatile loss of N was 27% (6% sem) of feed input across the year based on collection of liquid at the separator. On a daily basis, the number of cows in the barn was 146.4; mean feed N each day was 79.2 kg; mean volatile N loss was 21.6 kg/day. This represents 53.8 kg/cow/year of volatile N.

Erickson et al. (2001) found using a mass balance approach on feedlot yearling steers that 63.1% of feed N was volatilized over a feeding period of 137 days on a conventional feed lot diet. Twenty point nine (20.9) kg of N was volatilized per steer. By using phase feeding, varying protein supply to meet changing requirements over the feeding period, volatile losses of N could be reduced to 14.2 kg of N/steer, 52.6% of intake N. Feeding less N reduced volatile losses, an observation consistent with Smits et al. (1995).

Grazing cattle contribute significant losses of N as ammonia (Jarvis, et al., 1989a, 1989b). The loss is associated with urinary N. About 8% of urinary N is lost from urine of grazing cattle. Losses are higher when pastures are grass with high rates of fertilization, which increases protein content of herbage. Intense rotational grazing also increases losses due to higher stocking rates and reduced canopy of grasses over soil.

Reducing ammonia losses. It has long be recognized that ammonia losses from animal waste can be minimized by separating feces and urine at collection. This removes the urea from the urease. However, this requires unique barn systems with holes in floors to collect liquid. Once liquid has be mixed with feces, storage needs covered with straw or more inert materials to prevent volatilization from the storage unit. And then slurry needs to be injected or incorporated with 4 hours of surface application to minimize ammonia losses.

Since urease activity is pH dependent, Muck found that lime addition to alleyways reduced urea conversion to ammonia by raising pH and reducing urease activity (Muck and Herndon, 1985). Acidification of slurry can also reduce volatilization by increasing the concentration of ammonium ion in slurry, since NH_3 is the volatile substance. Muck also suggested that rapid scrapping of barn floors could reduce ammonia losses (Muck and Richards, 1983).

Prevention of ammonia emissions can be done by controlling N content in manure, primarily urea in urine, control of pH in alleys and slurries, capping of slurry structures. and injection at time of land application. Drying manure can decrease activity of urease. Which measures prove fruitful will depend on cost and feasible application.

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Table 1. Mean (sem) Feed and Fecal analysis for each group at the Marshak Dairy.

Item (% DM)		Heifer Group	High Group	Middle Group	Low Group
Feed					
	DM	53.5 (1.0)	56.0 (.6)	56.3 (.8)	55.6 (.8)
	CP	14.5 (.3)	17.0 (.2)	16.3 (.2)	15.9 (.2)
	NDF	40.8 (1.0)	38.1 (.6)	36.9 (.8)	41.4 (.8)
	FAT	4.3 (.2)	5.8 (.1)	5.6 (.2)	5.2 (.2)
	Starch	22.9 (1.1)	21.6 (.6)	24.3 (.9)	21.2 (.9)
	Lignin	4.5 (.2)	4.3 (.1)	4.2 (.1)	4.6 (.1)
	P	.34 (.01)	.42 (.01)	.40 (.01)	.37 (.01)
Feces					
	DM	16.8 (.5)	15.5 (.2)	16.2 (.4)	15.9 (.4)
	CP	15.7 (.3)	17.0 (.2)	16.1 (.3)	17.2 (.3)
	NDF	59.0 (.6)	55.5 (.3)	58.5 (.5)	56.4 (.5)
	FAT	2.2 (.1)	2.7 (.1)	2.7 (.1)	2.4 (.1)
	Starch	2.7 (.3)	2.9 (.1)	3.1 (.2)	2.4 (.1)
	Lignin	9.8 (.2)	9.5 (.1)	9.3 (.2)	10.3 (.2)
	P	.70 (.04)	.70 (.02)	.60 (.03)	.70 (.03)

Table 2. Nitrogen balance for each group. Mean (sem)

Group	FeedN,g	MilkN, g	FecalN,g	UrineN,g	Urea+NH3N,g
Heifer	241.2 (38.0)		115.6 (20.0)	122.8 (13.7)	99.9 (11.1)
High	581.4 (16.2)	176.5 (3.1)	264.2 (8.5)	212.1 (7.0)	165.5 (5.7)
Mid	594.5 (24.1)	154.8 (4.6)	283.9 (12.7)	190.4 (10.5)	140.3 (8.5)
Low	504.5 (24.1)	88.9 (4.6)	218.0 (12.7)	176.3 (10.5)	128.2 (8.5)
Herd	530.0 (80.0)	149.6 (15.4)	241.0 (42.0)	188.8 (34.7)	144.3 (28.1)

Balance,g		If all Urea+NH3N volatilized : Loss for each group as % of intake N
Heifer	2.8 (1.2%)	.46 (.02)
High	-71.4 (12.2%)	.29 (.02)
Mid	-34.6 (5.8%)	.24 (.03)
Low	21.3 (4.2%)	.26 (.03)
Herd	-49.4 (9.0%)	.29 (.03)

Table 3. Mean (sem) urine concentrations and concentrations in flush water from the top and bottom of alley for each group of cows.

Item	Heifer Group	High Group	Middle Group	Low Group
Urine				
NH3, mg/dl	1.76 (.50)	1.40 (.15)	1.25 (.20)	1.74 (.19)
UreaN,mg/dl	707.6 (68.4)	666.4 (19.6)	610.1 (27.2)	717.2 (26.0)
Creat.,mg/dl	109.3 (9.54)	78.4 (2.77)	86.1 (3.81)	101.2 (3.66)
Top flush				
NH3, mg/dl	35.02 (2.34)	35.50 (.88)	35.13 (1.22)	35.29 (1.56)
UreaN,mg/dl	0	0	0	0
Bottom Flush				
NH3, mg/dl	39.59 (1.66)	44.31 (.61)	41.03 (.87)	38.04 (2.33)
UreaN, mg/dl	2.64 (1.06)	4.00 (.39)	3.79 (.55)	4.56 (.71)