

USE OF ANIMAL NUTRITION TO MANAGE NITROGEN EMISSIONS FROM ANIMAL AGRICULTURE

Rick Kohn, University of Maryland, College Park
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SUMMARY

Animal agriculture is a major contributor of N emissions to air, particularly with respect to ammonia, and to a lesser extent with respect to nitrous oxide and nitric oxide. These emissions can occur immediately after excretion when urine N is hydrolyzed, or more slowly when fecal N is decomposed and hydrolyzed during storage and field application. As chemically fixed N has become an inexpensive input to agriculture, we have come to consume greater quantities of animal products and fruits and vegetables that use a great deal of fertilizer per unit of N in those products. The result has been increased amounts of N going into air and water, with animal production contributing large amounts of N to air via animal manure. Improved animal nutrition and feeding should aim to reduce manure N output, especially in urine, to proportionally reduce air emissions. In addition, feeding programs may eventually consider their effects on crop selection in order to further reduce environmental impact. The historical trends in animal production have resulted in reduced output of manure N per unit of animal product. Nonetheless, increased use of N fertilizer for greater output of animal products and fruits and vegetables, has resulted in an increased loss of N to the environment.

INTRODUCTION

Agricultural practices have become more intensive to provide for the nutritional needs of an increasing human population and as a response to economic pressures on individual farms. Higher production levels are possible on farms through the use of chemically fixed fertilizer and feeds imported to farms from other regions (Smil, 2001). However, such practices also may increase the potential for losses of reactive nitrogen to air and water. Losses of reactive nitrogen to the environment include nitrate leaching and nitrogen runoff from feedlots and crop fields, as well as volatilization of ammonia (NH_3), nitrous oxide (N_2O), and nitric oxide (NO) to air. This paper will focus specifically on the volatile emissions to air, and in a general way, address the problem of losses of reactive nitrogen (N) to the natural environment.

Although virtually no N is volatilized directly from animals, the N in animal manure can be converted to ammonium (NH_4^+) by hydrolysis of urea or uric acid or deamination of amino acids after hydrolysis of proteins. This ammonium equilibrates with ammonia (NH_3) which can be readily lost to air in a gaseous form. The urea (mammals) and uric acid (birds) in urine is rapidly hydrolyzed by enzymes present in the animal's feces (Oenema et al., 2001). Thus, a substantial amount of ammonium can be formed within hours of urination, and this can be readily emitted to air from animal housing. Nitrous oxide (N_2O) is formed from microbial processes of nitrification and denitrification that may occur when manure is stored or applied to land for crop production. Nitric oxide (NO) is released during nitrification in aerobic soils when manure or other fertilizer is applied.

Once emitted, the NH_3 can be converted back to NH_4^+ in the atmosphere, and this NH_4^+ reacts with acids (e.g. nitric acid, sulfuric acid) to form aerosols with a diameter of less than 2.5 micrometers (PM 2.5). These small particles are considered a health concern for humans and a contributor to smog formation. Removal of ammonium by deposition contributes to soil and water acidity and ecosystem overfertilization or eutrophication. Nitric oxide and N_2O are rapidly interconverted in the atmosphere and are referred to jointly as NO_x . Nitrous oxide diffuses from the troposphere into the stratosphere, where it can remain for hundreds of years contributing to global warming and stratospheric ozone depletion. A molecule of nitrous oxide has a global warming potential that is 296 times that of a molecule of CO_2 (IPCC, 2001).

A single molecule of ammonia or nitrous oxide once emitted to the environment can alter a wide array of biogeochemical processes as it is passed through various environmental reservoirs in a process known as the

nitrogen cascade (Galloway et al., 2003). A single molecule of nitric oxide can continue regenerating in the stratosphere while sequentially destroying one ozone molecule after another. Likewise, as reactive nitrogen is passed through various environmental reservoirs a single atom can participate in a number of destructive processes before being converted back to N₂. For example, a single molecule of reactive nitrogen can contribute sequentially to decrease atmospheric visibility (increase smog), increase global warming, decrease stratospheric ozone, contribute to soil and water acidity, and increase hypoxia in fresh and subsequently coastal waters.

World wide, more than half of the anthropogenic losses of reactive nitrogen to the air, and more than 70% of the ammonia losses, are estimated to derive from agricultural production (van Aardenne et al. 2001). About 50% of the anthropogenic ammonia losses to the environment derive directly from animal feedlots, manure storage, or grazing systems, with additional losses occurring indirectly from cropping systems used to feed domestic animals as well as feed humans directly. In addition, animals contribute 25% of the anthropogenic N₂O production with an additional 25% coming from cropping systems. Only about 10% of the anthropogenic NO production derives from agriculture, most of it coming from crop-soil systems.

The environmental problems caused by reactive nitrogen release into the environment are profound and ever increasing, and agriculture is the biggest source of reactive nitrogen losses to air and water (van Aardenne et al. 2001). Thus, it has become necessary to develop control strategies to reduce losses of reactive nitrogen to the environment.

NRC RECOMMENDATIONS

The importance of nitrogen emissions from agriculture was recently addressed in two reports from the National Research Council (2002, 2003). While these reports dealt with several different substances emitted to air from animal feeding operations, NH₃ emissions from animal agriculture were identified as a major global concern, and N₂O and NO were considered significant concerns. By “global” concern, the NRC indicated that the emissions were not only important around the world, but that it is the aggregate of these emissions throughout the world that matters more than their distribution in any specific locality. Thus, the NRC recommended: “the aim is to control emissions per unit of production (kg of food produced) rather than emissions per farm”. This specific recommendation may directly contradict often-recommended control strategies aimed at decreasing the intensity of agriculture rather than improving the efficiency. It is important to emphasize the need to use nitrogen more efficiently for animal production rather than to simply use less per farm or per unit area of land.

The NRC also emphasized the need to consider a systems approach, which integrates animal and crop production systems both on and off (imported feeds and exported manure) the animal feeding operation, and considers emissions from water as well as air. It is certainly possible to reduce N emissions to air by transferring them to ground or surface water, but such “solutions” are not acceptable. It is also possible to reduce emissions from an animal feeding operation by exporting manure or importing crops, but the emissions will still occur, albeit on a different farm. One of the greatest opportunities to improve efficiency of N utilization for animal production is to select crops that use N more efficiently, especially by using whole-crop legumes to fix N near crop roots rather than non-legumes that require additional N fertilizers. Of course, selection of such crops would require the aid of an animal nutritionist to consider various options for diet formulation with different types of feeds.

The NRC committee also recommended against using emission factors to estimate emissions on individual farms, and recommended use of a process-based model to estimate emissions. Currently, the Environmental Protection Agency (EPA) calculates the expected emissions on farms by multiplying the number of animal units on the farm by the expected emissions per animal. When the estimated emissions exceed defined limits, reporting or regulatory requirements go into effect. The NRC recommended against using these emission factors for a number of reasons: data are not available to define average emissions per animal; animals are not uniform within discrete classifications; and management to decrease emissions is not rewarded with this approach. Thus, the NRC recommended a process-based modeling approach to estimate emissions from

individual animal feeding operations. The process-based approach involves analysis of the farm system through study of its component parts. It uses mathematical modeling and experimental data to simulate conversion and transfer of reactants and products through the farm enterprise.

For N emissions, the process-based approach involves calculation of the N in manure as the difference between what is fed and what is transferred to animal products. The amount of N lost from manure is the difference between N excreted and that removed from storage, and this manure N loss can be divided between various forms of N lost to air and water. Additional losses can be estimated as fractions of the manure N applied to crops.

The NRC committee recognized that reactive N losses to the environment may occur as NH_3 , N_2O , or NO lost to air, as soluble nitrogen running off into surface water, or as nitrate leaching into groundwater. They recommended that control strategies be aimed at decreasing emissions of total reactive N from animal production systems. These strategies can include both performance standards based on process-based model estimates of N losses, or technology standards to decrease total system emissions of reactive N compounds by quantifiable amounts.

The role of the animal nutritionist was not lost on the NRC committee as evidenced in their reports. Calculation of N emissions using a process-based model uses feed and production information to calculate manure output, and this estimate drives the subsequent predictions of volatile losses. Furthermore, improvements in animal nutrition that decrease manure output would be reflected immediately in the process-based model estimates. Furthermore, diet formulation can affect what crops are used, and these decisions further affect the total losses of nitrogen, and the forms of losses, from the total animal production system. In essence, the NRC calls for an improvement in the efficiency of N utilization for animal production; animal nutrition is a key element in orchestrating this improvement.

ROLE OF ANIMAL NUTRITION

Within the animal production system, there are a number of ways to conserve nitrogen rather than let it be released to the environment in either air or water. Broad categories of improvement might include manure handling and management, crop selection and management or improved feeding and nutrition.

A mathematical model of nitrogen flows on a dairy farm (Kohn et al., 1997) was used to identify the critical control points for conserving nitrogen on a dairy farm system; however, the results are applicable to any animal production system. In this model, the efficiencies of N utilization (i.e. units of N used constructively per unit of N imported) were set to high and low extremes for each of these major subsystems (manure, crop, feed). For example, the efficiency of feed N utilization was calculated as the grams of N in animal products (milk and meat in this case) divided by the feed N consumed by the herd, and this was allowed to vary from 16 to 24%. The grams of feed N produced per g of N available at the root zone of crops ranged from 50 to 75% or would be as high as 95% for forage legumes. The amount of N available to crops in soil is likely to be 25 to 50% of the manure N produced.

When all three efficiencies were set at lower limits 5 units of N would be lost from the system for every 6 units of N fixed by legume crops, and 10 units of N would be lost for every 11 units applied as commercial fertilizer. Only the remaining unit would be converted to animal products. How much of the loss goes to air and in what forms depends on choices made regarding various management options. For example, incorporating manure or fertilizer immediately after application may decrease ammonia volatilization considerably, but increase leaching. It is still a recommended practice because it is a means of conserving N. Improving the utilization of N by the herd through better feeding and management programs, decreased these losses by 40%. Selecting more legumes, selecting highly efficient crops, and managing crops better also reduced N losses by to similar levels. However, improving manure management had little impact on conserving N in the system. Most manure N is still

lost to the environment before being recycled back to the feed, even under the best of conditions. Thus, it is best not to produce it in the first place.

In the past several years, regulators and other developers of pollution control strategies (e.g. NRCS) have become interested in the feeding and animal management option to reduce N and P losses to the environment. Nonetheless, they have been struggling with how to translate their interest into policies to improve nutrition or feeding. Cropping systems are the other vital half of the equation; but optimizing cropping has still not received much attention. The agronomists may consider this their domain, and to a large extent it is. However, nutritionist again need to be involved when it comes to optimizing selection of crops that are needed for nutritional reasons. Ultimately, diet formulation may some day consider the environmental impact of feed selection, as it is a means to use byproducts safely and drive production of environmentally friendly crops.

HISTORICAL TRENDS FOR ANIMAL PRODUCTION EFFICIENCY

Over the past 50 years there have been two simultaneous trends in N use for animal production. First, following World War II, the development and use of chemically fixed nitrogen has increased tremendously. This means that non-legume crops have replaced the leguminous crops that were previously the source of N input to agriculture. When chemical fertilizer is applied to crops, only 25 to 50% of that N is taken up by the crop while the remainder is lost to air and water, and a small amount is returned to the atmosphere as harmless, N₂ gas. In contrast, most N fixed by legumes ends up in harvested grains or crop residues. Thus, the increased use of N fertilizer generally represents a trend that has put a great deal more N into the environment.

The increased use of fertilizer and other aspects of agricultural intensification have made foods more available to humans in the US and around the world. As a result, we have the option to eat more meat, vegetable crops and fruits, all of which require greater N inputs per unit of N output than traditional diets of beans and rice. Today, many people eat much more protein than they actually need. In the US, we appear to throw away about half the food N we purchase at the retail level (Smil, 2001). The human body needs about 2 kg person⁻¹ yr⁻¹ nitrogen but human beings (collectively) create 20 kg person⁻¹ yr⁻¹ nitrogen during food production processes. All of the reactive nitrogen is distributed to the environment representing a biogeochemically active element that, in large excess, has detrimental consequences on environmental ecosystems (Galloway, et al 2003).

We need to reduce our dependence on N fixation if we are to reduce the losses of N to the environment. It is unlikely that consumers will choose to eat less of the foods they like and which are good for them (e.g. animal products, vegetables and fruits). But would it impact our standard of living to decrease how much food we waste? Otherwise, we need to produce food with fewer N inputs. In this regard, there has been positive trend for the past 50 years regarding animal production.

Figure 1 shows estimates of the amount of N and P that were excreted per kg live weight of broiler in 1957 and 1991. The data of Havenstein et al. (1994) were used to calculate excretion for the 1957 strain of broiler raised on the diets from that period, vs. the 1991 strain raised on diets fed at that time. There was a 51% reduction in the amount of N excreted per kg of live weight produced. It is not enough to offset the added inefficiencies, of the entire agricultural system, but it does show the positive effect that animal management has had.

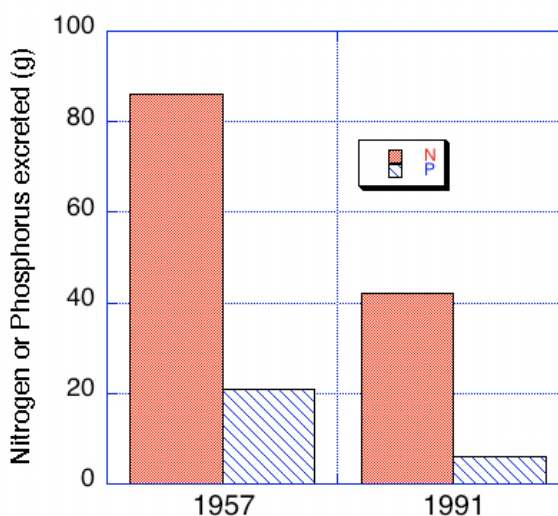


Figure 1. Excretion of nitrogen and phosphorus (g) per kg live weight of broiler produced in 1957 or 1991 (Data from Havenstein et al, 1994).

Table 1 shows a similar example for milk production. Production data were obtained from historical surveys, and assumed feeding levels were calculated using historical feeding recommendations. Excreted N was calculated as the difference between N intake and N in animal products (milk and growth). The total US dairy herd peaked in 1944 with 25 million cows, although today we produce 40% more milk with only 9 million cows. Although N excretion per cow per year has increased by about 12%, the total N excreted by all dairy cows in the US has decreased by 60%.

Table 1. Production and nitrogen excretion for the US dairy herd in 1944 and 2001.

	1944	2001
Milk per cow (kg/d)	7	27
N intake per cow (g/d)	360	490
N excreted per cow (g/d)	326	364
N excreted / N in milk (g/g)	10	3
N in milk / N intake (g/g)	0.09	0.26
Number of cows (10^6)	25	9
Milk per cow (kg/yr)	2073	8152
Total milk (10^9 kg/yr)	52	73
N Excretion per cow (kg/yr)	119	133
Total N excretion (10^9 kg/yr)	3.0	1.2

Calculated from agricultural statistics and historic animal feeding recommendations.

Sources: USDA 2003; NRC 2001; Morrison, 1950.

CONCLUSIONS

Improving animal nutrition is a means to reduce urinary and fecal N so as to proportionally reduce N emissions to air. In addition, feeding choices will affect crop selection and cropping practices that will have an additional impact on air as well as water loading of nitrogen.

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