AIR QUALITY

Diet and Feed Management to Mitigate Airborne Emissions

Air Quality Education in Animal Agriculture

Mitigation Strategies: Diet & Feed
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Scott Carter, Associate Professor
Department of Animal Science
Oklahoma State University
Al Sutton, Professor
Department of Animal Science
Purdue University
Rose M. Stenglein, Junior Scientist
Department of Bioproducts and Biosystems Engineering
University of Minnesota

This publication discusses how diet and feed management can be used to reduce excess nutrient and gaseous emissions from poultry and livestock.

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Multiple feed ingredients comprise livestock and poultry diets and are designed to provide all of the essential nutrients and energy needed for optimum production. Digestibility and nutrient availability affect nutrient absorption and retention within the body and, consequently, growth, nutrient output, and product (e.g., meat, milk, and eggs) yield. Livestock and poultry profitability is commonly enhanced by minimizing feed costs and using low-cost feed ingredients that provide the essential nutrients and needed energy.

However, diets are often formulated to exceed nutrient requirements as a safety factor so they won't limit animal performance. This practice can be costly for producers because excess nutrients are not utilized by the animal and excreted. This increase in nutrient excretion can increase airborne pollutant emissions. Ongoing animal nutrition research has led to a more accurate understanding of livestock and poultry dietary nutrient needs. This allows producers to formulate diets that optimize production while reducing nutrient and gaseous emissions.

Animal operations and manure storage facilities can be sources of a wide variety of gas and particulate matter (PM) emissions. The gases and PM emissions can have negative environmental and health impacts locally, regionally, and globally. Some gases are odorous. Hazardous gases emitted from animal operations include ammonia (NH_3) and hydrogen sulfide (H_2S). Greenhouse gases emitted include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Some emitted gases are precursors that react in the atmosphere to produce particulates that contribute to haze and impair visibility (Barthelmie and Pryor, 1998). Diet and feed management are one of several mitigation practices that can be used to help reduce gas and odor emissions.

Air Pollutant Formation

Microbial and enzymatic production of gases begins in the digestive system of animals, and continues after excretion and during manure storage. The type, amount, and characteristics of nutrients excreted depend on nutrient concentration of the diet, digestibility, and physical conditions in the digestive tract. The proportions and chemical composition of diet ingredients can influence the availability (digestibility) and retention of nutrients in the animal, and the levels and chemical forms of the nutrients excreted in the manure and urine (Applegate et al., 2008).

Animal manure includes feces, urine, bedding, wasted feed, and wastewater (ASAE 2004). The feces and urine contain unretained nutrients, undigested diet components, byproducts of intestinal metabolism, and bacterial cells from indigenous digestive tract microflora. The feces and urine contain most of the nutrients in animal manure (Sutton et al., 2008). Many of the gases and PM come from the animal manure generated and stored on the operation, the feeding system and spoiled feeds, bedding, and livestock and poultry dander (i.e., feathers, dandruff, and hair). Reducing nutrient levels in stored manure reduces the potential for gas and odor generation in manure storages.

Diet and feed management can be used to reduce and manage excess nutrient excretion and gaseous emissions from the animals, their voided feces and urine, and stored manure. This publication summarizes key diet formulation and feed management practices to minimize gas and odor emissions from livestock and poultry operations (Applegate et al., 2008). Precision feeding, which includes phase and split-sex feeding, limiting excess nutrients, and improving nutrient absorption, is a general diet and feed management practice that can reduce gas emissions. Feed processing and changing manure physical properties also can affect gas and particulate emissions.

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Feed Management Technologies

Precision Feeding

Precision feeding practices manage diets to provide animals with just the amount of nutrients required at a particular stage of growth or production cycle for optimum production and no more. Precision feeding uses nutrient forms that are readily available for the intended use by the animal. By targeting animal nutritional needs, precision feeding can reduce nutrients excreted in feces or urine while maintaining or even improving animal production and the economic viability of an animal operation. Reducing the nutrients in manure lowers airborne emissions.

Precision feeding techniques include: separating animals according to nutritional needs and production potential, limiting excess nutrients, and improving the efficiency of nutrient absorption.

Phase and Split-Sex Feeding

Two types of animal separation practices are used for precision feeding: phase feeding and split-sex feeding. For phase feeding, animals are separated by age or production state (e.g., dairy cows at different stage of lactation), and diets (e.g., nutrients) are matched to the different nutritional needs of each phase. For split-sex feeding, animals are separated by sex, and diets (e.g., nutrients) are adjusted accordingly. Both phase feeding and split-sex feeding are commonly used currently (*Figure 1*).

Limiting Excess Nutrients

Excess nutrients not absorbed in the digestive tract are voided in the manure and urine. Dietary protein provides amino acids, nitrogen, sulfur, and other elements

Figure 1. Swine producers frequently separate male and female pigs and feed different diets to better fit the different growth rates and nutrient requirements of the two sexes. (Photo courtesy of USDA Natural Resources Conservation Service)

needed for animal reproduction, growth, and milk or egg production. Crude protein is an estimate of the total protein in a diet based on the percentage of nitrogen measured. Animals use less than half of the nitrogen that they consume, with the remaining excreted in the feces or urine. Fecal and urinary nitrogen are ammonia emission sources. Limiting crude protein levels in the diet to only that used by the animal limits nitrogen excreted in urea or uric acid, which contributes to emissions.

While reducing crude protein content will reduce nitrogen excretion and ammonia emissions, reductions in crude protein can severely impact animal performance. To effectively reduce crude protein concentrations of diets for swine and poultry, additional supplementation of synthetic amino acids is needed. Animals require a specific profile (ratios) of available amino acids; thus, lowering crude protein levels requires supplementation with select amino acids that otherwise would be insufficient. Specific synthetic amino acids can be added to meet the nutritional needs of an animal according to genetic lines, age, sex, and other factors.

Research has shown that high-quality, protein-limited diets with appropriate supplementation of amino acids can effectively reduce nitrogen excretion and ammonia emissions from swine, poultry, and dairy and beef cattle operations without a loss in animal productivity. Commonly used amino acids are lysine, methionine, and threonine, which usually can be added to feed without additional costs (Applegate et al., 2008).

Other amino acids are typically more expensive. In general, each 1 percent reduction in crude protein with appropriate amino acids supplementation in poultry and swine diets results in approximately a 10 percent decrease in nitrogen excretion. Greater reductions in ammonia emissions have been reported for swine and poultry fed reduced protein, amino acid-supplemented diets (Powers et al., 2007; Carter et al., 2008, 2009; Powers and Angel, 2008).

Undesirable sulfurous compounds often originate from sulfur-containing amino acids and sulfur-containing mineral sources. Additionally, sulfur content of water supplies can impact the generation of undesirable sulfurous compounds. Limiting unnecessary sources of sulfur can reduce emissions of hydrogen sulfide and other volatile sulfur compounds.

Byproducts such as dried distillers grains with solubles from ethanol production have variable nutritional content and should be formulated carefully when added to animal diets. Ethanol production removes starch from corn and leaves a byproduct with high concentrations of crude protein, oil, fiber, and minerals (Varel et al., 2008). Dried distillers grains with solubles and other byproducts can alter the nutrient availability of the feed and create nutritional imbalances (Sutton, 2008). Adding wet distillers grains with solubles to cattle diets has been shown to increase manure slurry pH, odors, and concentrations of ammonia, hydrogen sulfide, phosphorous, and sulfur (Varel et al., 2008).

Two types of animal separation practices are used for precision feeding: phase feeding and split-sex feeding.

Improving Nutrient Absorption

Nutrients come in a variety of forms; some are more easily digested than others. Precision feeding includes techniques that enhance nutrient utilization. Some feed supplements provide nutrients in readily available forms that may improve nutrient absorption.

Inorganic minerals are sometimes used to meet dietary needs. Mineral sulfates in animal diets can increase the number and amount of sulfurous compounds emitted (Sutton, 2008). Organic mineral forms may be more efficiently absorbed, minimizing the additions needed and amount of minerals excreted (Sutton, 2008).

Antibiotics and beta-agonists improve feeding efficiency and can reduce production of some odor compounds. Enzyme additions to animal diets may increase the digestibility of some nutrients, which could reduce manure generation and odors. More research is needed in this area (Sutton, 2008).

Research has shown that high-quality, protein-limited diets with appropriate amino acid supplementation can effectively reduce nitrogen excretion and ammonia emissions.

Feed Processing Techniques

Feed processing can impact nutrient availability and gas emissions. For example, fine grinding of feed increases the grain particle surface area, allowing digestive enzymes to break down the feed more easily and increase nutrient utilization (Sutton, 2008). Decreasing feed particle size from 1000 to 600 microns increases dry matter and nitrogen digestibility by 5 percent to 12 percent and lowers the amount of nitrogen in manure by 20-24 percent.

The optimum particle size for swine is between 650 and 750 microns; smaller particles raise processing costs and may have negative health effects (Sutton, 2008). Generally, particle size for poultry is lower at approximately 400 to 450 microns. Fine grinding can increase digestibility but can also increase dust. Pelleting feeds can reduce feed waste by up to 5 percent and improve nutrient utilization (van Kempen and van Heugten, 2000; Sutton 2008).

Changing Physical Characteristics of Manure

The physical characteristics of manure affect the quantity and type of gasses emitted. The pH of manure, for instance, determines the rate of ammonia and hydrogen sulfide emissions. At low pH levels (the more acidic), ammonia emissions are lower but hydrogen sulfide emissions are higher. Research on the effectiveness of lowering manure pH has produced mixed results.

Adding organic acids such as fumaric, hydrochloric, propionic, citric, adipic, and sulfuric acids to the diet to alter the digestive system pH and improve microflora populations has had inconclusive results (Sutton, et al., 1999, citing Geisting and Easter, 1986). Calcium salts (sulfate, chloride, and benzoate) are also possible additives to reduce pH. Although calcium benzoate has been found to lower swine urinary pH from 7.7 to 5.5 and ammonia emissions by up to 55 percent, it is currently not approved as an animal feed additive (Sutton, 2008). Calcium chloride added at 1.96 percent to nursery pig diets reduced ammonia emissions from nursery rooms but reduced food intake and depressed performance (Sutton, 2008).

The ratio of urinary nitrogen to fecal nitrogen is another physical characteristic that impacts gas emissions. Nitrogen in urine is more readily released as ammonia than nitrogen in feces. Therefore, lowering the ratio of urinary to fecal nitrogen can lower ammonia emissions.

One means of accomplishing this is to add fermentable carbohydrates (i.e., fiber or non-starch polysaccharides) such as sugar beet pulp or soybean hulls (Shriver et al., 2003; Carter et al., 2009) to the diet. A diet with reduced crude protein and added fiber in the form of soybean hulls lowered the amount of ammonia emissions and nitrogen excretion more than 35 percent compared to a reduced crude protein diet alone (Hankins et al., 2001). Fiber should form 10 percent or less of the diet to avoid potential negative effects such as reduced digestibility of protein, fat, minerals, and energy, and consequential reduced performance (Sutton, 2008).

Manipulating Digestive Microbes

Some research has attempted to control microbial activity to improve digestion and reduce odors. For instance, dairy byproducts and organic acids have been included in swine diets in attempts to control intestinal microflora populations (Sutton, 2008). At this time, results have been inconclusive and more research is needed. Cattle diet composition will affect the populations of microflora in the rumen. High roughage (high in fiber) diets enhance fibrolytic bacteria concentrations versus a high concentrate (high in starch) diet, which will support starch degrading bacteria (Hodson and Stewart, 1997).

Figure 2. Improperly mixed feed or inconsistent feed deliveries can result in greater waste which will increase the amount of material entering the manure handling system with commensurate increases in emissions from the manure. (Photo courtesy of USDA Natural Resources Conservation Service)

Improve Management

How and how often animals are fed can impact feed spillage that ends up in manure (*Figure 2*). Feed waste can make up 3 percent to 8 percent of feed used, adding unnecessary feed expenses and encouraging bacterial growth that can increase odor and gas emissions from the manure system (Sutton, 2008). Proper feed storage can reduce spoilage. Lower-dust emissions from feed distribution systems for dry feeds can reduce PM emissions (Sutton, 2008). Adding fat (1 percent) or water (3:1 water to feed) to dry feed rations also can reduce PM emissions (Sutton, 2008). Using good bunk management practices with cattle can meet their feed intake needs and avoid excessive feed wastage.

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By Animal Species

Swine

Phase feeding and split-sex feeding have been shown to decrease air emissions from swine operations. For example, using three feed phases in grow-finish instead of one can reduce nitrogen excretion in manure by 15 percent and ammonia emissions by 17 percent (Sutton, 2008). Additionally, gilts need more protein than barrows of the same weight so sex separation can increase efficiency and reduce costs (CAST, 2002).

Reducing crude protein and adding amino acids to swine diets is an effective strategy for limiting emissions. A typical crude protein source in swine diets is soybean meal. Replacing soybean meal with amino acids (synthetic lysine, threonine, methionine, and tryptophan) and corn can reduce odors 40-86 percent (Hobbs et al., 1996).

Pigs fed lower crude protein diets with added amino acids can perform as well as, or even better than, those fed conventional corn-soybean diets with no added amino acids, though often with a slight increase in carcass backfat depth (Sutton, 2008). A diet with a 3.0-4.5 percent reduction in crude protein with supplemental amino acids, compared to a conventional diet, can lower pH by 0.4 units, total nitrogen excreted

Using a combination of several feed-related techniques can reduce ammonia and hydrogen sulfide emissions by 30-50 percent and odors by 30 percent with little extra cost for the producer.

30-40 percent, aerial ammonia emissions 40-60 percent, hydrogen sulfide emissions 30-40 percent, and total odors 30-40 percent (Powers et al., 2007; Carter et al., 2008; Sutton, 2008). Generally, crude protein reductions of up to 3 percent combined with amino acids supplementation have no impact on animal growth (Carter, 2009).

Lowering sulfur levels in the mineral mix will reduce volatile sulfur compound emissions (Sutton, 2008). Research has shown copper sulfate improves feed efficiency by 5 to 10 percent and potentially reduces odors (Richert & Sutton, 2006).

Adding small amounts (5-10 percent) of fiber to swine diets lowers manure pH and increases volatile fatty acid concentrations. Increasing volatile fatty acid concentrations of manure can decrease manure pH, thus influencing ammonia emission.

Soybean hulls have been used as a fiber additive in more studies than any other fiber source. Results indicate that including 10 percent soybean hulls with 3.4 percent fat in a typical commercial swine diet reduced ammonia emissions 20 percent, hydrogen sulfide emissions 32 percent, and odor threshold 11 percent. Manure pH dropped, manure nitrogen increased 21 percent and volatile fatty acid increased 32 percent (Sutton, 2008).

Combining fiber addition with other techniques can lead to even greater reductions in gaseous emissions. A reduced crude protein diet with supplemental amino acids and 5 percent soybean hulls decreased ammonia emissions 50 percent, hydrogen sulfide 48 percent, and the odor detection threshold 37 percent (Sutton, 2008). Shriver et al. (2003), and Carter et al. (2008) reported that the addition of soybean hulls to reduced crude protein, amino acids-supplemented diets did not affect total nitrogen excretion, but reduced slurry pH and ammonia emissions beyond that achieved with crude protein reduction alone.

Antibiotics in swine diets can improve feed efficiency from 5 to 15 percent and have reduced odor compounds (p-cresol, skatole) (Richert & Sutton, 2006). Beta-agonists promote lean growth (CAST, 2002), reduce nitrogen excretion, ammonia in slurry, ammonia emissions, and concentrations (Sutton, 2009).

Copper and zinc are also used as growth promoters. Copper sulfate has been shown to improve feed efficiency by 5 to 10 percent and to potentially reduce odors (Richert & Sutton). However, using growth-promoting levels of copper and zinc dramatically increases the excretion of these minerals. The use of organic forms of minerals may offer the potential to reduce mineral excretion, while capitalizing on the enhancement in growth performance and potential to reduce odors, although much more research is needed in this area.

Figure 3. Beef cattle need less protein toward the end of the feeding period. Reducing crude protein in cattle diets at this point can reduce nitrogen emissions significantly. (Photo courtesy of Sharon Sakirkin, Texas AgriLife Research)

Adding organic acids such as fumaric, hydrochloric, propionic, citric, adipic, and sulfuric acids to pig diets to alter the digestive system pH and improve digestive microflora populations has produced inconclusive results (Sutton, 2008). Increasing calcium benzoate levels in sow diets reduced the urine pH from 7.7 to 5.5 and lowered ammonia emissions by up to 53 percent (Mroz et al., 1998).

Management techniques to reduce air and particulate emissions in swine operations include reducing feed waste, providing good feed storage, using low-dust feeding systems, adding fat to feed, adding water to feed, fine grinding feed, and pelleting feed.

Cattle

Phase feeding has been shown to be effective for both dairy and beef cattle. Grouping cows according to milk production levels decreased nitrogen excretion by 6 percent (St. Pierre and Thaen, 1999). Reducing the crude protein in beef cattle diets from 13 percent to 11.5 percent in the last 56 days of the feeding period reduced nitrogen emissions by 19 percent (Cole, 2006).

Avoiding excess dietary crude protein is the easiest way to reduce ammonia emissions (*Figure 3*). Research has shown that feeding dairy cattle more than 16.5 percent crude protein does not increase milk yield, fat-corrected yield, or milk protein yield (Beede, 2006).

Balancing dietary proteins can reduce nitrogen excretion. Cattle feed includes two types of protein: rumen degradable protein and rumen undegradable protein. Rumen degradable protein is consumed in the rumen by microbes, which then pass into the intestine as a source of microbial protein. Rumen undegradable protein passes directly to the intestine.

The ratio of rumen undegradable protein to rumen degradable protein, along with energy (carbohydrates) supplied in the feed, impacts production levels and efficiencies. In one case, precision feeding decreased nitrogen excretion by 34 percent and increased milk production by 13 percent. It also improved economic returns by more than $40,000 per year for a 320-cow dairy herd (CAST, 2002, citing Klausner et al., 1998; also Rotz et al., 1999; Tylutki and Fox, 2000).

Methane production can be decreased by using more highly processed grain in feed. Increasing grain processing decreases fecal starch, which decreases odors and may decrease manure methane production. High quality grain also tends to decrease enteric fermentation and pH, and, therefore, decreases the amount of methane produced within the animal. Supplementing diets with fat can also decrease methane production.

More research is needed on the effects of distillers grains on cattle digestion. Corn wet distillers grain with solubles increased odor, pH, ammonia, hydrogen sulfide, nitrogen, and phosphorus concentrations in manure (Varel et al., 2008). Adding sorghum wet distillers grain with solubles had no effect on nitrogen excretion. Wet distillers grain with solubles should not be considered beneficial from an emissions reduction point of view (Cole, 2009).

Poultry

Phase feeding is frequently used in the poultry industry but usually with fewer phases than maximum emission reduction would call for (CAST, 2002).

Substituting amino acids for crude protein is also a common practice in the poultry industry (CAST, 2002). In particular, methionine and lysine are typically added to diets (CAST, 2002). Using additional amino acids results in greater decreases in emissions. Broilers fed six-phase diets and supplemental lysine, methionine, threoine, isoleucine, valine, tryptophan, and arginine had reduced ammonia emissions compared to a four-phase diet supplemented with methionine and lysine. The six-phase diet did not reduce breast weight or yield (Powers, 2006). In general, each 1 percent reduction in crude protein results in a 10 percent decrease in ammonia (Powers and Angel, 2008).

Figure 4. Using amino acids and phase feeding allows poultry producers to reduce the amount of crude protein fed to the birds. Research has shown that a 1 percent reduction in crude protein leads to a 10 percent decrease in ammonia emissions. (Photo courtesy of USDA Natural Resources Conservation Service)

Lowering poultry litter pH has been shown to reduce ammonia emissions. A diet fed to laying hens with 6.9 percent calcium sulfate (gypsum) and slightly reduced crude protein lowered ammonia emissions by 39 percent and methane by 17 percent (*Figure 4*). However, due to the increase in dietary sulfur, hydrogen sulfide emissions increased three-fold (Wu-Haan et al., 2007).

Costs

Using a combination of several techniques, such as phase feeding, split-sex feeding, minimizing feed wastage, and targeting diets to specific genetic lines, can reduce ammonia and hydrogen sulfide emissions 30-50 percent and odors by 30 percent with little extra cost for the producer (Sutton, 2008). The costs and availability of organic acids, calcium sources, and enzymes may be prohibitive for commercial use (Sutton, 2008). Supplementing diets with amino acids other than lysine, methionine, or threonine may not be economically feasible at this time (Applegate, 2008).

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Reviewers

Greg Zwicke, USDA-NRCS
Joe Rudek, Environmental Defense Fund
Wendy Powers, Michigan State University

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