Effects of Feeding on Air Quality Measures

Wendy Powers[1]
Department of Animal Sciences
Michigan State University

Summary

Livestock production causes unavoidable losses to the environment, and the concerns related to aerial emissions from livestock production is ever increasing. Losses to the atmosphere occur during respiration and from fresh and stored feces and urine. These losses may be an environmental burden as contributors to global climate change (CO_2, CH_4), regional particulate or acid deposition concerns (NH_3), and regional ozone concerns (volatile organic compounds, **VOC**). Diet modification serves as a primary pre-excretion strategy for reducing air emissions. Most strategies to reduce air emissions that have been employed to date adjust nutrient content to better match estimated nutrient needs of the animal through improved feed quality, reduction of excess nutrients offered, grouping of animals, and a change in feed ingredients. Data demonstrate that substantial reductions in air emissions can be realized; however, as the animal is fed closer to nutrient needs, the incremental gain that results from making dietary changes diminishes. Strategies that challenge efficiency of nutrient use, shift the site of digestion, and reduce endogenous losses relative to maintenance requirements need further development and exploration in order to continue to address the magnitude of challenges ahead. Because air emissions occur post-excretion, tools that estimate air emission losses based on diet inputs and animal characteristics and performance are poorly developed relative to tools that estimate nutrient excretions.

Introduction

The dairy industry faces increasing environmental challenges that span media (water and air) as well as nutrient and non-nutrient issues, such as pathogens and endocrine disruptors. Air quality issues remain at the forefront of challenges for the dairy industry. Recent reporting requirements under the Emergency Planning and Community Right-to-Know Act **(EPCRA)** for large concentrated animal feeding operations **(CAFO)** suggests that regulation of air pollutants may intensify for animal agriculture. Yet, it is uncertain what pollutants will be targeted and how standards will be established. As the Environmental Protection Agency **(EPA)** winds down its National Air Emissions Monitoring Study, many are eager to see how the data will translate to policy and what pollutants will be addressed. Air emission concerns include odor, nitrogen, and sulfur emissions, and health impacts. More recently, states have addressed emissions of VOC and particulate matter. Greenhouse gases **(GHG)** are being addressed at both state and Federal levels.

Reactive N **(Nr)** refers to all forms of biologically active, chemically reactive, and radiatively active forms of nitrogen, including ammonia, nitrous oxide, and nitrogen oxides (EPA Science Advisory Board Integrated Nitrogen Committee, 2009). In a draft report, the Integrated Nitrogen Committee **(INC)** presents 4 overarching research and management recommendations to assist EPA in developing an integrated N

---

[1] Contact at: 2209 Anthony Hall, East Lansing, MI 48824, (517) 614 8207, Email: wpowers@msu.edu

management strategy and 5 specific recommendations proposed to decrease the amount of Nr lost to the US environment by 25% with no specific target date for achievement. Within the recommendations, several pertain to agriculture. One recommendation is to maximize the N efficiency of both crop and livestock production systems and to develop strategies for avoiding increased Nr load in the environment. A second recommendation promotes a policy, regulatory, and incentive framework to improve manure management to reduce Nr load and ammonia losses. The INC recommends a goal of decreasing livestock derived NH_3 emissions to approximately 80% of 1990 emissions, a decrease of 0.5 (terragram) N/yr [by a combination of best management practices (BMP) and engineered solutions]. While the report was a draft when first accessed, it is a strong indication that recent regulatory activity (i.e., EPCRA reporting in 2009) may be the beginning of what may follow. A final version of the report may be available from the committee website later in 2010.

Research indicates that dietary strategies can have a profound effect on gaseous emissions, particularly ammonia. Work in the area of diet and air emissions is still a relatively new field of research and what research has been conducted has focused primarily on reducing nutrient excesses in the diet. In this manner, animal needs are met and excess nutrients that are excreted are reduced, thereby representing a measure of source control. Much of the work with ruminants has targeted reduction of methane and ammonia emissions, thus these 2 gases will be the focus of this review.

Diet as a Tool to Reduce Ammonia Emissions

Nutritional strategies currently available to reduce ammonia emissions include lowering dietary protein levels, changing the ratio between urinary N and fecal N, reducing urine pH, inhibiting urea degradation, and binding ammonia. Many of these examples have been tested in swine and poultry research; however, the principles should apply to the dairy animal as well. As the issue of reducing ammonia emissions increases, innovative strategies will require development and testing.

Reduced dietary protein

Minimization of N excretion is the most obvious method to curb ammonia emissions. By reducing the available substrate, less ammonia will be formed and volatilized. Endogenous N losses are unavoidable; however, as milk yield increases, endogenous losses are diluted out over greater units of product. In Holstein heifers, James et al. (1999) observed a 28% reduction in ammonia emissions when N intake was reduced 14%. Total N excretion was reduced only 20%. Tomlinson et al. (1996) reported an approximate 20% reduction in N excretion associated with a 3% reduction in dietary CP for lactating dairy cows. Limited data are available that demonstrate how reducing N excretion corresponds to reduced ammonia emissions in the dairy animal. Generally, as a guide, for each 1% reduction in dietary CP, estimated ammonia losses are reduced by 10% in swine and poultry (Aarnink et al., 1993; Jacob et al., 1994; Blair et al., 1995; Kay and Lee, 1997; Sutton et al., 1997). James et al. (1999) and Tomlinson et al. (1996) show similar findings in the dairy animal. Greater reductions in ammonia emissions from swine have been measured in recent work (20% reduction for each one percentage unit reduction in dietary protein; Powers et al., 2007). As animals are fed closer to true N requirements, further reductions in dietary CP may result in less pronounced reduction in N excretion and ammonia losses. Thus, this issue is really, "How close to requirements can we economically achieve?" Regardless, for the ruminant, we continue to be challenged with trying to more precisely define the N and amino acid requirements of the rumen and lower gastrointestinal tract, separately, in order to better feed the animal as a whole. Restrictions on ammonia emissions add urgency to these needs.

Fecal and urinary nitrogen ratios

Inclusion of fermentable carbohydrates into swine diets has been shown to shift N excretion from urine to feces (Canh *et al.*, 1997b). Fecal N is less easily degraded to ammonia. Hindgut fermentation can increase fecal N while decreasing urinary N. Tomlinson *et al.* (1996) illustrated that cows fed calcium soaps of long chain fatty acids (Ca-LCFA) excreted greater urine N (g/day) than those fed control diets (P=0.0006). The authors attributed this to reduced microbial protein synthesis in the Ca-LCFA diets, with concomitant increase in ammonia conversion to urea and excretion in the urine. Fecal N (g/day) was numerically less in cows fed the Ca-LCFA diets, demonstrating that a shift in N excretion patterns may have occurred. While this study was not designed to examine strategies to shift N excretion in the dairy animal, future studies are needed to investigate dietary manipulation of N excretion to promote reduced ammonia emissions. Similarly, Canh *et al.* (1997a) observed reduced ammonia emissions of 26 to 53% by including Ca-salts in swine diets up to dietary Ca levels of 7 g/kg to 10 g/kg (0.7 to 1%).

Urease inhibition, pH manipulation, and additives

Other dietary approaches to reduce air emissions that have been tested include diet acidification and use of feed additives. By acidifying the diets, excreta also is acidified. The acidic conditions promote retention of N in excreta, thereby decreasing volatilization of the N as ammonia. Recent work with laying hens demonstrated a 40% reduction in ammonia emissions with no negative performance effects when acidified diets were offered (Wu-Haan et al., 2007). Several feed additives claim to reduce N excretion and ammonia emission potential by binding ammonia or inhibiting urease. Amon *et al.* (1995) fed a De-Odorase (Alltech; Nicholasville, KY), a yucca extract, to fattening pigs and observed reduced ammonia concentrations in the feeding rooms over a 7-wk period. Ammonia concentration was reduced, on average by 26% in rooms where the extract was fed. Similarly, ammonia emission was reduced 26% in the study. Preliminary data demonstrate that dietary inclusion of yucca extracts in steer diets reduces ammonia emissions by a similar magnitude (Li, unpublished). Dietary inclusion of clinoptilolite (Wu-Haan et al., 2007) and other clay minerals to reduce ammonia emissions has resulted in variable findings, and studies incorporating these additives into dairy diets are absent. Other additives that are of current interest for swine and poultry diets are bacterial products, including probiotics, which may improve intestinal health and promote better utilization of feed nutrients. As a post-excretion amendment, effectiveness of these same strategies (acidification, urease inhibition, or N binding) towards reducing ammonia emissions is mixed. Yucca plant extracts have been evaluated by Powers et al. (1999), finding that ammonia concentrations in stored dairy manure were reduced. Similar findings were reported by Panetta et al. (2005) when yucca extract was added to swine manure. Kithome *et al.* (1999) observed that application of a layer of 38% zeolite placed on the surface of the composting poultry manure reduced NH_3 losses by 44%. Amon *et al.* (1997) observed greater ammonia concentration and emission when clinoptilolite was used in broiler houses. Continued investigation into acidification, binding, and inhibition strategies is warranted as is delineation of the mechanism of effective strategies.

Diet as a Tool to Reduce Methane Emissions

Interest in reducing enteric methane production continues to grow due to concerns about climate change, coupled with the yet unresolved potential to capture carbon credits on the dairy farm. While earlier work that reduced enteric methane targeted improved animal performance through reduced energy losses (use of ionophores, higher grain diets, and better quality forages), more recent efforts have the primary objective of reducing enteric methane. Results have often demonstrated a decrease in enteric methane at the expense of animal performance.

Recently, Hollmann et al. (2009) found that while feeding coconut oil to lactating dairy cows did reduce methane emissions, feed intake and milk production suffered. So while methane per unit of milk was reduced in cows offered the diets containing coconut oil, it is unlikely in the near future that carbon credit opportunities will be sufficiently attractive to entice one to increase diet cost by adding coconut oil to the diet and withstand a reduction in milk produced. Similarly, Beauchemin et al. (2009) demonstrated that adding sources of long-chain fatty acids to the diet in the form of processed oilseeds could reduce methane emissions, but in some cases (sunflower seeds or flax seeds), the reduction in methane was at the expense of diet digestibility. Use of crushed canola seed reduced methane emissions without the negative impacts on diet digestibility or milk production (Beauchemin et al., 2009).

Wina et al. (2005) reviewed studies that had evaluated the use of saponins (steroid or triterpene glycoside compounds found in a variety of plants) and reported that some in vitro and in vivo experiments had demonstrated beneficial effects of saponin, such as defaunation of the rumen and manipulation of the end products of fermentation. The surfactant properties of saponins result in antiprotozoal activity due to cell lysis when the saponin complexes with the cholesterol in protozoal cell membranes. Saponins have antibacterial activity and modify ruminal fermentation by suppressing ruminal protozoa and selectively inhibiting some bacteria and reducing ruminal ammonia concentrations. Saponin sources within the U.S. include the desert plant, *Yucca schidigera.* Yucca extract contains 4 to 6% of steroid saponins, representing numerous different structures. *Quillaja saponaria,* from the soapbark tree in Chile, contains 8 to 10% total saponins and more than 20 different structures of triterpenoid saponin. Both yucca and quillaja saponins are commercially available products that have been used as feed additives. Holtshausen et al. (2009) reported that diet inclusion of *Yucca schidigera* or *Quillaja Saponaria* at levels that lowered in vitro methane production also reduced fiber digestibility and ruminal fermentation. Feeding at a lower level (in vivo) produced no differences in methane production compared to a control diet (Holtshausen et al., 2009). Preliminary in vivo findings by Li (unpublished) are encouraging in that dietary inclusion of *Quillaja saponaria*, at an inclusion level higher than that fed by Holshausen et al. (2009), appears to reduce methane emissions from steers without negatively impacting steer growth. However, the data do not show benefits from including *Yucca schidigera* in the steer diets. This study is still in the early stages and further replication of findings is needed.

No long-term studies have been conducted to evaluate extended animal performance or adaptation of rumen bacteria. One approach to avoid adaptation is to offer diets containing saponins intermittently or to rotate the source of saponin in the diet (steroid and triterpenoid sources).

Conclusions

Certain dietary approaches (source reduction or nutrient input mass reduction strategies) may be better-suited to long-term beneficial effects on air emission mitigation than others (manure nutrient form modification strategies). Nutrient form modification changes the chemical form of the nutrients being excreted through diet modification (i.e. diet acidification, dietary inclusion of additives such as urease inhibitors, or feedstuff selection to shift the site of N excretion). Those strategies that reduce nutrient input mass must, by mass balance definition, decrease nutrient mass output, yet those that only change the form may initially reduce nutrient emissions to air because they "trap" nutrients in chemical forms that are not volatilized. However, the long-term effects of trapping nutrients in unknown; at some point those nutrients may escape.

An additional consideration is that while dietary strategies are currently at a stage of 'untapped potential' and as strategies are implemented, the magnitude of additional strategy adoption will likely follow the law of diminishing returns. Diet strategies alone, likely won't be sufficient to meet the pending compliance challenges that animal production could face, particularly as industry adopts practices that reduce dietary nutrient excesses. A combination of nutrition and engineering strategies will likely be needed. Post-excretion mitigation strategies are needed in combination with pre-excretion (diet) strategies in order to address emissions that occur during storage, particularly when diet manipulation methods that change the nutrient form but not the nutrient concentration are employed.

References

Aarnink, A.J.A., P. Hoeksma, and E.N.J. Ouwerkerk. 1993. Factors affecting ammonium concentration in slurry from fattening pigs. Pages 413-420. *In*: Proc. of the First International Symposium on Nitrogen Flow in Pig Production and Environmental Consequences. Wageningen, The Netherlands. (June 8–11).

Amon, M., M. Dobeic, T.H. Misselbrook, B.F. Pain, V.R. Phillips, and R.W. Sneath, 1995. A farm-scale study on the use of De-Odorase for reducing odour and ammonia emissions from intensive fattening piggeries. Bioresource Tech. 51:163-169.

Beauchemin, K.A., S.M. McGinn, C. Benchaar, and L. Holtshausen. 2009. Crushed sunflower, flax, or canola seeds in lactating dairy cow diets: Effects on methane production, rumen fermentation, and milk production. J. Dairy Sci. 92: 2118-2127.

Blair, B., J. Jacob, and T. Scott. 1995. Reducing manure pollution. Poultry Highlights. Research Report, Page 2. Department of Animal Science, The University of British Columbia.

Canh, T.T., A.J.A. Aarnink, Z. Mroz, and A.W. Jongbloed. 1997a. Influence of dietary calcium salts and electrolyte balance on the urinary pH, slurry pH and ammonia volatilization from slurry of growing finishing pigs. J. Anim. Sci. 75(Suppl. 1):1989. (Abstr).

Canh, T. T., M. W. A. Verstegen, A. J. A. Aarnink, and J. W. Schrama. 1997b. Influence of dietary factors on nitrogen partitioning and composition of urine and feces of fattening pigs. J. Anim. Sci. 75:700-706.

EPA Science Advisory Board Integrated Nitrogen Committee (INC). 2009. Draft report available and accessed May 2009; http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/c83c30afa4656bea85256ea10047e1e1!OpenDocument.

Hollmann, M., W.J. Powers, A. Fogiel, N.M. Bello, J.S. Liesman, and D.K. Beede. 2009. Increasing dietary concentration of coconut oil reduces enteric methane emission from lactating Holstein cows. J. Anim. Sci. Vol. 87, E-Suppl. 2/J. Dairy Sci. Vol. 92, E-Suppl. 1. Abstract 371.

Holtshausen, L., A.V. Chaves, K. A. Beauchemin, S.M. McGinn, T. A. McAllister, N.E. Odongo, P.R. Cheeke, and C. Benchaar. 2009. Feeding saponin-containing *Yucca schidigera* and *Quillaja saponaria* to decrease enteric methane production in dairy cows. J. Dairy Sci. 92: 2809-2821.

Jacob, J.P., R. Blair, D.C. Benett, T. Scott, and R. Newbery. 1994. The effect of dietary protein and amino acid levels during the grower phase on nitrogen excretion of broiler chickens. Page 137. *In*: Proceedings of the 29th Pacific Northwest Animal Nutrition Conference. Vancouver, B.C. Canada.

James, T., D. Meyer, E. Esparaza, E.J. DePeters, and H. Perez-Monti. 1999. Effects of dietary nitrogen manipulation on ammonia volatilization from manure from Holstein heifers. J. Dairy Sci. 82:2430-2439.

Kay, R.M., and P.A. Lee. 1997. Ammonia emission from pig buildings and characteristics of slurry produced by pigs offered low crude protein diets. Pages 253-259. *In*: International Symposium on Ammonia and Odour Control from Animal Production Facilities. Rosmalen, The Netherlands.

Kithome, M., J.W. Paul, and A.A. Bomke. 1999. Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments. J. Environ. Qual. 28:194-201.

Li, W. (Unpublished). Impact of dietary saponins on gaseous emissions from ruminants. Dissertation research. Michigan State University.

Panetta, D.M., W.J. Powers, and J.C. Lorimor. 2005. Management strategy impacts on ammonia volatilization from swine manure. J. Environ. Qual. 34(4):1119-1130.

Powers, W.J., H.H. Van Horn, A.C. Wilkie, C.J. Wilcox, and R.A. Nordstedt. 1999. Effects of anaerobic digestion and additives to effluent or cattle feed on odors and odorant concentrations. J. Anim. Sci. 77:1412-1421.

Powers, W.J., S. Zamzow, and B.J. Kerr. 2007. Reduced crude protein effects on aerial emissions from swine. Applied Engineering in Agriculture 23(4): 539-546.

Sutton, A.J., K.B. Kephart, J.A. Patterson, R. Mumma, D.T. Kelly, E. Bogus, B.S. Don, D.D. Jones, and A.J. Heber. 1997. Dietary manipulation to reduce ammonia and odorous compounds in excreta and anaerobic manure storage. Pages 245-252. *In*: International Symposium on Ammonia and Odour Control from Animal Production Facilities, Rosmalen, The Netherlands.

Tomlinson, A.P., W.J. Powers, H.H. Van-Horn, R.A. Nordstedt, and C.J. Wilcox. 1996. Dietary protein effects on nitrogen excretion and manure characteristics of lactating cows. Trans of the ASAE 39:1441-1448.

Wina, E., Muetzel, S., and K. Becker. 2005. The impact of saponins or saponin-containing plant materials on ruminant production: A review. J. Agric. Food Chem. 53:8093-8105.

Wu-Haan, W., W.J. Powers, C.R. Angel, C.E. Hale, III, and T.J. Applegate. 2007. Effect of an acidifying diet combined with zeolite and slight protein reduction on air emissions from laying hens of different ages. Poult. Sci. 86:182-190.