# Strategies to Modify Nitrogen (N) in Poultry Manure and Litter

## Dietary strategies

**Formulate based on amino acid requirements rather than crude protein (CP).** Amino acids are the building blocks of proteins. There are more than 20 amino acids that comprise proteins. About half of these are essential (must be provided in the birds' diet) with the remainder being non-essential (the bird can make them in adequate quantities). Dietary formulation based on bird amino acid requirements rather than CP can minimize N excretion by simply reducing total dietary N intake. For example, Ferguson et al. (1998) demonstrated with broilers that litter N could be reduced more than 16% when dietary CP was reduced by 2%, while maintaining similar levels of dietary amino acids. Since the 1950s, nutritionists have utilized methionine, followed by lysine, and more recently, threonine and tryptophan in poultry diets on a cost-effective basis (Waldroup 2000). More than ten years ago, scientists at the University of Georgia showed that additions of methionine and lysine to layer diets could reduce dietary protein from 18% to 16% and reduce the cost of the diet by more than $4/ton (Savage 1990). Keshavarz and Jackson (1992) showed that substitutions of methionine, lysine, tryptophan, and isoleucine for as much as 4% CP in hen diets significantly reduced protein intake while maintaining egg production and egg weight. According to Waldroup (2000) all indications point to further development of feed-grade amino acids that may result in greater reductions in dietary CP.

Attempts to reduce CP in broiler diets have only been successful to a point. At some reduced level of CP, the bird's performance suffers even though one has theoretically met all requirements for essential amino acids. Compared to either a 23% CP positive control diet or 22% CP with 100% or 110% of recommended amino acid levels, broiler chicks fed a 20% CP diet with 100% of recommended amino acids weighed less (Waldroup 2000). However, when the minimum amino acid level of the 20% CP diet was increased to 110%, bird performance was not different from the positive controls. Therefore, although it is possible to reduce dietary CP levels by 3% to 4% (13-22% N) for broilers and layers at our current level of understanding, there are biological limits to the amount of dietary protein that can be replaced with synthetic amino acids. There are similar limitations with turkeys that suggest we do not fully understand the amino acid requirements of these birds; therefore, CP is still quite critical and necessary to realize full performance.

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**Optimize the dietary amino acid profile with bird requirement, e.g., "ideal protein concept."** The closer the amino acid composition of the diet matches bird requirements for maintenance, growth, and production of meat and eggs, the fewer amino acids (N) excreted in the feces. In corn and soybean meal (CSM)-based broiler diets, the most critical amino acids are methionine and lysine. Dietary supplementation of these two amino acids can be used to reduce the diet's CP content and thereby N excretion until the requirement for the next limiting amino acid is reached. However this method leaves many amino acids in excess of their requirement (Figure 11-1) with the excess excreted as fecal N. Another approach is to deliver an "ideal protein" whereby the protein

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portion of the diet meets bird requirements for each amino acid with no excesses or deficiencies. With the ideal protein concept, N excretion would be reduced to a minimum level. Baker and coworkers at the University of Illinois have published work on the dietary concentrations of amino acids in an ideal protein approach for broiler chickens (Baker and Han 1994). The levels of amino acids are based on the ratio of digestible lysine to the requirement for other individual amino acids. The large body of information about lysine's requirement, function, levels in feed ingredients, and economic feasibility as a supplement make it the clear choice as the reference for other amino acids.

Practical implementation of the ideal protein concept is partially restricted by economics and the availability of dietary ingredients with amino acid profiles that more closely match the bird's requirement. In the United States and other countries that rely heavily on corn and corn byproduct ingredients, the branched chain amino acid concentrations, especially for leucine, are far in excess of the bird's requirement (Figure 11-1) and present a challenge to fully realize the benefits of the ideal protein concept. However, genetically modified cereal grains, new dietary enzymes, and creative formulation with less traditional ingredients will allow progress in this area.

Phase feeding is another technique that can reduce manure N and feed cost.

**Phase feed poultry for their current rate of growth or production.** Phase feeding is another technique that can reduce manure N and feed cost. Commercial phase-feeding programs may include as many as six phases to step down dietary protein, amino acids, and other nutrients for broilers starting from 22% CP at hatching to 16% CP when the birds reach 4 lbs in less than 6 wks (Leeson and Summers 1997). Similar strategies are used with commercial turkeys and may include more than ten phases with a range in CP from 29.3% to 13.9% for heavy toms. While not new to the poultry industry, this technique of breaking the requirements of growing and adult birds into phases of greater or lesser need for protein and amino acids can be further refined to include more dietary phases when birds are consuming large amounts of feed and N near market weight.

The same concept of nutrient refinement can be applied to broiler breeders and commercial laying hens producing table eggs. Economics and convenience will most likely drive the implementation of additional phases of dietary protein (Warren and Emmert 2000). It may be cost effective to deliver additional finisher feeds to growers within a certain radius from the feed mill. Implementation within company-owned flocks may be technically and logistically more feasible versus contract farms or cash feed sales.

Formulating poultry diets based on the true amino acid digestibility rather than the total amino acid concentration goes a long way in refining amino acid levels provided in the diet.

**Utilize the "true amino acid digestibility" of feed ingredients to enhance N retention and reduce excretion**. A fourth technique to enhance N retention and reduce N excretion is to feed highly digestible feedstuffs. Work published by universities and amino acid manufacturers gives the true digestible amino acid concentration and/or coefficients of amino acid digestibility of cereal grains, plant proteins, and animal proteins. Formulating poultry diets based on the true amino acid digestibility rather than the total amino acid concentration goes a long way in refining amino acid levels provided in the diet.

The benefits of formulation based on true digestible amino acid recommendations and ingredient amino acid true digestibility are twofold. First, it helps one compare the ecological value of different ingredients. Consider the value of a low-quality meat and bone meal (MBM) with a high-quality fish meal (FM) (Esteve-Garcia et al. 1993) as sources of digestible amino acids (Figure 11-2). Because true amino acid digestibility coefficients are directly related to N retention and inversely related to N excretion per g of amino acid, the ecological value of FM threonine or methionine+cystine is more than sixfold greater than that of the low-quality MBM. Secondly, it allows a better definition of the amino acid content of feed ingredients, permitting a closer match with the birds' requirement. And lastly, formulation based on digestible amino acids improves daily gain and feed conversion of growing birds (Esteve-Garcia et al. 1993). Work summarized by the NRC (1994) suggests that calculated digestible amino acid requirements are 8% to 10% lower than the requirements for total amino acids.

**Select feed ingredients with low nutrient variability to reduce margins of safety in protein and amino acid formulation**. Better feed formulation is possible when one has a better handle on the protein and amino acid concentration of feed ingredients and does not oversupply them in the

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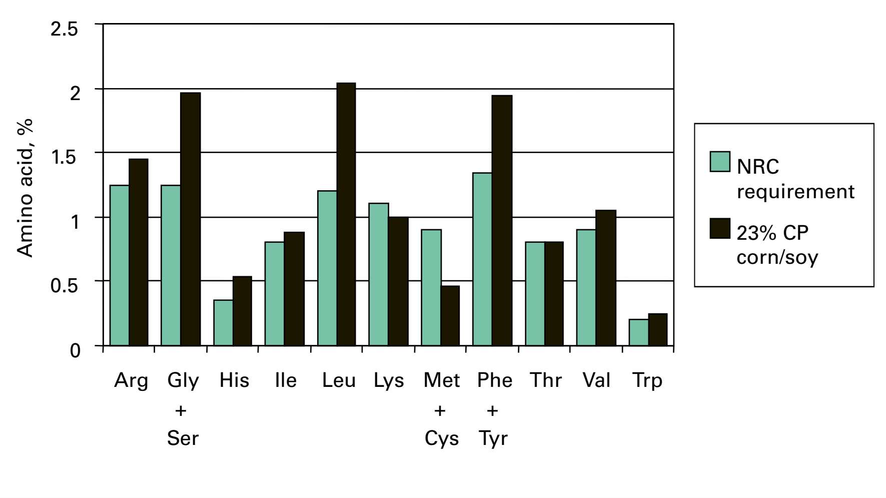

**Figure 11-1. Dietary amino acid requirement vs. supply in a 23% CP CSM broiler starter diet.**

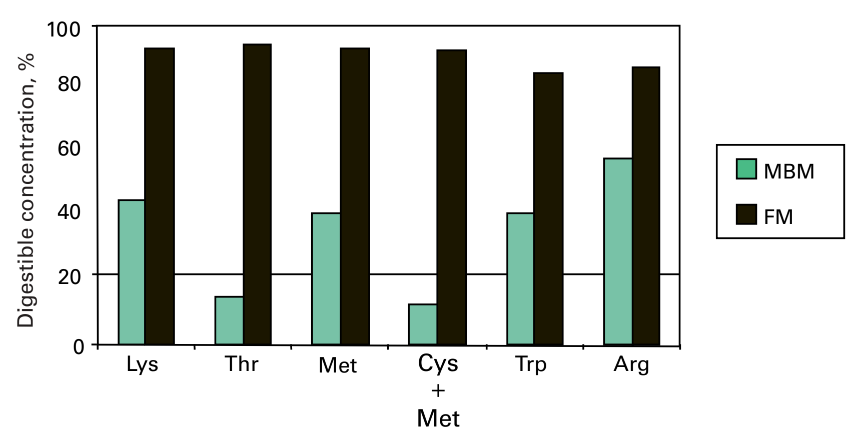

**Figure 11-2. Digestible amino acid concentration of MBM and FM, %.**

**Table 11-2. Variation in meat meal amino acid concentration.**

| | Meat Meal Sample | | | | |
|---|---|---|---|---|---|
| **Amino Acid** | **A** | **B** | **C** | **Mean** | **CV %** |
| Methionine | 0.61 | 0.41 | 0.49 | 0.50 | 20.00 |
| Cystine | 0.70 | 0.30 | 0.39 | 0.46 | 45.28 |
| Lysine | 2.77 | 1.93 | 1.94 | 2.21 | 21.78 |
| Threonine | 1.73 | 1.12 | 1.25 | 1.37 | 23.51 |
| Arginine | 3.62 | 3.00 | 2.90 | 3.17 | 12.29 |

Source: Wicker 1993.
Note: Samples A, B, and C are from a single renderer.

diet, leading to greater N deposition in the manure. Variability of ingredient nutrients can be a significant problem and push nutritionists to apply a margin of safety to meet the birds' requirements. This can be a challenge with byproduct meals such as meat meal and bakery byproducts. For example, the amino acid concentration in meat meals supplied by some renderers can greatly vary by as much as 8% to 45% coefficient of variation (CV) or as little as 2% to 8% (Table 11-2).

Rapid ingredient analysis techniques at the feed mill such as near infrared reflectance (NIR) provide nutritionists with real-time nutrient concentration and variability to minimize overformulation and margins of safety (Angel 2000). Near infrared reflectance technology for quick determination of protein, fat, and fiber exists and has been in place in some commercial mills for several years. While digestible amino acid predictions from NIR analysis have been developed (Van Kempen and Simmins 1997), commercial mills have not utilized this tool to its fullest extent for nutrient management purposes.

Another way to account for nutrient variability of ingredients if quantitative analysis cannot precede formulation is to include it in your ingredient database. Roush et al. (1996) compared computer feed formulations using linear programming with a margin of safety (LPMS) versus a stochastic nonlinear (STCH) approach. When diets were formulated for 23% CP with corn, soybean, corn gluten, and MBMs using both approaches, each with a requested 69% probability for the protein requirement, the results were not the same. The LPMS diet cost slightly more than the STCH diet ($178.70 vs. $178.31/ton) and protein levels were slightly higher (23.46% vs. 23.28%). The STCH approach applies the actual CP standard deviation (SD) for each ingredient compared with the LPMS approach that subtracts 0.5 times the SD (probability of meeting the requirement greater than or equal to 69%) to standardize the margin of safety. The authors then compared LPMS and STCH diet formulations at several different requested probability levels (50, 60, 70, 80, 90) for meeting a 23% CP requirement. Diets formulated by STCH programming more accurately met the CP amount with lower levels at requested probability from 60% to 90%. The SD of the diet CP decreased with increasing probability level from 50% to 90%. The lowest SD was achieved by an increase in the inclusion ratio of soybean meal (SBM) to MBM [SBM: 48.8% CP, 0.4 SD; MBM: 49.3% CP, 3.2 SD]. The take home message is that better accounting for ingredient CP, amino acid variability, and digestibility can reduce over

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**To enhance N retention, utilize enzymes and feed additives**. Dietary enzymes have the ability to free up the carbohydrate and fiber portions of many cereals and byproduct ingredients for poultry. On a world scale, enzyme supplements are used extensively with wheat- and barley-based diets for both broilers and layers.

Water-soluble, nonstarch polysaccharides (NSP) including arabinoxylans are the major fiber constituents in wheat and rye that give rise to highly viscous intestinal digesta. Their gel-like viscosity impedes the digestion and absorption of proteins, fats, and carbohydrates. Endogenous enzymes cannot hydrolyze these pentosans; however, inclusion of dietary enzymes (xylanase, arabinoxylanase) can greatly improve their nutrient utilization.

Another NSP present in barley, oats, and wheat are the beta-glucans. They also reduce nutrient utilization by way of greater digesta viscosity and are characterized by sticky feces and poor litter conditions among birds fed significant levels of these cereals. Dietary enzymes tailored for these ingredients contain β-glucanase.

While there has been widespread use of cereal hydrolyzing enzymes for poultry in certain parts of the world, relatively little attention has been paid to the remaining 25% to 35% of dietary ingredients supplied predominately as vegetable proteins. Soybean and rapeseed meal, peas, beans, and sunflower seeds are commonly added to poultry diets for their protein and energy value. However, even more complex NSP are an integral part of the cell wall of these oilseeds and legumes. These NSP increase the viscosity of the digesta and interfere with nutrient digestion and absorption. The amount of protein in cell walls may account for 10% to 30% of the total dietary fiber mass. For birds and other monogastrics, this protein remains encapsulated with the polysaccharide matrix and unavailable to the animal. However, it is possible to improve the NSP digestion of SBM. Even after oil extraction and heat treatment, soybeans contain 6% to 8% oligosacharides (predominantly raffinose, stachyose, and cellobiose) that are associated with reduced nutrient utilization. Oligosacharides can be extracted with ethanol, resulting in a 10% to 20% improvement in dry matter digestibility (Leeson and Summers 1997). Enzymatic release of these proteins through selective enzymatic additions can increase amino acid availability as well.

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Zanella et al. (1999) demonstrated in broilers that enzyme supplementation of CSM-based diets with a cocktail of xylanase, protease, and amylase significantly improved CP digestibility by almost 3% as well as starch, fat, and energy by intestinal contents analysis. Amino acid digestibility was similarly improved for 15 of 16 amino acids measured and significantly so for threonine, serine, glycine, valine, and tryptophan. In a performance trial with male broilers to 45 days of age, enzyme supplementation significantly improved body weight gain by 50 g and feed-to-gain ratio by 4 points (1.86 vs. 1.82). While enzyme supplementation should allow a reduction in CP formulation for nutrient management purposes, the authors cautioned that individual amino acid digestibilities were not improved equally and should be balanced for optimum bird performance.

Another of these polysaccharides, β-Mannan, and its derivatives (β-galacto-mannan or β-gluco-mannan) are integral components of the cell walls in many legumes including canola and SBM (1.3%-1.6%). Enzymes with β-Mannanase activity have improved feed conversion of swine and broilers fed CSM diets. Recently Jackson et al. (1999) demonstrated a beneficial effect of adding

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β-Mannanase to the CSM-based diets of laying hens. Significant improvements were realized in early egg weight and egg production later in the hen's cycle. Because studies have shown that β-galacto-mannan interferes with glucose metabolism and insulin secretion rates in swine, it is theorized that suppression of insulin secretion may impair intestinal uptake and utilization of glucose from starch and amino acids in peripheral tissues, resulting in reduced growth and feed conversion.

Phytate P found in most plant materials is a bound form of P that is not well utilized by monogastrics, especially the young bird. In the birds, gastrointestinal tract phytate binds to protein-amino acids and protein-minerals, forming complexes, which are difficult to digest, thereby reducing protein utilization. Another action of phytate is to inhibit proteolytic enzymes such as pesin and trypsin, yielding the same result. Sebastian et al. (1997) studied the apparent digestibility of protein and amino acids in broiler chickens fed a CSM diet supplemented with the microbial enzyme phytase. Phytase supplementation increased growth performance in both males and females and both apparent ileal and fecal digestibility of most amino acids, particularly in females.

Other work with both broilers (Namkung and Leeson 1999; Ravindran et al. 1999) and turkeys (Yi et al. 1996a) demonstrated significant improvements in the digestibility of amino acids and protein and apparent metabolizable energy, when phytase was added to the diet. According to Ravindran et al. (1999), mean digestibility of 15 essential amino acids in feedstuffs with and without added phytase (1,200 FTU/kg) in 5-week-old broilers was improved an average of 3.8%. However, the degree of impact varies, depending on the cereal or oilseed one considers (Table 11-3).

Antibiotics used as growth promoters have also been tested for their ability to reduce ammonia volatilization. Alvares et al. (1964) reported that antibiotics reduced bacterial ureolytic activity and ammonia ($NH_3$) levels in the intestine of poultry. Their studies using broilers showed increases in growth with an improvement in feed efficiency when urea hydrolysis was

**Table 11-3. Impact of supplemental phytase on average digestibility of 15 essential amino acids, %.**

| | Phytase | |
|---|---|---|
| **Ingredient** | **Absent** | **Present** |
| Corn | 78.0 | 80.4 |
| Sorghum | 74.7 | 79.4 |
| Wheat | 77.7 | 84.6 |
| Soybean meal | 82.2 | 85.5 |
| Canola meal | 78.7 | 80.7 |
| Cottonseed meal | 70.8 | 74.2 |
| Sunflower meal | 76.7 | 80.7 |
| Wheat middlings | 70.8 | 73.4 |
| Rice polishings | 62.1 | 66.9 |
| Average improvement | — | **3.79%** |

Source: Ravindran et al. 1999.

suppressed. Others have indicated that supplementation of zinc bacitracin or thiopeptin to the diet reduced ammonia volatilization (Kitai and Arakawa 1979). Anaerobic bacteria in the bird's ceca and multiple species in litter (aerobic oxidation) that decompose uric acid to urea with hydrolysis to $NH_3$ are impacted by dietary antibiotics. However, the use of antibiotics per se in livestock and poultry production has gradually decreased, although other growth-promoting agents are still used extensively. The mode of action of most growth-promoting agents is comparable to antibiotics in terms of beneficial modification of the gut microflora. Eliminating deleterious microorganisms can reduce thickening and keratinization at the level of the intestinal mucosa (site of absorption), thereby improving nutrient utilization and feed conversion, and reducing nutrients in the waste.

Probiotics, unlike antibiotics, imply the use of live microorganisms that are either viable microbial cultures or their fermentation products. Most products are centered on *Lactobacilli*, *Bacillus subtillis*, and some *Streptococcus* species. In most instances, feeding live cultures of "good bacteria" modify the gut microflora of birds at the expense of coliforms such as *E. coli* and *Salmonella* species. The beneficial effects on nutrient utilization and feed conversion are then similar to antibiotics. With the advent of genetic engineering, these bacteria can be modified to carry other desirable gene characteristics including the production of digestive enzymes or antimicrobial substances to aid nutrient utilization and waste reduction.

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Other feed additives made from the desert plant *Yucca schidigera* and the *Quillaja saponaria* tree of South America have nonsteroidal saponins with surfactant activity. These additives act by reducing the surface tension for nutrients at the site of absorption, resulting in increased weight gain, improved feed conversion, and less waste N remaining with the manure and litter. While the exact mode of action of these compounds is still debated, researchers have reported lower levels of noxious gases including $NH_3$, hydrogen sulfide, and others associated with the manure and litter. Extracts of the *Yucca schidigera* have reportedly had a variety of beneficial effects when included in the diets of farm animals. However, the benefits in poultry are not well documented (Dziuk et al. 1985, Johnson et al. 1981, Johnson et al. 1982, Rowland et al. 1976).

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**To improve protein digestibility, avoid or control ingredient anti-nutritional factors**. Anti-nutritional compounds including trypsin inhibitor in soybeans, lectin in legumes, tannins in sorghum, and the previously mentioned NSP and phytate P can negatively affect the digestion and use of amino acids and other nutrients. These inhibitors are present in many legumes and cereals.

Soybeans contain a number of anti-nutritional factors for poultry, the most problematic being trypsin inhibitor. Trypsin is a pancreatic enzyme that aids in the digestion of proteins. Fortunately, the heat treatment used during SBM processing or soybean roasting, is usually adequate to destroy it. Since there is no simple assay for trypsin inhibitor, levels are usually measured indirectly by determining the urease activity as a marker enzyme via a change in pH, with an acceptable range of 0.05 to 0.2 (Leeson and Summers 1997).

Lectins are proteins in legume seeds that have a high affinity for certain sugar molecules. They can disrupt the brush borders of cells lining the duodenum and jejunum, causing various adverse effects including reduced growth, diarrhea, and decreased nutrient absorption. While lectins in soybeans are relatively nontoxic with little negative activity, field beans (*Phaseolus*) including kidney beans are highly toxic in terms of reduced animal performance without moist heat destruction (Cheeke 1998).

Various strains of sorghum are well known for their high tannin content, which can decrease the protein's digestion and utilization, leading to increased excretion in the feces (Cheeke 1998). Specifically, condensed tannins in sorghum react with dietary protein, forming indigestible complexes that bind with digestive enzymes and reducing the digestibility of all dietary nutrients. Condensed tannins cause irritation and erosion of the intestinal mucosa, resulting in the increased secretion of mucus to protect against cell damage. This hypersecretion of mucus increases the metabolic protein requirement of the bird because of extra endogenous protein excreted in the feces. While not commonly fed in the United States, high tannin varieties of sorghum can result in up to a 10% reduction in dry matter and amino acid digestibility (Leeson and Summers 1997).

It is apparent from the previous discussion that selecting plant varieties with low levels of anti-nutritional compounds, employing heat and extraction treatments, and/or using strategic dietary enzymes are all strategies to improve nutrient digestibility and reduce N excretion.

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## Management strategies

Field work conducted with commercial pullets, laying hens, broilers, and turkeys in Pennsylvania before strategic measures were taken to modify nutrient excretion (1994-1997) indicated that between 18% and 40% of dietary N is lost to the atmosphere as $NH_3$ or other nitrogenous compounds (Table 11-4). Today, because of concerns for grower health, bird performance, and the impact on the environment, numerous management strategies have been developed to minimize $NH_3$ losses. While allowing $NH_3$ losses from the litter or manure might seem like a good way to reduce the N level, a better means of managing this N is to trap it in the litter, where its environmental fate can be better controlled. Ammonia N losses to the atmosphere can result in direct contamination of surface water. Nitric oxide (NO) and nitrous oxide ($N_2O$) losses can contribute to the formation of nitric acid ($HNO_3$), one of the principal components of acid rain.

Damp litter or manure more readily gives off odor and ammonia gas.

**Reduce or eliminate moisture contamination of litter and manure.** Damp litter or manure more readily gives off odor and NH3 gas. Ideally, litter should be managed to have 20% to 25% moisture. The easiest way to maintain dry litter conditions is to prevent all sources of exogenous water from coming in contact with the litter. In the poultry house or storage shed, repair all roof leaks and damaged gutters and spouting. Raise curtains and

**Table 11-4. Partitioning of feed N in commercial poultry.**

| | Percent | | | | |
|---|---|---|---|---|---|
| **Poultry** | **Feed** | **Manure or Litter** | **Carcass** | **Eggs** | **Atmosphere** |
| Laying hens | 100 | 25.01 | 0.84 | 34.07 | 40.01 |
| Pullets | 100 | 43.20 | 25.30 | — — | 31.50 |
| Turkeys | 100 | 28.00 | 46.00 | — — | 26.00 |
| Broilers | 100 | 30.56 | 51.08 | — — | 18.36 |

Sources: Patterson and Lorenz 1996; Patterson and Lorenz 1997; Patterson et al. 1998; and Patterson et al., unpublished data.

shut doors and windows to prevent driving rain from coming in contact with the litter. Proper house siting and grading before construction can eliminate surface water or groundwater as a litter contaminant.

Proper drinker management goes a long way to prevent water contamination of the litter. Adjusting the height of the nipples, cups, or bell drinkers to the height of growing birds greatly reduces spillage. Walk the house daily, checking drinker adjustment and repairing system leaks. Maintain the watering system by using proper filtration and sanitation, which prevent leakage due to contaminants or buildup. After five years, most drinking devices should be checked for wear. Replace or repair worn nipples or cups as needed. Malone (2000) indicated reductions in litter cake volume of 50% to 90% are often reported following nipple replacement in broiler houses.

Lastly, ventilation is the primary tool available to poultry producers that minimizes manure and litter moisture. Proper design and capacity of the ventilation system as well as maintenance are essential to exhaust the moisture generated by the birds (1,000 gallons of water are produced daily by 20,000 4-lb broilers). Furthermore, reducing manure moisture to less than 25% decreases the ability of flies to reproduce, eliminating a nuisance at the urban/rural interface.

**Compost stored litter or manure to a stable endpoint.** For centuries, organic waste streams have been composted. More recently, composting has been used as a management tool to stabilize large quantities of livestock and poultry manure that might otherwise generate $NH_3$ odors and propagate flies. Composting is a biological process of decomposing organic materials to a humus-like product. While this process will occur naturally, it can be speeded up when key elements are provided (Carr 1994).

A proper nutrient mix or recipe includes a blend of carbonaceous (sawdust, wood shavings, straw) and nitrogenous (manure) materials at a desirable carbon-to-nitrogen (C:N) ratio. The ratio can vary between 20:1 to 35:1. Lower C:N ratios produce rapid composting activity at the beginning; however, more $NH_3$ and odors are given off. Broiler and turkey litter usually have ample carbon for the composting process, while hen manure is lacking sufficient carbon.

Moisture in the range of 40% to 60% is acceptable for most composting. Moisture levels greater than 60% may result in liquid leaching from the compost pile and can create anaerobic conditions, odors, and gaseous N losses.

Oxygen is required to maintain the composting process. Aerobic conditions are necessary for the multiplication of thermophilic (heat-loving) bacteria to control odors including $NH_3$. As oxygen is depleted from the compost, one of the indicators may be a temperature drop in the compost mix. Infrequent turning of the compost pile may not be sufficient to optimize the process, and other mechanical systems for introducing air may be required.

Heat is generated during the composting process by microorganism metabolism. If the mixture is too wet, does not have the right C:N nutrient ratio, or is improperly aerated, the mesophilic bacteria (grow at < 110ºF) and thermophilic bacteria (grow between 110-115ºF) will not propagate. Good composting temperatures range from 135ºF to 145ºF.

Litter pH is another important factor for successful composting. If a mixture has a pH of 8 or greater, ammonia volatilization as well as odors may become a problem. A desirable pH range is between 5.5 and 7.5.

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However, depending on the initial ingredients and composting conditions, the pH can fall outside this range and require chemical adjustment to better trap manure N with the compost.

Further reading about the successful composting of poultry and livestock manures and farm mortalities can be found in Lessons 25, 43, and 51.

The best way to prevent $NH_3$ emissions from poultry litter and manure is to...[dry] freshly produced manure as soon as possible and [keep] it dry.

**Implement technologies for rapid drying of litter and manure.** Ammonia emissions from poultry houses result from the decomposition of uric acid in the droppings to $NH_3$, carbon dioxide, and water. This reaction is largely due to microbial activities. The best way to prevent $NH_3$ emissions from poultry litter and manure is to reduce microbial decomposition, which can be accomplished by drying the freshly produced manure as soon as possible and keeping it dry. New and evolving poultry housing and cage systems can have a major impact on the moisture level, composition, and characteristics of litter and manure generated in these systems.

Noll et al. (1997) showed that using a partially slotted floor system for market turkeys significantly reduced litter moisture by more than 10% and average $NH_3$ levels from 36.6 to 24.4 ppm. While 18-week body weights were consistently increased on the partially slotted floor system, the incidence of breast blisters and leg problems were alternatively increased or not influenced by the slotted floor in the two studies. Supplemental energy use (kbtu/bird) on the partially slotted floor system was reduced to almost half (51%-66%) of the standard litter floor. Overall, it is apparent that partially slotted flooring systems in cold climates can reduce litter moisture, $NH_3$ levels, and energy use when excessive litter moisture is a problem.

Another system developed in the Netherlands for commercial broilers uses a ventilated floor that is capable of reducing $NH_3$ production by 90% (Middelkoop 1994). The system forces air through an elevated floor built on slats and covered with a special permeable cloth. Fans placed in the raised floor force air from the upper bird area down under the floor, which is sealed at the walls. Warm air moves up through the litter and droppings on the permeable cloth, rapidly drying fresh droppings and maintaining litter in a dry state.

Litter moisture levels are less than half (20.3% vs. 44.2%) on the ventilated floor system compared to conventional house litter. Relative $NH_3$ emissions can be reduced from 90% to 50% of conventional houses, depending on the use of full or partially ventilated floor systems. While there are challenges with cold season brooding temperatures and dust with the very dry litter, benefits with the ventilated floor systems include better hot weather management and greater ease catching the birds at the end of the grow-out period. Motors slowly wind the cloth and convey birds to one end of the house where a cross conveyor separates birds from litter and directs them to a crate-loading crew. While the cost of such systems may be prohibitive in the United States, they may be economical in a green or environmental niche market or in sensitive regions with environmental or air quality concerns.

A similar Japanese system uses an intermittent (3 times/hr), slow-moving (24 in/min) belted floor to remove manure from the house for better moisture and N management. This system offers the birds a healthy environment with less carcass pathogens and better air quality. Commercial application of this system is yet to be determined (Okumura and Hosoya 2000).

Many new cage systems have been developed for both egg- and meat-type chickens that use rapid manure-drying technologies. Manure belts under the birds catch fresh manure in a thin layer, exposing it to various drying mechanisms before removing it from the bird's environment. One system uses ductwork in the backs of cages to carry warm air the length of the house with venting directed down over the manure belt to bring about drying. Another system fans the manure on the belts with many paddles connected on a single cable running the length of the house. A third elevates manure on multiple belts to a heated drying chamber above the birdcages; moisture is given off in the exhausted air as manure passes the length of the chamber multiple times before leaving the house as a dry product. Each of these systems causes substantial drying (30%-10% moisture, depending on conditions) from the fresh moisture level of approximately 80% moisture.

**Utilize litter/manure amendments for N and $NH_3$ control**. Numerous amendments can affect $NH_3$ volatilized from poultry litter. Many benefit bird performance and facilitate the recycling of litter at reduced heating and ventilation costs. However, the results realized from any litter amendment depend on the vast range of poultry management scenarios. Many types of litter/manure treatments either affect the microorganisms that convert uric acid or urea to $NH_3$ or the respective enzymes responsible for hydrolysis of these compounds. Many chemical amendments exert their effect by changing litter pH, while others trap $NH_3$ in a bound form that is not lost to the atmosphere (Malone 1998).

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Aluminum sulfate or "alum" is an acid that produces hydrogen ions ($H^+$) when it dissolves in litter. These $H^+$ react with $NH_3$ to form ammonium ions ($NH_4^+$). The ammonium ions react with sulfate ions to form ammonium sulfate; a water-soluble fertilizer that reduces the $NH_3$ emitted from the litter and increases its N fertilizer value. Alum, when applied to broiler litter at the rate of 2 tons/house or 0.2 lbs/bird reduces ammonia volatilization by 97% for the first four weeks in commercial houses (Moore 1998). Improvements in body weight, feed conversion, mortality, and reduced energy costs for ventilation have shown a favorable cost/benefit ratio.

Recent work by Wilson (2000) evaluated liquid alum and an automated delivery system to control $NH_3$ in high-rise laying hen houses. A 25% liquid alum solution was delivered over each of five rows of manure in the pit of a commercial hen house. The system uses RainBird® irrigation nozzles, which can be run manually or automatically using timers or $NH_3$ sensors, to deliver the liquid alum. Ammonia levels dropped from 70 to 40 ppm in less than 20 minutes. Each 10-second alum treatment reduced $NH_3$ levels to a new level lower than the previous treatment, creating a stair-step pattern. The author noted that spraying liquid alum in a hen house is much different than spraying in a broiler house, where reductions in pH cause lower $NH_3$ emissions. In this case, the liquid alum is actually scrubbing the $NH_3$ from the air, rather than preventing its volatilization.

Terzich (1998) reported a commercial blend of sodium bisulfate at 2.5 kg/10 sq. meter significantly reduced litter pH and $NH_3$ levels in 100 treated houses compared to 100 control houses. Other benefits of the treated litter environments included less ascites, reduced litter *Salmonella enteritidis*, reduced carcass *Campylobacter* contamination, and better bird performance.

The direct application of mineral or organic acids has also been used to reduce litter pH. While these products can successfully reduce ammonia volatilization, there can be drawbacks. Phosphoric acid is a concentrated acid (44.6N) that readily binds $NH_3$ as $NH_4H_2PO_4$. Unfortunately, additional

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phosphates make it less desirable because litter P levels already limit field application, and phosphoric acid is a highly soluble form of P that can readily migrate off the field and into surface water and groundwater. Concerns about worker safety, equipment corrosion, and strict transportation guidelines are considerations with some products, which likely limits their commercial application (Adams 1998).

To maximize the effectiveness of any litter treatment, proper preparation, application, and management of the poultry house and litter are essential. While there might be many reasons for their use, reduced $NH_3$ emissions and beneficial cost/benefit ratios are likely to be realized.

**Reduce bird stress and maintain health**. Many stressful conditions for birds can result in greater nutrient losses to the environment. For example, heat-stressed birds drink excessively to cool their rising core body temperatures. Unfortunately, excessive drinking also increases the rate of intestinal passage and flushes nutrients through the birds' system. Other challenges are pathogenic bacteria and coccidia that can overwhelm the birds' gastrointestinal system. These cause thickening and lesions of the absorptive surface lining the intestine, resulting in less efficient feed utilization and the unnecessary passage of nutrients. Therefore, any efforts made to maintain bird comfort and health pay dividends in nutrient utilization.

**When possible, implement sex-separate rearing**. Poultry meat consumption continues to increase, and the demand for nuggets, patties, parts, and buckets has fostered greater specialization in raising the ideal-sized bird for the marketplace. Finishing birds at different ages is used to its fullest advantage to generate the right size and weight carcass, or parts, for the market. However, as birds mature, differences between males and females become more evident and influence feed consumption, feed conversion, bodyweight, and carcass composition. During the first 3 weeks of life, the nutritional requirements of female broilers for amino acids are substantially lower than they are for male chicks (Baker 1995). To better meet market specifications as well as nutritional efficiencies, use the advantages gained by rearing male and female flocks separately.

**Recycle fecal N via livestock feeding systems**. When properly treated, residual carbon, N, and other nutrients remaining in poultry (and livestock) manure still have considerable feeding value. These endogenous nutrients (byproducts of metabolism), microbial nutrients, and residual feed nutrients that pass unabsorbed from poultry can be effectively used again by another animal. The concentration of nutrients in poultry manure from caged layers and floor-reared broilers is described in various publications (Bahattacharya and Taylor 1975, Dale 1999).

Broiler litter is usually the most desirable byproduct for cattle feeding because of its superior nutritional value (20%-30% moisture and CP). Properly treated litter makes a good protein supplement for brood cows, dry cows, and as a supplement for back grounding mature calves before they enter the feedlot. Litter is also an economical alternative for hay. Pregnant cows can receive 13 to 15 lbs of litter/concentrate mix per head per day along with 2 lbs of hay or forage equivalent. Cows nursing calves can be increased to 18 to 20 lbs of litter mixed per day with 2 to 3 lbs of hay or roughage. Winter calves can be fed on 50% litter and 50% ground corn, along with hay fed free choice. Four to five hundred pound calves fed 7 lbs of the litter/corn concentrate should gain a little over 1 lb per day. Processed turkey litter,

litter from broiler breeders, and hen manure are also successfully used but present challenges with feathers, moisture, or handling that require greater effort. Nutrients can be stabilized and pathogenic bacteria/viruses eliminated by various treatment strategies including anaerobic digestion, ensiling, deep stacking, simple dehydration, and extrusion pelleting. Deep stacking is the most common process of stockpiling litter for later use. Before litter is fed, it should be deep stacked and undergo a combined partial composting-ensiling process with an extended period of heating at 140ºF to 160ºF. The final product should have a fine texture and an odor similar to caramelized chocolate (Collins et al. 1999).