Dairy Nutrition and Air Quality

David K. Beede[1]
Department of Animal Science
Michigan State University

Introduction

The time is fast approaching when dairy farmers and their nutritionists will be more obligated than in the past to manage and even reduce gaseous air pollutants and odors in their farms. Some emissions are considered harmful to the environment or to human health. Air quality standards as a result of the Air Quality Consent Agreement will come from the U.S. Environmental Protection Agency **(EPA)** in accordance with the federal Clean Air Act **(CAA)** enacted in 1990. Additional new rules may be set by state or local governments.

In the long run, as environmental certification becomes a more and more important (if not mandatory) global trading factor, compliance with worldwide air quality standards will be crucial for the U.S. dairy industry to be competitive. Investing today in the search for solutions to reduce air emissions will have environmental and potential economic benefits tomorrow. Doubtless, proper nutrition will play a significant role in minimizing emissions to the furthest extent biologically possible, now and into the future.

The objectives of this paper are: to provide a short background on the current pursuit to establish air emission standards for animal agriculture; to briefly summarize information about air emissions currently considered important in regulation, and thus, to the U.S. dairy industry; and to briefly review known nutrition and feeding strategies that have been suggested or employed to reduce specific air emissions from livestock or dairy operations.

Background

Why air quality and animal agriculture?

Although, the federal CAA was enacted in 1990, it typically has not been enforced within animal agriculture by federal or state agencies. However, the Act also did not specifically exempt agriculture or concentrated animal feeding operations **(CAFO)** from regulation or compliance. Through a complicated set of evolving circumstances over the last 20 to 30 years involving both changes in rural demographics (e.g., many more people with little or not previous experience or acceptance of the odors associated with animal agriculture) and relatively recent increased concentrations of animals and use of new manure collection and storage systems in some farms, odors have become an unavoidable social and political contention. Whereas odors generally are addressed at the local level (e.g., township, county, and state) through nuisance laws (often with some protection of animal agriculture from nuisance lawsuits, depending on the state), other gaseous emissions are known to have broader specific negative impacts on the environment and human health. The latter category of emissions are typically thought to have consequences in greater spatial dimensions, and thus, have received more focused attention and actions of federal and in some cases state legislation

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[1] Contact at: 2265K Anthony Hall, East Lansing, MI 48824, (517) 432-5400, FAX: (517) 432-0147, Email: beede@msu.edu

and regulatory agencies based on the specific gaseous species emitted, their relative perceived or estimated impacts, and the amounts emitted (Tables 1 and 2).

Air Emissions of Interest

Gaseous emissions generally can be classified in two categories based on spatial scale (Table 1; NRC, 2003): those with which concerns are local and those which have potential regional, national and global impacts.

Gaseous emissions of local concern are those which raise issues, often with neighbors, most frequently regarding a number of compounds emitting human-detectable odors affecting quality of life (whether perceived or real), hydrogen sulfide **(H_2S)**, and particulate matter **(PM)** which include particles with properties that cause haze and affect human health. Volatile organic compounds **(VOC)**, although perhaps not presently considered a significant or primary health or environmental concern, are important because they may be odorous and because the EPA must monitor their concentrations according to the CAA.

Gaseous emissions with potential regional, national, or global impact and major concern include atmospheric deposition of ammonia and the haze it causes, atmospheric deposition and haze produced by nitrous oxide (N_20), and the effects on global climate of NO_x (nitric oxide + nitrogen dioxide) and methane.

On the national and global scales, agriculture and particularly animal agriculture is considered a major emitter of ammonia (50% of total) and N_2O (25% of total), and a significant (18% of the total) emitter of methane in the U.S. (Table 2). Additionally, about 25% of the nitrogen (N) in dairy manure is lost as ammonia emission with current manure management practices (Pinder et al., 2003 as cited by Broderick, 2005). Based on model estimates from 100 years of data, only fossil fuel combustion and production, industrial processes, and landfills rival animal agriculture in air emissions (Table 2; van Aardenne et al., 2001). Additionally, reliable (quantified) estimates of animal agriculture's contributions to VOC (and odor) have not been established, yet work is under way currently to determine VOC contributions from dairy operations.

To better understand and explore the potential for reduction of air emissions from animal agriculture systems, a summary of the chemicals and their transfer and conversion characteristics is useful (NRC, 2003).

Ammonia ***(NH_3^+)***

Agricultural animals are the single largest source of ammonia (Table 2) and ruminants are the single biggest contributor among farm livestock to overall ammonia-N emissions (Bouwmann, et al., 1996). Ammonia results from hydrolysis of urinary urea (the main N-containing excretory product of ruminants) via microbial urease which is ubiquitous in manure and in the environment. When the ammonia is emitted into the air, it can be converted (hydrolyzed) into ammonium (NH_4) and removed from the atmosphere by dry or wet deposition. Once removed from the atmosphere, both chemical species contribute to ecosystem fertilization, acidification, and eutrophication, and can impact visibility, soil acidity, stream acidity, and natural and cultivated aquatic and terrestrial ecosystems' biodiversity and productivity (Galloway and Cowling, 2002). Ammonia also contributes indirectly to the formation of $PM_{2.5}$ (particles with diameters up to 2.5 microns) via airborne ammonium salt crystals.

Nitrous oxide **(N_2O)**

Nitrous oxide is formed through microbial nitrification and denitrification and contributes to depletion of stratospheric ozone and increased global warming. Animal agriculture contributes significantly (Table 2).

Nitric oxide **(NO)**

Direct emission of nitric oxide from animal systems is estimated to be small (compared with fossil fuel combustion and refinement/production; Table 2). However, N-fertilizer applied to cropland soils in dairy systems can result in the emission of NO. Nitric oxide and nitrogen dioxide (signified together as NO_x in the literature) are readily inter-convertible and removed from the atmosphere by dry and wet deposition. The NO_x is an important precursor of ozone production and aerosol nitrate is a contributor to $PM_{2.5}$ and N deposition as HNO_3.

Methane **(CH_4)**

Methane (CH_4) is produced through anaerobic fermentation in the rumen and anaerobic digestion of manure. When emitted into the air, which currently happens with the vast majority of the world's methane production, methane is an important greenhouse gas contributing to global warming. In the U.S. and globally, animals are believed to contribute about 18 and 29% of total methane emissions, respectively; fossil fuel burning and landfills both contribute more or similar proportions (Table 2).

Volatile organic compounds **(VOC)**

Though not well-quantified from animal operations at this time, VOC from livestock operations include organic sulfides, disulfides, aldehydes of 3- through 7-carbon lengths, trimethylamine, C_4 amines, quinoline, demethylpyrazine, short-chained organic acids, and aromatic compounds. The quantitative significance of VOC emissions in dairy production systems is not yet known but suspected to be significant. The CAA requires that EPA monitor VOC from industrial operations, which will include some or all livestock (dairy) farms once the standards are set (discussed below).

Hydrogen sulfide **(H_2S)**

Hydrogen sulfide is formed during the anaerobic reduction of sulfate in aqueous solutions and suspensions, and decomposition of S-containing compounds in manure. Once released into the atmosphere, H_2S is oxidized to sulfur dioxide and removed by wet or dry deposition from the air. On a global basis, it does not appear that hydrogen sulfide has much environmental impact. However, effects in more highly concentrated animal feeding systems are of special interest because hydrogen sulfide also has been used as an odor indicator in some instances (e.g., in Minnesota).

Particulate matter **(PM)**

Particulate matter indirectly or directly occurs from livestock operations through animal activities, housing fans, incorporation of air into materials from scruf, soil, and manure, and conversion of aerosols of ammonia, nitric oxide, and hydrogen sulfide to crystalline forms. Respiratory health from deposition in the airways of animals and humans and visibility can be affected deleteriously by both $PM_{2.5}$ and PM_{10}.

Odors

Odors result from a variety of compounds emitted from animal operations. They have been difficult to quantify but include, among many other compounds, VOC and perhaps hydrogen sulfide. Nonetheless, they are of significant local societal concern in some areas and likely will continue to be the focus of environmental research and regulation if humans continue to spread into agricultural areas and animal production units continue to increase animal densities and chemical (nutrients and waste products) concentrations.

U.S. Animal (Dairy) Industries' Current Engagement

Various legal actions have challenged animal agriculture to comply with standards set as part of the 1990 federal CAA. Currently, CAFO are asked to comply with CERCLA (the Comprehensive Environmental Response, Compensation, and Liability Act) that covers ammonia and hydrogen sulfide emissions and EPCRA (the Emergency Planning and Community Right-to-Know Act) that addresses monitoring of ammonia and hydrogen sulfide emissions. The CAA also specifies the monitoring of VOC, particulate matter (PM of up to 10 microns in diameter [PM_{10}] and $PM_{2.5}$ up to 2.5-micron diameter particles, and total suspended particulate [TSP]), and NO_x (various N-oxygen species).

Based largely on the paucity of reliable information from which to develop workable standards for air emission (NRC, 2003), early in 2005 the EPA announced the Air Quality Consent Agreement between EPA and some major segments of the U.S. livestock industry with the following objectives: to monitor emissions; to develop protocols for emission monitoring from various livestock production operations (varying in size, animal species, and housing and management systems); to determine what sizes of operations (within livestock species) are likely to exceed regulatory thresholds; and to determine what enforcement will be required (EPA, 2005). The national swine, layer (poultry), and dairy industries have engaged to participate in the Consent Agreement to gather air emissions data. Very sizable investments have been budgeted by each participating industry to collect needed emission data, with hopes of gaining some additional information about mitigation of emissions later in the study period. To date, other major segments of the U.S. livestock industry (e.g., beef, broiler, turkey, and sheep) have not engaged.

Dairy industry investment

In 2005, a task force of dairy producers from across the U.S. facilitated through the National Milk Producers Federation (NMPF) met several times to determine the best ways for the dairy industry to engage in the EPA Consent Agreement efforts. In January 2006, the U.S. Congress approved a one-time amendment to the National Dairy Promotion Act to allow the National Dairy Board (NDB) to authorize (only for fiscal year 2006) expenditure of funds from the national dairy check-off to address environmental and public health considerations. Following, the NDB voted to authorize $6 million to fund air quality research to help establish baseline standards of air emissions from some types of U.S. dairy farms and to explore strategies to help mitigate a portion of emissions as part of the EPA Consent Agreement. The identity of the six dairy sites around the U.S. has not been publicized, and the actual on-farm measurements have not begun as of this writing, late March 2006.

Doubtless, the stage is set. Likely, some significant portion of the U.S. dairy industry will have to respond to regulations of CAA — even with the multitude of variable conditions such as different housing, management, and manure storage and application systems — once the baseline standards are set from work through the Consent Agreement.

Potential Strategies to Reduce Emissions

In general, 5 on-farm operational categories are considered to reduce air emissions from dairy operations: housing system; manure handling, treatment, and storage; manure disposal, distribution and land application; conversion of the components of manure into value-added products; and emission mitigation through nutrition and feeding management. Considering the previously listed compounds released into the air from dairy operations, what can be done to reduce the rate and amounts of various emissions? To address this question, the following must be considered: the potential relative amount of emission (relative to that from other sources of the compound, e.g., in Table 2); the potential environmental impact of the emitted compound; the potential relative emphasis in both small and larger spatial scale regulatory actions; and the potential for success in mitigation as well as risk if mitigation proves difficult. Starting to address emission mitigation at the beginning of the nutrient and emission compound flow— with the nutrition and feeding of the animals— would seem logical.

Nutritional Strategies to Reduce Emissions from Dairy Farms

The no brainer

To varying extents, livestock producers have often over-fed some nutrients and energy relative to animals' nutritional requirements to be more certain that requirements were actually met and because of real or perceived issues with variability in operational practices (e.g., ability to repeatedly mix and deliver rations accurately and precisely through time) to meet requirements. Feeding in excess of true nutrient requirements will not minimize air emissions. For example, crude protein **(CP)** supplied in the diet in excess of cows' requirements can have profound effects to increase N losses and ammonia release from manure (Swensson, 2003).

Broderick (2005) showed in one experiment using diets with CP concentrations varying from (13.5 to 19.4%, dry basis) and typical midwestern feeds that, in general, there were no improvements in actual milk yield (ranged between 80 to 85 lb/cow/day), fat-corrected yield (ranged between 75 to 81 lb/day), or milk protein yield with more than 16.5% CP. Similar responses were observed in other work when CP concentration of the ration exceeded that needed to meet requirements. It is not uncommon for the CP concentration in practical rations to exceed that needed (NRC, 2003). Dairy producers, nutrition consultants, and extension professionals have as an immediate tool the ability to reduce excess dietary CP as a way to reduce N emissions from dairy operations. The related topic of efficiency of dietary protein utilization will be mentioned subsequently.

Precision feeding

Perhaps, the second most obvious strategy to reduce excretion and air emissions of N is to group animals by productivity level or other distinguishable characteristic (e.g., gender or body weight) to improve dietary N utilization. Grouping dairy cows into separate production/management groups decreased N excretion by 6% compared with feeding all lactating cows the same ration (St-Pierre and Thraen, 1999).

Increase efficiency of nutrient and energy utilization

Feed efficiency (3.5% fat-corrected milk yield/unit of feed dry matter [DM] consumed) has gotten special recent attention as a nutritional management monitoring tool to help optimize nutrient and energy utilization and profitability (Hutjens, 2005; Shirley, 2006). Nutritional efficiency certainly is not a new concept to dairy producers, nutritionists, or scientists. However, improving the efficiency of nutrient utilization for environmental management and reduction of excretion of pollutants (e.g., unutilized nutrients or their components or byproducts of energy metabolism) into air and water will receive even greater management attention in the future. Efficiency equals nutrient or energy in usable product divided by nutrient or energy intake. Thus, a reduction of the denominator or an increase in the numerator will enhance efficiency - for example, increasing the nutrients in milk per unit of intake (e.g., milk protein/protein consumed).

Dairy nutritionists and researchers have worked for a long, long time to improve the efficiency of dietary N utilization. It is well known that the amount of metabolizable protein and the profile of potentially absorbed essential amino acids are very important. In addition to ruminally synthesized metabolizable protein, dietary protein as rumen undegraded protein **(RUP)** and rumen-protected methionine or lysine, when in short supply, limit lactational performance and the overall efficiency of dietary N utilization (NRC, 2001; Noftsger and St-Pierre, 2003; Broderick, 2005; among many others). The resulting inefficiency of N utilization increases emission of N-containing compounds, especially ammonia from urea excretion.

Whereas some progress has been made, brilliant (e.g., greater than 30 to 35%) improvements in the efficiency of ration protein conversion to milk protein seem unlikely and certainly will not happen until we achieve a much greater basic understanding of the influences of various feed and animal variables (e.g., intake rates, types and interactions of feed carbohydrates and proteins, etc.) on ruminal fermentation kinetics (e.g., pool sizes, flow and turnover rates, and microbial protein synthesis rates) and animal performance to affect N excretion.

Increasing productivity to reduce relative emissions (e.g., reduce emissions per unit of edible food produced).

Van Horn et al. (1994) used a modeling approach to illustrate conversion of dietary N to milk N and the excretion of N as affected by level of herd productivity. The overall conversion of intake N to milk N ranged from about 25% to nearly 30% as milk yield per cow per year increased from 18,000 to 26,000 lb, respectively. Concomitantly, the absolute amount of N excreted per unit of milk produced decreased from about 6.5 g/lb to about 5.5 g/lb; about a 15% reduction in excretion. This analysis illustrated the potential power of high productivity, at presumably similar (fixed) biological and operational maintenance inputs, to lessen emissions per unit of edible product.

Thus, some effective management practices that increase herd productivity also might be expected to reduce N excretion per unit of milk produced. Jonker et al. (2002) examined a set of dairy management practices with modeling in combination with survey data of 454 dairy farms in the Chesapeake Bay Basin. On average, this set of dairy farms fed nearly 7% more N than recommended by the National Research Council (NRC, 2001), resulting in a 16% increase in urinary N and nearly a 3% increase in fecal N. The overall efficiency of conversion of dietary N to milk N was 28.4% (standard deviation = 3.9). The following herd management tools (some expected to increase lactation performance per cow) reduced N losses in manure per unit of milk N produced: use of bovine somatotropin; routine use of milk urea N testing; use of a complete feed; management of the photoperiod with artificial lighting; and being a member of the Dairy Herd Improvement Association. Factors in their analysis that did not affect conversion of dietary N to milk N included use of a total mixed ration, milking three times per day, seasonal calving, use of cover crops, and having a nutrient management plan for N.

In another study, Dunlap et al. (2000) demonstrated that increasing milk yield of dairy cows by bovine somatotropin **(bST)**, 3-time versus 2-time/day milking, and increasing photoperiod with artificial lighting reduced manure N excretion by 16% for a given amount of milk produced.

Increased productivity, often gained through more intensively managed herds, actually does not increase air emissions, but in fact, can result in a considerable decrease in waste nutrient excretion per unit of milk produced - even considered in a herd size-neutral context. Emissions per unit of edible product may be a logical index to consider as a standard for regulatory compliance. However, until actual air emission data from actual farms with known (definable) environmental and herd characteristics are known, it is unlikely to receive much consideration.

Methane

To this point, the discussion has focused mainly on N. However, of the approximately 19.8 lb of carbon consumed daily by a lactating cow (66 lb/day of milk), about 40% is expired as carbon dioxide and about 3% is converted to methane (Pfeffer and Hristov, 2005). However, the increase in methane emissions associated with U.S. and global animal agriculture is of potential concern because this molecule is chemically relatively stable in the atmosphere and contributes to the increase and acceleration of global warming.

To date, only modest advancement has been made to reduce methane emissions from dairy cattle. In Canada, Sauer et al. (1997) studied the effects of feeding monensin (ELANCO, Greenfield, IN) (24 ppm of dietary dry matter (DM) after a gradual step-up introduction of monensin over 1 week) by lactating dairy cows (n = 88 to 109) fed a TMR (corn silage, alfalfa haylage, hay, and concentrate in DM proportions of 30: 26: 9: 35, respectively) continuously. Methane and CO_2 emissions were sampled and measured continuously with infrared gas analyzers in the tie stall barn environment under a practical management routine. In the first trial, monensin reduced methane production by 21% per cow during the 3 week period it was fed compared with the previous period of over 3 months before monensin-feeding. Also, improved feed conversion efficiency, increased milk production, reduced ruminal fluid ratio of acetate to propionate (A:P), and reduced milk fat percentage were observed. Monensin was then removed from the diet for a period of about 160 days. When monensin was reintroduced in a second trial (67 of the cows that had received monensin in the first trial plus 21 cows that had calved recently and had never received monensin), there was neither a significant reduction in methane production, ruminal A:P, milk fat percentage, nor an increase in milk yield and feed conversion efficiency due to monensin. The authors suggested that there might be some adaptive mechanism that is not understood and that rotating use of different ionophores (if and when approved) or other feed additives might be helpful.

Other nutritional factors known to reduce methane production include type of dietary carbohydrate and higher concentrations of concentrate feeds (e.g., grains with more nonstructural carbohydrates reduce methane production compared with forages). Also, methane production from ruminants can be reduced by feeding more digestible (higher quality) forages by harvesting at earlier stages of maturity or processing methods that increase digestibility (Johnson and Johnson, 1995). Supplemental fat is known to reduce the amount of methane produced. Similarly, the quantity of feed consumed also affects methane production. Each of these strategies also reduces the maintenance subsidy per unit of edible product relative to the quantity of methane produced.

Odors

To date, most concerns over air emissions related to animal agriculture have been evidenced through state-level discussions about odor regulations (Powers, 2003). There are numerous compounds that are known to impart human-detectable odors if in sufficient concentrations in air. For example, over 330 odor-causing compounds have been identified in swine manure (Schiffman et al., 2001). Comparable data have not been found for dairy facilities (NRC, 2003); however, far fewer odor-causing compounds likely be expected. Thus far, nutrition or feeding strategies backed by sound, unbiased research to appreciably reduce odors have not been advanced.

Other emissions

The amounts of hydrogen sulfide and VOC emitted from dairy operations (from the animals themselves plus the manure handling and storage systems) have not been quantified; research is under way.

Summary

- Dairy producers and nutritionists will have an important role and increasingly important function in air quality management in commercial dairy farms in the Tri-State area.
- Concerns about gaseous emissions exist in two categories. Concerns with odor, VOC, H_2S, particulate matter, and haze are raised locally; whereas, ammonia, nitric oxide, and nitrogen dioxide emissions are strong greenhouse gases of concern for our regional, national, and global climates.
- In 2005, the EPA announced the Air Quality Consent Agreement with U.S. animal agriculture aimed at studying emissions from farms. Several animal industries have agreed to participate to gather scientific data for use in setting standards, including the national dairy industry (via the National Dairy Board), which pledged $6 million to fund air quality studies.
- On-farm operational categories considered to reduce air emissions from dairy operations are: housing systems; manure handling, treatment, and storage; manure disposal, distribution, and land application; conversion of the components of manure into value-added products; and, emission mitigation through nutrition and feeding management.
- Some nutrition strategies for reducing emissions include not overfeeding livestock, precision (targeted group) feeding, increasing efficiency of nutrient and energy utilization, and increasing productivity.

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Table 1. Proposed relative importance (in rank order within spatial scale) of air emissions from animal feeding operations based on the NRC (2003) special committee's scientific evaluation.[1]

	Spatial Scale		
Emission	Local – property line, or nearest dwelling	Global, national and regional	Primary Concern
Ammonia (NH_3)	Minor	Major	Atmospheric deposition, haze
Nitrous oxide, N_20	Insignificant	Significant	Global climate change
NO_x[2]	Minor	Significant	Atmospheric deposition, smog
Methane (CH_4)	Insignificant	Significant	Global climate change
VOC[3]	Minor	Insignificant	Quality of human life
Hydrogen sulfide (H_2S)	Significant	Insignificant	Quality of human life
PM_{10} (µm)[4]	Significant	Insignificant	Haze
$PM_{2.5}$ (µm)[5]	Significant	Insignificant	Health, haze
Odor	Major	Insignificant	Quality of human life

[1] Rank order (high to low) of concern = major, significant, and insignificant.

[2] NO_x = nitric oxide + nitrogen dioxide ($N0_2$).

[3] VOC = volatile organic compounds.

[4] PM_{10} = particulate matter includes particles with aerodynamic equivalent diameters up to 10 micrometers.

[5] $PM_{2.5}$ = particulate matter includes particles with aerodynamic equivalent diameters up to 2.5 micrometers.

Table 2. Annual estimated percentages and total amounts of some air emissions from most known sources in the United States and globally in 1990.[1]

	NH_3-N		N_2O-N		NO-N[2]		CH_4-C		VOC-mass[3]	
Source	U.S.	Global	U.S.	Global	U.S.	Global	U.S.	Global	U.S.	Global
	% of total emissions									
Agriculture										
Agriculture and natural land	36	29	25	33	5	14	1	18	NA	NA
Animals	50	49	25	33	1	3	18	29	NA	NA
Biomass burning										
Savannah burning	0	4	0	3	0	8	0	2	0	3
Deforestation	0	3	0	0	0	3	0	2	0	4
Energy										
Fossil fuel combustion + production	0	0.2	25	7	88	58	53	29	42	37
Biofuel combustion	7	5	0	3	1	4	1	5	4	17
Industrial processes	0	0.5	25	17	1	4	0	0	49	31
Waste										
Agriculture waste burning	4	3	0	3	3	6	2	4	5	8
Landfills	4	6	0	0	0	0	24	11	0	0
Total amount of source, Tg[4]	2.8	43.4	0.4	3	7.6	36.6	30.9	239.7	24.3	181.1

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[1] Adapted from NRC (2003) as adapted from van Aardenne et al. (2001). Percentages may not sum exactly to 100% because of rounding. NH_3-N = nitrogen in ammonia; N_2O-N = nitrogen in nitrous oxide; NO-N = nitrogen in nitric oxide; CH_4-C = carbon in methane; VOC = volatile organic compounds; and NA = not available. The H_2S emissions are not available for the level of disaggregation shown for other emission species, but they are small relative to other sulfur sources (e.g., SO_2 from fossil fuel combustion) on a national and global basis. They might be important on a regional basis in some areas.

[2] Estimates of NO emissions from manure applied to fields vary substantially. Reported values for the fraction of manure nitrogen lost as NO have been as high as 5.4%, but 2% was selected as a mid-range value in the calculations (uncertainity is about a factor of two).

[3] VOC = volatile organic compounds; quantities of these emissions are not available for agricultural sources except agriculture burning.[4] Tg = 1 teragram = 1 million metric tonnes.