

EB 368

Broiler Production and The Environment: 2006



COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

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In recent years, issues related to animal production and the environment have been focal points for regulators and thus for producers. This increased emphasis on regulation has driven changes in how we feed and manage animals and will continue to do so, possibly in an accelerated manner. Although the technologies developed have provided tools for producers to meet, at least in part, the new standards without greatly affecting production costs, new regulations are imminent, primarily regarding air emissions that will, in all probability, challenge again the producer's ability to maintain productivity and economic viability. This bulletin addresses current and upcoming regulations, and examines the tools that are available or are being developed to meet these new challenges. It also aims to start a discussion on the need to look at environmental stewardship in a holistic manner where it is made clear that implementation of different strategies will impact other production cycle areas.

The poultry industry has made tremendous strides in the past 50 years to meet the demands of the retail and food service industries for an increased supply of inexpensive and safe meat and eggs. Pressure to lower costs and increase supply has led to more efficient operations, made possible only through the use of larger, more integrated facilities and through improvements in the broilers' genetic potential and in animal and feed management. In certain areas, the use of larger facilities, associated with higher concentrations of livestock, has given rise to environmental concerns and to legislative measures.

It is important to keep in mind that the genetic, management, and feed formulation improvements made in the last 50 years have led to increases in productivity accompanied by large decreases in the amount of nutrients

needed and excreted per pound of broiler produced. Work reported by Havenstein et al. (1994 and 2004) shows that not only are broilers heavier at an earlier age (591 vs. 2,903 grams at 42 days of age for male broilers that were fed their respective year representative diet) but also that broilers are more efficient in utilizing the diet nutrients fed, which leads to much lower excreted nutrients per pound of broiler produced to market weight. Excretion calculations based on these publications show that primarily through genetic potential improvements, and to a lesser extent through diet formulation changes, nitrogen (N) and phosphorus (P) excretion by broiler genetic lines from 1957, 1991, and 2001, that were fed their respective year representative diets, were approximately 40, 14, and 10 grams of N and 10, 4, and 2.4 grams of P excreted per pound of broiler produced, respectively. On a percent basis, the decreases have been 65 and 60% in N and P excretion between 1957 and 1991 breeds. As demonstrated by the decrease that occurred between 1991 and 2001 of 34 and 40% in N and P excretion per pound of broiler produced, genetic and feed management improvements appear to have accelerated in the last 15 years. These improvements in broiler productivity have been, in large part, responsible for the ability of the broiler industry simultaneously to increase productivity and maintain low product costs, and to reduce the environmental impact associated with greater production numbers. However, despite these dramatic improvements, environmental concerns associated with the concentrated production of broilers remain a priority issue today.

REGULATORY ISSUES

Water quality

Water quality protection is addressed through the Clean Water Act. In 2002 the Act was revised, largely due to poor enforcement and poor compliance with standing policy and to advances in incorporating impacts from large animal feeding operations (AFOs). Perhaps the most significant impact of the revision was a national shift toward applying manure to land on the basis of a P application rate in areas with a high risk of P loss to water. The P Index, a risk assessment tool that, based on site characteristics, P source properties, and P management practices, determines the relative potential for P loss from a field was developed in response to these concerns and is now widely used in the U.S. to assess the risk of nonpoint P pollution of ground and surface waters. This has had a greater impact in the eastern U.S. than in other regions. Moreover, it has drawn greater attention to whole-farm flows of P with the aim of minimizing the disparity between acres needed to utilize manure based on N content and acres needed to utilize manure based on P content.

For a large portion of the U.S., the 2002 revision of the Clean Water Act has resulted in few changes in standard practices. Feedlots are applying for NPDES (National Pollutant Discharge Elimination System) permits. The P Index is being used to assess water quality risk potential but because of ground slope and/or distance from waterways, many areas, even those with high soil test P, are able to continue to apply manure based on N. Although the 1970s water quality regulations and their recent revisions have had little impact on how animal products are produced for U.S. consumption, the advent of air quality regulations for AFOs, largely undeveloped at this point, may drastically change the

face of livestock and poultry production in the U.S.

Air quality

During the last decade there has been increasing interest in how AFOs affect air quality. This increased interest is mainly due to odor nuisance from AFOs. Recently, the EPA has initiated activity with respect to air quality and AFOs. While the research is limited, the continued rise in the number of people afflicted with asthma, irrespective of the relationship to animal agriculture, and the perceived notion that something that smells offensive 'can't be good for you' will very likely propel this issue further. Producers must be kept aware that in addition to worker safety issues, as overseen by the Occupational Safety and Health Administration (OSHA), concerns over downwind human health impacts will not go away anytime soon and, in fact, will likely draw greater attention from regulatory agencies and advocacy groups.

In the Clean Air Act amendments of 1990, the Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) for pollutants that are applicable to all industries. Primary standards were established to protect public health while secondary standards were established to protect public welfare (e.g., decreased visibility and damage to crops, animals, and buildings). Particulate matter (PM) was included in the standards with PM_{10} defined as particulates with an aerodynamic diameter of 10 microns or less. These, considered coarse particulates, arise primarily from combustion processes and are addressed in large part through secondary standards because they have impacts on visibility and regional haze effects. In 1997 the Clean Air Act was amended and a new criteria pollutant was proposed— $PM_{2.5}$, a fine particulate with respirable health impacts. Particles can

settle into the respiratory system, causing asthma and bronchitis as well as potential systemic effects. Cumulative exposures to respirable dust are one of the most important causes of progressive declines in lung function.

Much attention has been paid to ammonia (NH_3) emissions from AFOs. Besides functioning as respiratory irritants, NH_3 emissions are related to particulate matter. In the atmosphere NH_3 reacts with SO_x or NO_x , and forms ammonium sulfate or ammonium nitrate, both of which are $\text{PM}_{2.5}$ fine particles that contribute as much as half of the total $\text{PM}_{2.5}$ measured in the U.S. The EPA estimates that more than 70% of the national NH_3 emissions come from livestock operations. Steps to curtail NH_3 emissions from AFOs are under way. In 1997, and in response to non-attainment of PM_{10} and ozone standards, the California South Coast Air Quality Management District established local emission reduction goals for animal agriculture. The district established a goal of 30% reduction of volatile organic carbon (VOC) emissions from livestock waste by 2006 and a 50% reduction of NH_3 emissions from dairy operations by 2006. The district recognized that in order to meet these ambitious goals it would be necessary for a portion of the dairy industry to relocate.

Hydrogen sulfide is both an irritant and an asphyxiant that can be fatal at high concentrations and has been associated with deaths (both animal and human) inside animal feeding operations, most commonly as a result of manure agitation combined with insufficient ventilation. Both Minnesota and Iowa have state hydrogen sulfide standards for livestock operations that are based on human health exposure conditions. It is likely that other states will apply similar standards.

Both NH_3 and hydrogen sulfide are addressed in federal regulations as part of the Comprehensive Environmental

Response, Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) as reportable compounds if emissions from a source exceed 100 lbs/day for either NH_3 or hydrogen sulfide. Ammonia emissions have received attention because they far exceed those of hydrogen sulfide (40- to 50-fold) for AFOs. Recent CERCLA and EPCRA violations by AFOs prompted the EPA to establish a consent agreement that allowed the animal production industry to finance and conduct a monitoring study intended to establish baseline emissions of both gases from AFOs.

More recently, volatile organic compounds (VOCs) have been targeted as concern compounds in some areas, specifically California, because they are components of odor, are precursors to ozone formation, and because they have established recommended exposure limits. The Agency for Toxic Substances Disease Registry (ATSDR), a non-regulatory federal agency, has recommended, based on dose response studies, exposure limits that are a function of the concentration and duration of many individual VOCs, as well as of hydrogen sulfide and NH_3 . The San Joaquin Valley Air Pollution Control District of California has recently established a VOC production value for the dairy industry that will be used to assess compliance status with the regional VOC standard.

Odor chemistry is complex and still poorly understood. Hundreds of odorous compounds, in varying proportions, interact to create a perceived odor. Odor perception is highly subjective depending on the individual, which makes odor nuisance standards difficult to set and thus to regulate. However, odor has generally been considered a nuisance and there is considerable interest in determining its impact on human health. Some states have pursued this issue through state and

local boards of health. States that have implemented some sort of odor standard include North Dakota and Colorado. Missouri requires odor control plans and has a proposed, but as yet unapproved, odor standard. As a result of the complex nature of odor, more recent air quality activity, born out of concern for odor nuisance, has focused on the more tangible and measurable characteristics of odor and specific gases.

Emerging/potential issues

Limited and unduplicated data suggest that animal facilities produce antibiotics emissions. One such report suggests that swine buildings exhausted, in active form, approximately 30% of the tylosin administered. Although the data are not duplicated, and despite broad-scale efforts to reduce sub-therapeutic use of antibiotics in the animal industry, in the future the implications to human health could lead to regulatory activity. Anthropogenic sources are reported to contribute 6% of global greenhouse gas emissions, of which livestock contributes 17% of the total emissions from natural and anthropogenic sources, combined. In addition to direct emissions from cattle, methane is produced from the anaerobic decomposition of manure or poultry litter during storage. Animal agriculture activities produce other greenhouse gases besides methane. The decomposition of organic matter results in nitrous oxide production. Although the U.S. has not signed the Kyoto treaty, there is considerable interest in reducing greenhouse gas emissions. Recently there has been renewed discussion in the media regarding the U.S. decision to abstain from signing the treaty. At this time it is uncertain how a change in U.S. policy would impact animal production.

The effects of endocrine disrupting compounds (EDCs) on fish and bird populations have been widely studied. Regulation of pesticides took place in the 1970s and 1980s to minimize the prevalence of endocrine disruptors in the environment. Today, there is renewed interest in the issue and it is likely that the contributions of EDCs to the environment from animal agriculture will be scrutinized by EPA as a source that can be regulated and to which excretion standards may be applied in the future. To meet such standards, evaluation of breeding and estrus-synchronization programs may be necessary. These programs would particularly challenge the dairy industry. However, feeds also contain EDCs, which challenges all animal production facilities. While the extent to which feed EDCs affect the total amount of EDCs that leave the farm boundary is unknown, feed EDCs will nevertheless affect all animal and poultry production units.

Perhaps one of greatest challenges we face now as regulators, scientists, industry leaders, and producers is to determine the best ways to look at the broiler industry, and for that matter any animal industry, in a more holistic manner. We must develop approaches that allow us to understand better the impacts, interactions, and true costs of the tools we research, develop, and implement in order to be viable into the future. Viability in this context implies sustainability.

As developers or implementers of new technologies we tend to look for answers or solutions to specific questions often disregarding collateral effects unless these effects are already part of our cost/benefit equation. For example, as we are challenged to reduce air emissions from broiler production units we tend to look for one-sided solutions. Depending on our areas of expertise, we look for solutions through changes in nutrition, animal management, litter amendments and/or

litter management, house environmental changes, etc., with little regard for how each of these areas overlap and interact. It may be that a slight decrease in animal density at placement may allow us, in a holistic approach either to improve or not change productivity from a broiler house while decreasing litter moisture, litter nutrient content, and air emissions. Decreasing animal density would also decrease input costs (diet, chicks). Data that would allow us to make educated decisions about the holistic impact of reducing animal density requires that we know what the correlations between animal density, productivity, nutrient excretions/emissions, and costs are. However, the existing information base is simply not this broad.

DIETARY MODIFICATION

Phosphorus

Broiler diets consist predominantly of plant-based ingredients. Plant ingredients contain most (50 to 80%) of their P as part of a compound called phytic acid that is generally considered to be poorly available to monogastric animals. In most cases, in order to meet the P needs of the animal, broiler diets are formulated to contain inorganic sources of P primarily in the form of calcium phosphates. This results in diets that have total concentrations of P that far exceed the animal's needs. However, if phytate P (PP) can be released from the phytate molecule as inorganic P, it can serve as a bioavailable nutrient to monogastric animals. If this P release can be achieved, there would be, in the plant feedstuffs that typically make up broiler diets, adequate levels of P to meet dietary needs and therefore the need to supplement broiler diets with inorganic sources of P would be reduced significantly.

Phytate phosphorus

Phytic acid (*myo*-inositol 1,2,3,4,5,6-hexakis dihydrogen phosphate), an organic phosphate, is a phosphorylated cyclic sugar alcohol that in mature seeds contains six phosphate groups. The anion form of phytic acid, phytate, is present in all plants, primarily in the seed portion. Roots contain low amounts and vegetative parts such as leaves are either devoid of phytate or have only trace amounts. The location of phytate in the seeds varies according to the type of plant. For example, 90% of the phytate in corn is found in the germ portion of the kernel, while in wheat and rice most of the phytate is in the aleurone layers of the kernel and in the outer bran. In most oilseeds and grain legumes, the majority of phytate is associated with protein and is concentrated within subcellular inclusions called globoids that are distributed throughout the kernel; however, in soybean seeds, there appears to be no specific location for phytate. Location within the seed makes it possible, at least in the case of corn, to remove most of the phytate when corn is degermed. In mature seeds, phytate is present as a complex salt of calcium (Ca), magnesium (Mg) and potassium (K), and in some cases proteins and carbohydrates.

Phytate P content in grains is variable. Factors that influence this variability are still unknown, but it is known that soil and environmental factors affect this content. Soil P content and productivity of the grain in relation to soil P content will influence the amount of PP and total P in the mature grain. Thus, because corn is brought in from different regions, a safety margin in formulation systems is important in most broiler feed manufacturing plants.

Phytate is highly reactive and readily forms complexes with Ca, iron (Fe), Mg, zinc (Zn), carbohydrates, and proteins. These complexes are substantially less

soluble in the digestive tract than the phytic acid molecule alone. A precipitated complex is less likely to be acted upon by an enzyme such as phytase. For this reason, phytin is often considered to be an anti-nutrient because of its ability to bind with other nutrients, rendering those nutrients partially or completely unavailable to the animal.

Phytase

The hydrolytic action of the enzyme phytase on PP has been known for some time; however, fungal and bacterial phytases have been commercially produced on a large-scale only since the 1990s. One unit of phytase is defined as the amount of enzyme required to liberate 1 μmol of orthophosphate from phytic acid per minute at pH 5.5 and at 37°C. Because enzyme characteristics differ among phytases, a unit of activity in the above conditions does not necessarily translate into the same amount of P released within the animal. This last point is key, because it is not the commercially misused term “efficacy” that is important when considering commercial phytases. What should really be considered is the amount of P liberated in the broiler’s digestive system by phytase at the manufacturer’s recommended, and presumably implemented, inclusion level for the dietary ingredients and nutrient concentrations being used. This would ultimately translate into a cost of the phytase per unit of P made available to the animal.

Understanding some of the chemical interactions that the phytate molecule is capable of with other dietary constituents may allow for a better understanding of why the efficacy of phytases differs between different poultry, why the action of phytases can differ between flocks, and why the physiological changes in the bird affect the various phytase sources

differently. Most important to understand is why when an enzyme capable of hydrolyzing P from phytic acid is present in the intestinal mucosa of broilers it appears to have very limited efficacy.

At pHs encountered in the broiler digestive tract (2.5 to 7), phytate will carry a strong negative charge and is capable of binding cations such as Ca, Zn, copper (Cu), Fe, manganese (Mn), cobalt (Co) and Mg, among others, in very stable complexes. The availability of any nutrient held in these complexes is greatly reduced. This means not only that seed-based ingredient P is poorly available to broilers but also that any diet Ca, Zn, Cu, Fe, Mn, Mg, and Co bound to phytate will also be poorly available to the animal. At the higher pHs encountered in the small intestine, where the broiler’s phytase is located and where most of the digestion and absorption occurs, these phytate complexes tend to precipitate; the efficacy of any enzyme on precipitated complexes is, at best, poor. This means that the pH activity range of the phytase, relative to broiler physiology, should be an important factor in choosing a commercial phytase, as it will determine, to a great extent, how well the enzyme works under different physiological conditions and feed nutrient concentrations.

Reducing litter phosphorus through diet modifications

Broiler diets can be modified in several ways to reduce substantially the concentration of P in broiler litter. Broilers can be fed to requirement, essentially by reducing overfeeding of P via decreasing the amount of P included in the diet from inorganic sources. In conjunction with feeding closer to requirements, the addition of enzymes or other dietary amendments that enhance P availability and thus P use by the broiler from diets fed can substantially decrease P in litter.

Under research conditions, diet P reductions of 21%, in the presence of dietary phytase, have reduced litter total P by 39%. Limited survey work done on farms in Delmarva, prior to the use of phytase and two years after phytase use was implemented, showed that under commercial conditions broiler litter P was reduced by 30% when diet P was reduced by 10%. In conjunction with feeding closer to requirements and with the use of phytase, diet management has the potential to reduce, as compared to 2002 industry concentrations, up to 40% in fed P and 70% in litter P. The most promising diet management strategy is the use of moderately high concentrations of available P in the pre-starter and starter phase combined with no added inorganic P in the finisher and withdrawal phases. Research-based information shows that further decreases in litter P under field conditions are possible, but it is important to recognize that as diet P is reduced further and broilers are fed closer to their P needs, the potential for deleterious effects on animal productivity and processing yields increases.

Recently, some questions have been raised about the use of phytase in broiler diets. Some research and field data suggests that the use of phytase in poultry diets increases the amount of water-soluble P in broiler litter, which in turn increases the potential for more P runoff when the litter is land-applied. Reviewing concentrations of P fed in these studies and field data makes it clear that the reductions made in the amount of P fed when phytase was added were not large enough and that this resulted in concentrations of diet available P that were greater than those needed by the broiler. Consumed available P that exceeds the broiler's needs is excreted in a more soluble form, which leads to increases in litter water-soluble P. A series of studies has demonstrated that when diets are correctly modified to include

the effect of phytase, both the amount of total P and of soluble P in litters will be reduced (Angel et al., 2005). Clearly, misuse of phytase is a possibility when diet P reductions are not large enough. Under commercial conditions, where safety margins must be considered when formulating diets, some excess available P will be present in the diet but the goal is to minimize this.

Another promising tool is the development of low-phytate grains. These grains tend to contain the same amount of total P as their unmodified counterparts but have usually one third of the phytate P. Unfortunately, these modified grains have resulted in reduced yields, in most cases related to low germination. Research continues in this area and as regulations tighten and greater P reductions are required this tool may become cost effective.

In the U.S. the most widely used inorganic P source has been deflourinated phosphate (DFP). Among the three commercially available inorganic P sources, DFP is the source with the lowest availability of P. Relative to monocalcium and dicalcium phosphate, the two other main sources of supplemental dietary inorganic P, the P in DFP is between 70 and 80% available when monocalcium phosphate is 90 to 95% available. In absolute terms, though, the availability of P in DFP is closer to 40 to 45%. This means that of the diet P from DFP that the animal consumes, only 40 to 45% is absorbed and retained by the animal, while for monocalcium phosphate retention can be as high as 55%. The industry prefers DFP because DFP has properties beyond its contribution of P to the diet, such as improved diet throughput through the pellet mill and thus lower energy costs for pelleting. A second, less important, reason is the higher content of P in DFP that results in less physical space being occupied in the diet by the P source in

a diet that is already tight for space. Up to now costs have favored the use of DFP, despite its reduced P availability compared to other inorganic P sources. The lower costs associated with using DFP are related primarily to cost reductions in feed mill operations rather than to cost savings for any ingredient or to the space-saving properties of DFP. The improved throughput leads to greater productivity of the pellet mill partly because there are fewer stoppages due to die plug ups and because less energy is needed for pelleting when DFP is used (possibly because the pellet dies are abraded clean when this ingredient is used). It is still to be determined what DFP level in the diet is needed in order to see these positive benefits at the pellet mill but dietary inclusion levels of 0.25% are thought to be sufficient. This means that even though research suggests that broiler grower, finisher, and withdrawal diets do not need any inorganic P added when phytase is included, DFP may be used in the diet because of its non-P properties, which in turn results in higher diet P and litter P concentrations. Ultimately, economics will dictate how fully research-developed tools are implemented by the poultry industry. In the future, costs of production related to P may be dictated by regulations. Recently, the cost of DFP has increased relatively more than the cost of the other two inorganic sources because the energy costs for the production of DFP are higher related to increases in the cost of petroleum. It is important that nutritionists and regulators consider the other costs/benefits associated with formulation changes, beyond those costs/benefits purely related to the nutrient needs of the animal.

Protein and Amino Acids

The current trend to lower N excretion (in litter and in air emissions) is forcing the broiler industry to look

for ways to minimize the feeding of excess crude protein in poultry feeds, while still maintaining adequate levels of amino acids to optimize performance. Historically, crude protein has been used as a measure of the amino acid content of the ingredient or feed, because protein is comprised of amino acids linked in chains (peptides). The crude protein of an ingredient or feed is calculated by measuring the concentration of total N ions and then multiplying that concentration by a constant factor (6.25). This provides an inaccurate estimate of the protein quality in feed or ingredients, because quality is related to the specific amino acid content, the ratio of amino acids, and their availability to the animal. Excretion of N is primarily a function of the utilization of the amino acids in the feed and of the subsequent breakdown of excess amino acids.

Modern broilers require a source of abundant, highly digestible feed proteins to allow them to grow to their genetic potential. Genetic selection over the years has resulted in broilers that have the genetic potential to reach 6.6 lbs. of body weight at 42 days of age with a feed conversion of 1.7 lbs. of feed per pound of live weight gain. This has resulted in extremely efficient conversion of plant proteins, the primary ingredients in broiler feeds, to animal proteins (meat).

The U.S. is fortunate to have a plentiful supply of high quality feed ingredients, namely corn and soybeans. The marketable broiler product, mainly meat, made up primarily of protein (amino acids), is based on muscle growth that occurs only if the animal consumes sufficient energy (calories) and protein (amino acids) to meet its needs for these nutrients. Corn is regarded as an ideal source of calories for these fast growing birds and soybeans (after removal of the oil) are considered the gold standard of vegetable proteins for animal feeding. To maximize growth

performance and efficiency, these nutrients (energy and amino acids) must be supplied to the animal in the correct concentration and balance. One of the primary functions of nutritionists is to use scientific or practical knowledge to formulate, within a cost frame, diets with the highest nutrient availability. It is important for nutritionists to understand the exact nutrient needs of these animals as well as to understand the variability of nutrients from the different ingredients available and in turn the variability of these nutrients within an ingredient. The nutritionist must then formulate the feeds to meet the animal's requirements at the least cost within knowledge and regulatory constraints. Nutritionists arrive at the correct balance of nutrients by blending various feed ingredients with different nutrient profiles.

Unfortunately, even though corn and soybean meal are excellent feed ingredients, they do not provide the exact balance of amino acids needed to meet the bird's requirement for amino acids. Therefore, if only corn and soybean meal are used, in order to meet at least the minimum level of the first limiting amino acid, the resulting formulation will have other amino acids in excess. Any animal will utilize amino acids efficiently up to the first limiting amino acid; all other amino acids are therefore in excess of nutrient needs and will be excreted, in the case of birds primarily in the form of uric acid. In addition to these nutritional losses, as part of the normal growth process the animal undergoes continual production and breakdown of body tissue. Together these become the source of excreted N. This excreted N may remain in the litter in the chicken house or, when exposed to bacterial fermentation, will be released into the air, mainly as NH_3 .

Soybeans are deficient in the amino acid methionine and corn is deficient in lysine; both are essential amino acids for body maintenance and growth and

are the first two limiting amino acids in most broiler diets. Even though corn and soybean meal complement each other in terms of methionine and lysine content, unless the diet is supplemented with methionine and lysine sources or unless the remaining amino acids are dramatically overfed, these two ingredients alone do not supply enough of either amino acid to meet the broiler's requirement for growth. In the late 1950s the chemical industry developed a process where methionine is chemically synthesized. In addition to methionine, other amino acids—lysine, threonine and tryptophan—were introduced commercially in the 1980s and were produced by fermentation rather than through chemical synthesis. Today lysine and threonine are available in quantities and at prices that make them practical for use in broiler feeds.

The current trend to reduce N excretion (in litter and in air emissions) is forcing the poultry industry to look for ways to minimize excesses of crude protein in poultry feeds, and yet maintain adequate levels of amino acids to optimize performance. To accomplish this, nutritionists need to conduct research to define accurately the continually changing (due to fast and frequent genetic improvements in broiler lines) amino acid needs of the broiler over every growth phase. The research needs to be aimed also at utilizing feed ingredients with highly digestible amino acids, making use of commercially available amino acids to balance the feeds more accurately, and to changing feed formulations frequently (phase feed) in order to meet more closely the needs of the bird as it ages. Commercially available crystalline amino acids are a practical and cost-effective way to reduce excess protein in feeds. As an illustration, consider a typical industry grower feed that uses corn, soybean meal, and meat meal as the primary ingredients.

To meet amino acid needs in limiting amino acid order

- a. without any added amino acids diet protein would be in excess of 26%; this, however, is an impractical feed.
- b. with methionine added, the diet protein would be around 20%.
- c. with the next limiting amino acid, lysine added, in addition to methionine, the diet protein would be reduced by another percentage point to 19%.
- d. utilizing threonine in addition to methionine and lysine would reduce diet protein to 17.5%.

Using this approach, dietary protein could be reduced by a relative 33% or absolute 8.5 percentage units. The reduction in this excess of diet protein, which is unused by the animal and is therefore excreted, corresponds to a reduction in N excretion of 20 to 30%. This is consistent with research conducted by Ferguson et al. (1998a, b), where lower protein amino acid-sufficient feeds were fed to broilers and N and NH₃ measurements were made on the litter. Unfortunately, contradictory research has been published in which the experimental design did not fully supplement amino acids; this caused amino acid deficiencies in the birds that had been fed the reduced crude protein diets and in turn ultimately led to negative impacts on performance and meat yields. This has caused confusion in the industry and created a belief that lower protein feeds will negatively affect performance.

Industry has used DL-methionine and L-lysine in diets for broilers for more than two decades, while use of L-threonine is more recent and its adoption by industry is not yet 100%. Further reductions in crude protein, to 16% in grower diets, are technically possible if the next limiting amino acids can be

supplemented economically. If we consider a typical broiler feed (corn, soybean meal and animal protein), the next limiting amino acids after methionine, lysine, and threonine are believed to be valine, isoleucine, arginine, and tryptophan. If no meat products are used, glycine becomes limiting as well. Although these amino acids are currently being commercially produced, the quantities and price make their use in poultry feeds unfeasible. A major problem with these next limiting amino acids is that they are hypothesized to be co-limiting, meaning that these amino acids need to be simultaneously available in the diet. In order for further practical reduction in broiler diet protein to occur, these co-limiting amino acids need to be commercially available at a cost-efficient price.

Air Quality and Particulates

Research indicates that dietary strategies can have a profound effect on gaseous emissions, particularly emissions of NH₃. However, the area of research that focuses on the impact of diet on air emissions is still a relatively new field. Also, the research that has been conducted has focused, primarily, on reducing nutrient excesses in the diet. In this manner, animal needs are met and there is a reduction in excess nutrients excreted.

Most of the work to date has focused on reducing dietary protein through supplementation of amino acids that are most limiting in the diet. The effect then is to reduce feed protein sources (i.e., soybean meal, meat meal) that are oversupplying amino acids that are not limiting. This result leads to reductions in diet protein and in excreted N. As a guide, for each percentage unit reduction in diet protein, estimated NH₃ losses are reduced by 10% in poultry. As mentioned earlier, current industry broiler diets are being formulated with crystalline L-lysine,

DL-methionine, and L-threonine, but as availability increases and cost decreases for the next co-limiting amino acids further reductions in excreted N will occur. Note, however, that as the animal is fed closer to requirements the magnitude of the impact that a change in diet protein can have on air emissions decreases.

Other dietary approaches aimed at reducing air emissions that have been tested include diet acidification and use of feed additives. By acidifying the diets, excreta are also acidified. The acidic conditions promote retention of N in excreta, thereby decreasing N volatilization as NH_3 . Recent work with laying hens demonstrated a 40% reduction in NH_3 emissions with no negative performance effects when the diet was acidified. Similarly, NH_3 emission reductions of 26 to 53% have been observed in swine fed pH modifiers that have included calcium salts, calcium benzoate, or a combination of phosphoric acid and calcium sulfate. These findings suggest that similar approaches may also be successful for broilers.

Several feed additives claim to reduce N excretion and NH_3 emission potential by binding NH_3 or inhibiting urease. These include extract of the *Yucca schidigera* plant, one of the most researched additives, but results have been mixed. Similarly, dietary inclusion of clinoptilolite and other clay minerals to reduce NH_3 emissions has resulted in variable findings. However, there has been recent, renewed interest in evaluating these clays as both feed additives and as manure amendments. Other additives that are of current interest and in need of investigation are bacterial products, including probiotics, which may improve intestinal health and promote better utilization of feed nutrients.

As previously mentioned, with the exception of protein reductions and associated reductions in NH_3 emissions, data supporting the impact of dietary changes on gaseous emissions are still

sparse. However, this is currently an active area of research, so in two to three years there should be considerably more information including impacts on other gases such as hydrogen sulfide, methane, and volatile organic compounds. An assessment of the duration of impact must be considered in future research plans. Certain dietary approaches (source reduction or nutrient input mass reduction strategies) may be better suited to long-term beneficial effects on air emission mitigation (manure nutrient form modification strategies). Nutrient form modification 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) changes the chemical form of the nutrients excreted. Those strategies that reduce nutrient input mass must, by mass balance definition, decrease nutrient mass output. Strategies that only change the chemical form may initially reduce nutrient emissions to air because they “trap” nutrients in a chemical form that does not volatilize. These strategies do not change the mass of the excreted nutrient. However the long-term effects of trapping nutrients and how long they will be trapped is unknown. Trapping nutrients does allow for the planned movement and use of the nutrients that are in a solid rather than a volatilized form.

An additional consideration is that although dietary strategies are currently at a stage of ‘untapped potential’, the magnitude of additional strategy adoption and implementation will likely follow the law of diminishing returns. For example, with phytase the magnitude of P excretion reduction is dependent on the starting dietary P content. If one is already feeding only slightly above the available P needs of the animal, then the result of adding phytase to the diet will be a smaller decrease in P excretion, less than if the

starting point formulation far exceeded the broiler's needs.

As we await the results of diet modification research currently under way we need to be cognizant of the fact that diet strategies alone will probably not suffice 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.

Micro-minerals and Heavy Metals

To meet nutritional requirements, several micro-minerals are included in diets for poultry. These include: Fe, Mn, Mg, iodine, and selenium. The typical concentrations contained in excreta, therefore, are minor and pose relatively little environmental concern. Other minerals, such as Cu and Zn are included for the bacteriostatic, bacteriocidal and antifungal properties at concentrations well above the bird's need. An additional heavy metal that is often included in poultry diets is arsenic (As), as the organic molecules 3-nitro-4-hydroxyphenylarsonic acid (roxarsone) or p-aminobenzenearsonic acid (arsanilic acid). These organic forms of arsenic are used as antimicrobials for growth promotion and as coccidiostats. Average concentrations of As, Cu, and Zn in poultry litter have been reported to be 37, 390, and 377 ppm (Gupta and Charles, 1999). The environmental risk of these heavy metals is largely dependent upon the soils' ability to adsorb and desorb these

elements and the potential for leaching or soil loss to water by erosion.

Arsenic

Average broiler consumption of roxarsone, when utilized at maximal dosages (as regulated by U.S. Food and Drug Administration) of 45 grams/ton of feed (5.7 lb bird, 1.7 feed:gain to 42 days of age, assuming 5 day withdrawal), would be 170 mg/bird or 48 mg of arsenic (As)/bird. To prevent resistance build up, coccidiostat drugs are rotated during the year, thereby limiting the use and eventual excretion of As. Roxarsone is predominantly excreted as the same organic molecule, 3-nitro-4-hydroxyphenylarsonic acid. However, when it reaches the soil it is rapidly converted into arsenate (As^{5+}) by soil microorganisms. Depending on soil hydration, when As^{5+} is placed into a low oxygen environment, soil microorganisms can also readily convert As^{5+} to arsenite (As^{3+}) or methylate of As^{5+} to dimethylarsinate.

Arsenic in poultry litter is easily mobilized, but strongly adsorbed by most soils, thus the leaching rate in amended soils appears to be slow enough to prevent groundwater contamination. Solubility of As after field application is only about 20% after the first rainfall (Rutherford et al., 2003) and the soluble form appears to be adsorbed to nanoscale particles in streambeds rather than being retained in the aquifer (Schreiber, 2005), which therefore limits to some degree contamination of groundwater supplies. While stored in soils, arsenic is largely associated with organic matter or metal oxides or hydroxides. Application of broiler litter that contains As to corn and soybean fields promotes the formation of As^{5+} versus the much more mobile or soluble form, As^{3+} . Nevertheless, during large rainfall events, losses of soil or surface applied broiler litter from fields

could transport As to surface waters. Notably, As is not totally recoverable from poultry manure amended soils due to oxidative and reductive transformations and the possibility exists for volatilization as methanoarsonates. The extent of this transformation is relatively small and has not been quantified.

Copper and zinc

The concentrations of Cu and Zn needed by the animal are moderately low at levels of 8 ppm for Cu and 40 ppm for Zn (NRC, 1994). Yet, throughout the U.S., most broiler diets include prophylactic concentrations of Cu (125 to 250 ppm) because it often results in improvements in feed efficiency. These improvements are similar to those observed when growth-promoting antibiotics are used. The exact mechanism for the improved feed efficiency has been purported to be through cytotoxic effects on intestinal microbiota and intestinal immune capacity and suppression. Nevertheless, these positive aspects of over-supplementation need to be weighed against possible environmental concerns including reduction in the efficacy of phytase and on P retention reductions.

Environmental concerns over litters of birds fed high Cu diets involve soil and plant health, as well as the health of the grains produced on croplands that have had high concentrations of Cu applied to them. Several aspects are involved in determining the effect of high concentrations of Cu application to croplands. Various soil properties affect the extent of Cu phytotoxicity. Factors such as soil pH and organic matter content will affect the various chemical forms of Cu within the soil (Alva et al., 2000). For example, increasing the concentration of Cu applied to soils increases the readily soluble portions, and the exchangeable and sorbed forms of the Cu content in

low pH soils. However, in high pH soils, the predominant fraction of total Cu content is precipitated. The motility of Cu in soils is quite low and Cu exhibits a strong fixation to organic matter, so if the growing vegetation does not take up Cu, it will accumulate in the upper layer of soil bound to organic matter. In a variety of soils with pHs ranging from 4.6 to 6.4, the major forms of Cu taken up by crops such as corn and wheat are the organic and exchangeable forms (Sims, 1986). The soluble forms of Cu that are exchangeable are the most phytotoxic, but, because plant roots accumulate significantly greater concentrations of Cu at higher soil pH than at lower pH (Alva et al., 2000), it is soil pH that plays the major role in the level of Cu phytotoxicity.

In a study conducted by Anderson et al. (1991) the effects of long-term applications of Cu-rich swine manure were followed over an eleven-year period. This study utilized three very diverse soil types: a fine sandy loam soil, a fine clay loam soil, and a silt loam soil. The application rate of 325 kg Cu per hectare exceeded the U.S. Environmental Protection Agency recommendation for safe Cu loading concentrations for croplands. The Cu-rich manure contained an average of 1316 ppm Cu from a diet that contained an average of 251 ppm Cu. The application of Cu-rich manure over an eleven-year period did not have a negative impact on the range of recommended Cu concentrations within the corn leaves, on the grain itself or on corn yields.

The concentration of Zn fed in commercial poultry diets averages 120 ppm, resulting in litter concentrations of 377 ppm. These Zn concentrations are much lower than those for Cu. For this reason, Cu phytotoxicity is usually a greater concern after long-term application of poultry manure to fields. Results reported by Gupta and Charles (1999) after using soils in Delmarva where broiler

litter had been applied every other year for 15 to 20 years showed that the Zn content of soils where litter had been applied were indistinguishable from neighboring woodland soils. However, Zn soil accumulation is highly soil-type dependent. Build-up of Cu and Zn can be a concern for phytotoxic sensitive crops, such as red clover, where phytotoxic concentrations can be achieved when broiler litter is applied to fields for approximately 16 years (Van der Watt et al., 1994).

Endocrine Disruptors

Endocrine disruptors are a class of compounds either synthesized or present naturally in nature that are suspected to have adverse effects in animals. They affect organisms primarily by binding to hormone receptors and disrupting the endocrine system. Monitoring for the presence, concentration, and distribution of these compounds in the environment and in food is becoming an important issue because of the potential negative consequences these compounds can have when present at relatively low levels. Testing for these compounds fully, in food products, litter, and water is still a developing science. Regulation of endocrine disrupting chemicals (EDCs) will be a reality in the foreseeable future. These compounds have emerged as possible influencers of reproductive performance in domestic poultry. As defined, EDCs include pesticides, herbicides, plant phytoestrogens, and other chemicals that interact with endocrine systems. Many of these EDCs have mild estrogenic activity and interact with reproductive function.

When it comes to domestic poultry, the challenge is not only to identify what EDCs may be found as residues in the feed constituents, but also to characterize the exposure levels that have the potential for affecting reproductive performance and

other physiological systems. Apparently the most sensitive life stage for EDC exposure is the developing embryo and the exposure to the embryo occurs by maternal deposition of the chemicals into the egg. This occurs because many EDCs are lipid soluble and therefore readily incorporated into the yolk. A critical element in defining impact is establishing reliable indices of exposure and determining if there are sufficient levels in the eggs to impact, short and long term, the developing chick.

One important activity that is currently under way is the development of tests with model species as a way of assessing potential impact. The most likely model species for birds are galliforms, particularly the Japanese quail as this species matures rapidly and is similar to other domestic poultry. In addition, the hope is that the information found using this model will be relevant for wild populations of birds and that this knowledge may make it possible to assess potential risk of EDCs to these species. Furthermore, there are a large number of suspected EDCs, so, in order to select representative chemicals for conducting testing, it becomes essential to establish chemical categories.

In broiler production, EDCs can both enter and leave the production cycle. Different sources can supply EDCs to the broiler during its production phase. These come primarily as contaminants in litter or grains used to make feeds. But because of the use of soybean meal in most if not all broiler diets the main source would be feed. Legumes can contain EDCs, specifically phytoestrogens called isoflavones. Soybean meal has been reported to contain 90, 910, 71, and 600 ppm of the isoflavones genistein, genistin, daidzein, and daidzin respectively (Konno et al., 2002). These compounds, especially genistein and daidzein have well-known estrogenic activity. Phytoestrogens have been linked to infertility in animals,

but there is mounting evidence that they can also have beneficial effects. Human populations in the Far East have consumed soybeans at high levels without any apparent deleterious effects. The isoflavones genistein and daidzein found in soybeans have been shown to influence sex hormone metabolism as well as protein synthesis and growth factor activities that potentiate anticarcinogenic effects. In fact, it is thought that they may act as chemopreventive agents.

Broilers can produce EDCs, in the form of steroid hormones that are excreted into litter. The steroids of greatest concern are estrone and 17 β -estradiol because they are often found in the environment at concentrations above lowest effect levels. Research has shown that broiler litter contains estrogen (17 β -estradiol), estrone and testosterone in measurable concentrations and that these EDCs persist in litter (Nichols et al., 1997; Shore and Shemesh, 2003; Fisher et al., 2005). Degradation of steroids in broiler litter during storage seems to be minimal. However, once steroids have reached waterways their degradation is rapid (half-life 0.2 to 8.2d). Research into the endocrine disruption impact of these naturally occurring steroids on fish suggests that, in preserved run-off from fields where broiler litter has been applied, steroid levels are high enough to cause endocrine disruption. However, when runoff was not preserved but was allowed to age in the waterway, steroid hormone levels were not high enough to cause any negative effects.

Agronomic practices can impact the loss to surface and groundwaters of EDCs in the same manner as other litter or soil contaminants that are water soluble. Conventional tillage, as compared to "no till," greatly decreases losses to water of steroid hormones from soils where litter has been applied. Use of chemical binders such as alum in litter can reduce steroid

transport into waterways from litter applied to soils. Some research has been done on the impact that age, gender, and reproductive status have on the excretion of steroids in poultry (Shore and Shemesh, 2003). Nevertheless, the influence that age and growth rate have on steroid excretion over the productive life of a broiler or roaster (hatch to 63 days of age) is not clearly understood.

Although not directly relevant to domestic poultry, exposure of wildlife is a highly visible issue. Moreover, field relevant exposures often occur at sub-lethal concentrations, making the detection of the effects of EDCs challenging, especially when attempting to separate other interacting factors in the animal's environment.

Feed Management

Developing feed management techniques that improve growth and/or feed efficiency is a longstanding goal of the poultry industry. Any technique that improves efficiency of feed conversion to growth results in better use of nutrients for production purposes and therefore reduces the amount of excreted nutrients found in poultry manures and litters. Some of the existing tools (light programs, black-out housing, intermittent lighting, light spiking, and phase feeding, among others) are used extensively but are applied variably. Lighting programs, for example, modify feeding behavior and are in part a tool to change feed consumption amounts and patterns. They can either enhance or decrease growth rate but generally result in feed efficiency improvements. The use of intermittent lighting and light spiking, which has become more prevalent recently, increases feed consumption and growth and results in some improvement in feed efficiency. Black-out housing, implemented widely in the last few years, results in improved feed efficiency

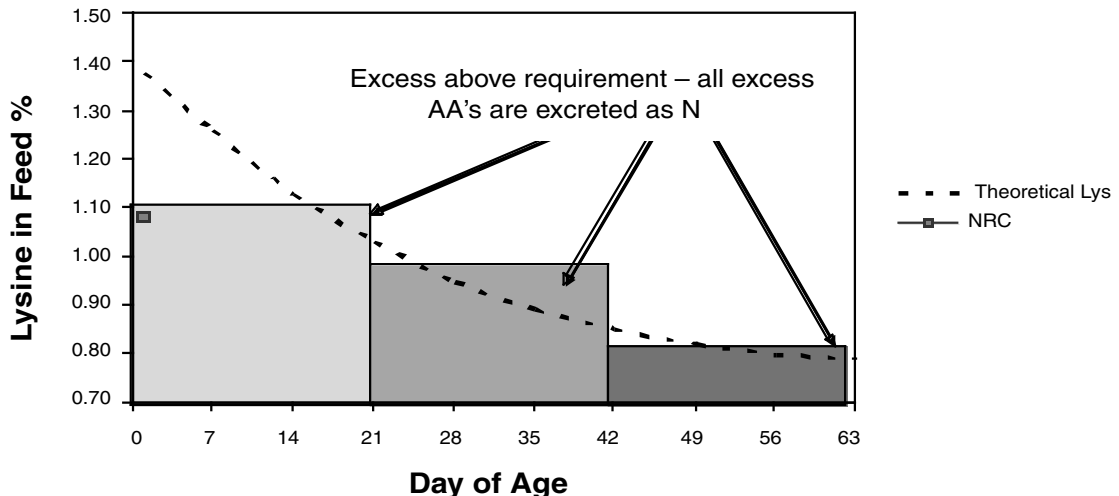
due to a decrease in animal activity for nonproductive purposes.

Another feed management area that needs further study and implementation is phase feeding. While this tool has been used by some segments of the poultry industry for many years, the concept has only been partially implemented. The concept is based on the fact that the needs of the animal, as it ages, change constantly. Ideally, feed nutrient content should change daily to meet the specific requirements for the stage of growth. Yet broilers are still sometimes grown under a three-phase feeding program. In Europe, where environmental regulations are more rigorous, phase feeding has been taken to the extreme of blending diets in proportions that change daily. This entails having two diets (high and low nutrient density) that are blended daily. In this way, the nutrient content of the feed consumed is slightly decreased on a daily basis, and meets, more closely, the nutritional needs of the animal. This minimizes nutrient excesses and thus nutrient excretion and improves growth. In contrast, in a three-phase feeding program (Figure 1), the animal is fed an excess of nutrients at the start of every phase while at the end of the phase the diet does not provide the nutrients needed to maximize growth.

These times of excess and deficiency are minimized in the blend system, and thus the feed efficiency is much greater. This tool has not been implemented in the U.S. to any extent. The broiler industry in the U.S. feeds between three- and five-feed phases. There is an initial equipment cost required to implement the blending system. Up to now, the economic and/or regulatory incentives for widespread adoption of a blending system have not warranted this change.

Physical factors in feed will affect feed efficiency. In the U.S. broiler industry, it is standard to use pelleted feed but pellet quality (hardness, durability, percent fines) is still an issue. Concerns with pellet durability and percent fines in the feeding troughs have come to the forefront with the post-pellet application of ingredients such as enzymes like phytase. Post-pellet application means that the enzyme is located primarily on the outer surface of the pellet. Any loss from the pellet surface in the form of "fines," through normal abrasion that occurs in bins and especially augers, will result in a large percent of the applied enzyme being separated off with the fines. In most U.S. commercial broiler feeding systems, where feeding lines range from 250 to 500 feet, the fines tend to settle off at the beginning of the feeding

Current feeding practices vs. actual requirements



line. Therefore, most of the enzyme is consumed by birds in the side of the house where the feeding line begins; those eating at the end of the line consume feed with a much lower content of enzyme. This is of special concern in the finisher and withdrawal phases when bird movement or migration within the house is limited.

MANAGEMENT (ANIMALS AND HOUSE)

Disease

Healthy animals routinely encounter pathogens that have the potential to infect and produce disease. The rapid detection and elimination of these disease-causing microorganisms is paramount for maintaining health. Deficiencies or impairments in the animal's defense processes enhance the potential for disease. It is no surprise that significant animal and health management efforts and producer dollars are spent on reducing the possibility of infectious disease. Many of these costs are directed toward modulation of the immune system because it is the system in charge of protecting the host from pathogen entry, replication, and disease. The innate immune system detects and eliminates pathogens and provides protection during early stages of infection. The adaptive immune system consists of humoral and cell-mediated immunity that functions to confer specific, long-term protection to the host. Therefore, maintaining animal health and ultimately animal productivity depends in large part on the optimal function of the constitutive and adaptive components of the immune system.

Viruses, bacteria, fungi, and parasites each display invariant structural motifs that the immune system uses as general markers for detecting these different classes

of pathogens. Cells of the innate immune system contain specific receptors for these pathogen markers. In the presence of a pathogen, these cells are directly activated. Activation of the innate immune system initiates a cascade of events that promotes pathogen elimination. The innate immune system releases communication molecules that not only orchestrate pathogen clearance, but also act to decrease skeletal muscle accretion, to increase N excretion, to decrease bone strength, to alter mineral metabolism, to alter hormone release, and to decrease food intake. Consequently, the immune defense mechanisms that are mounted against a pathogen oftentimes occur at the expense of animal productivity. These growth-inhibiting structures or responses have the potential to serve as markers for monitoring dietary quality and animal husbandry environments.

Sub-therapeutic levels of antibiotics in animal feed promote growth in part by suppressing the frequency and severity of immune responses to pathogens. Animals fed antibiotics have fewer immune cells within the intestine and lower circulating levels of communication molecules that function to antagonize growth. As antibiotics continue to be removed from animal feed, suitable alternatives must be identified to maintain high rates of animal growth, and stable production retail costs. The most suitable alternatives are likely to function in a manner similar to antibiotics; however, approaches other than dietary-based attempts to reduce the frequency and severity of immune responses are also likely to be effective. For example, animal management approaches can minimize housing and environmental stressors while improved biosecurity measures can aid in eliminating the prevalence of pathogens. The customary use of litter for several flocks that is routine in the U.S. is an area that warrants further investigation if chronic challenges to the

innate immune system are to be decreased and productivity maintained or enhanced.

In contrast to innate immunity, the adaptive immune system can be influenced through vaccination to develop more resistance toward a particular disease-causing pathogen. Vaccination increases the number of antigen-specific cells that react to a particular pathogen. The greater number of antigen-specific cells responding to a particular pathogen leads to an increase in the rate of pathogen neutralization and clearance. Unlike innate immunity, an activated adaptive immune response does not secrete the similar type of communication molecules that act systemically to decrease the efficiency of animal growth. Consequently, promoting adaptive immunity through the use of vaccination protocols can aid in maintaining animal health and productivity. Vaccine-based immunity depends on the availability and effectiveness of vaccines. Understanding the structure and function of pathogens can lead to more targeted approaches to vaccine development. Additionally, inclusion of adjuvants that act directly or indirectly on the ability of the adaptive immune system to respond to a vaccine may also enhance protective immunity. Novel strategies, including the use of immunostimulants and cytokines as adjuvants, may prove useful toward this end. Further advancements in vaccine-based immunity are dependent upon a more thorough understanding of the interaction between the host and the pathogen. This will permit the enhancement of the components of the immune system that have the most direct effect on preventing and eliminating disease while having minimal to no negative effect on productivity.

Minimizing animal stress through management

Any management tool that minimizes stress will result in improved productivity, including improved efficiency of feed conversion. For example, at lower animal densities, broilers will grow more rapidly and more efficiently. Average U.S. broiler growing densities range between 0.75 and 0.9 ft² per broiler; the lower densities (0.9 ft² per broiler) tend to be used in summer months. In the first few weeks after hatch, broilers perform better at higher densities. Better performance is possibly related to a higher need for heat at young ages. Typically, broilers will be started in only 1/3 of the whole production house, primarily to minimize heating costs. Reducing animal density by at least 25%, once broilers reach a weight of approximately 1.5 lb, results in improved growth rates and efficiencies. It is necessary to conduct research that is sensitive enough to determine the correlation between broiler density and performance parameters at densities situated between half of those currently used and slightly higher than current densities. The choice of densities is a least cost decision that includes overhead and non-feed production costs as well as productivity. Housing and labor costs will remain relatively stable regardless of the number of animals housed, while heating costs early on will be higher at lower densities. Because of the lack of reliable data on correlations between density, productivity and overhead costs, it is difficult today to assess what a 5 or 10% change in animal density will do to productivity in relation to costs. As regulatory pressures mount in relation to how animal production affects the environment, more attention will have to be paid to the tools that even marginally improve the efficiency of feed conversion.

As mentioned earlier, the use of black-out housing has resulted in improved productivity and efficiency of feed conversion mainly because the animals are less active and there is less potential for negative animal-to-animal interaction. Another important way to reduce broiler stress is the correct management of litter moisture. Very dry litter tends to be dusty and can be a respiratory irritant that elicits an immune response and leaves the animal more vulnerable to respiratory pathogens. Wet litter, on the other hand, has negative effects not only on the health of the animal, but on the environment because high litter moisture content promotes NH_3 formation and volatilization of litter N. Also, it has a negative impact on carcass quality (foot pad dermatitis and breast blisters are more common with wet litter); additionally wet litter promotes the bacterial conversion of organic forms of P to more soluble forms (McGrath et al., 2005). Appropriate management of waterers (height and pressure as well as leak prevention) will help maintain dryer litter.

Air quality also affects the stress level of the birds. Maintaining good air quality is paramount, but care must be taken to minimize drafts especially with young birds. Maintaining broilers at their temperature comfort zone will usually entail adding heat when the birds are young and cooling when the birds are nearing market weight. If broilers are maintained at their temperature comfort zone, they will spend less energy for maintenance purposes, which results in better feed efficiency.

Litter reuse is a common practice in the U.S. where 10 to 15, and sometimes more, flocks are raised on the same litter. In general, after every flock, litter is decaked. Decaking refers to the removal at the end of a flock of a thin solid top layer that forms primarily around feeders and waterers. In some cases, but not all,

a thin layer of fresh litter is added on top (top dress) especially in the brood chamber of the house. The decision to reuse litter stems from logistics and least cost. In Europe, for the most part, litter is never reused, a practice primarily dictated by regulations. In most regions in the U.S. there are frequent shortages of bedding materials, which rules out the possibility of changing litter after every flock. The cost of changing litter after every flock is not only represented in the cost of new litter and its application but also in the costs of year-round removal and disposal of very large quantities of litter, especially in areas of very concentrated broiler production. Given how concentrated broiler production is in certain geographical areas, changing litter every flock would be extremely difficult and very costly.

On the other hand, there are production costs associated with placing hatchlings on used litter. Reuse of litter implies that broilers are grown in an environment that is constantly challenging their immune system. Thus, there is, in general, a constant low-grade challenge to the immune system that negatively affects animal performance and feed efficiency costs. This is one of the most important reasons why growth-promoting antibiotics are frequently used in the U.S. with great success. Yet, animal agricultural industries are faced with the very real possibility that antibiotic use for growth-promoting purposes will be banned. In the absence of growth-promoting antibiotics, the broiler industry as well as researchers must look for management options that decrease these chronic immune challenges in a cost-effective manner. Research is needed on the use of fresh litter in the absence of growth-promoting antibiotics within the U.S. broiler management system. Also, the resulting decrease in excreted nutrients and improved production efficiency needs

to be documented and incorporated into the least cost equation.

LITTER MANAGEMENT AND APPLICATION

Broiler litter is a combination of bedding material, fecal matter, feathers, and wasted feed. The nutrient density of the most common bedding materials (i.e., pine sawdust, shavings, and rice hulls) is low, so the type of bedding generally has little influence on broiler litter composition. Broiler litter has been used for decades as a soil amendment for agronomic crops. There are many benefits, and some problems, when litter is used as a fertilizer for row crops, pastures, and in other cropping systems. In general, litter is a very good source of N, P and K, the most important plant nutrients needed for crops. Litter also contains other plant nutrients, such as Ca, Mg, sulfur, boron, Cu, Mn and Zn, and adds organic matter to soils. Years of research on the agronomic value of broiler litter have identified the situations where litter will be an economically valuable soil amendment. Moreover, recommendations for the efficient use of litter are available from all U.S. land grant universities. Past research has also shown that litter must be managed carefully to prevent environmental impacts on air, soil, and water quality. The most significant environmental challenges with broiler litter use are related to: (1) nitrate contamination of groundwater; (2) nonpoint pollution of surface waters by N and P; (3) losses of N, primarily as NH_3 , to the atmosphere during litter production, storage, handling, and land application; and, (4) buildup in soils of trace elements from litters that are known to affect human and ecosystem health, such as As, Cu, and Zn. Properly implemented, comprehensive nutrient

management plans can take full advantage of the agronomic benefits of broiler litter and at the same time prevent negative environmental consequences.

Litter management within the house and during storage

Numerous factors affect litter nutrient content. The frequency of cleanout and the total bedding usage (initial placement depth, replacement to maintain adequate depth, and topping over used litter) have a great impact on litter composition. The relative rate of nutrient accumulation in litter is highest in the first flock because clean litter has such low nutrient content. Relative accumulation continues to be high over the first 4 to 5 flocks but the relative rate of accumulation is quadratic, that is, there is relatively less accumulation with every flock up to flock 4 or 5 when a moderately stable nutrient content plateau is reached. This does not mean that after flock 4 or 5 nutrients are not added to litter, but it means that the litter itself is constituted primarily (approximately 95%) of dry manure (depending on extent of top dressing and decaking after every flock). On a percentage basis, a nutrient plateau is reached but on an absolute basis, the mass of nutrients continues to increase at a similar rate when flock type, feeding, and management remain the same. Since the cleanout frequency of most broiler production in the U.S. is every one or two years or every 6 to 13 flocks, after the first year the major nutrients (N, P, and K) increase at a rate of approximately one pound per ton per flock.

Nutrient density is also influenced by other factors such as market weight of the animals grown on the litter, feed composition and efficiency of nutrient use, and location within the house (brood versus grow-out chamber, feed line and

water lines versus open areas). Due to current bedding shortages in many broiler production areas the practice of reusing litter for extended periods of time will continue. Nutrient density increases with this practice, making litter more economical to transport and perhaps more valuable for alternative uses. However, this can pose greater management challenges in controlling disease, dust, NH_3 , and odor. With either alternative bedding materials must be found in order to supplement current supplies or innovative materials that enhance litter composition and reduce air quality concerns must be developed. An alternative approach is to develop cost-effective non-litter broiler production systems. Cage systems with manure belts and ventilated, elevated screen non-litter floor systems have shown promise in improving air quality (Patterson and Adrizal, 2005).

Litter pH has a greater impact on NH_3 volatilization than moisture; and reducing litter pH ($< \text{pH } 7$) is an effective means of controlling NH_3 release. Amendments that acidify litter are extensively used by the broiler industry to suppress NH_3 and litter pathogens. These products (i.e., sodium bisulfate, aluminum sulfate, and acidified clay) are often applied to the brooding section of houses and offer effective immediate suppression but have limited longevity. Higher application rates of these products to the whole house are being considered as a means to reduce further NH_3 emissions and conserve litter N. Some aluminum, iron, and Ca-based acidic compounds have the added benefit, when used at higher rates, of binding soluble P in litter. A list of the litter amendments and other products that bind, manipulate microbial populations, or alter enzymatic activities has been recently reviewed by Ullman et al. (2004), and Patterson and Adrizal (2005). The current amendments used by the industry will continue to be an important management tool to address

both production and air quality issues. New products and other novel strategies to alter litter chemistry and microflora hold additional promise.

In addition to litter moisture and pH, air velocity, which is controlled inside the poultry house by the ventilation rate, and temperature are among the most important factors when it comes to controlling the rate of NH_3 release from manure. However, the relationships between temperature, air velocity and the NH_3 release rate flux are complex. Overall NH_3 mass transfer coefficient is influenced by, and expressed in, terms of the manure or air temperature and the velocity of air over the manure surface. However, the exact relationship between the NH_3 mass transfer coefficient, temperature, and velocity must be experimentally determined for each system because it depends on manure characteristics and many other factors, which explains the wide range in the reported values (Ni, 1999). Nevertheless, it is always true that increases in either temperature or air velocity enlarge the NH_3 mass transfer coefficient. Consequently, NH_3 release rate flux varies with temperature and/or ventilation rates. In addition, as temperatures rise, there is an increase in the rates at which urea and complex organic N forms are converted to NH_3 in litter, in the dissociation of NH_4^+ to the volatile NH_3 form, and in the amount of NH_3 that partitions into the air above manure. Each of these effects increases gaseous NH_3 concentration at the interface with manure, which results in a stronger driving force for the release of NH_3 . Finally, when air temperature rises, it is necessary to increase ventilation rates in order to maintain the birds' environment as close to their comfort zone as possible. As the air velocity increases, the gaseous NH_3 concentration in the free air stream decreases, which again creates a stronger driving force for NH_3 release. On the other

hand, high temperatures and ventilation rates tend to dry litter out, and if litter becomes sufficiently dry, the production of NH_3 and, consequently, its release may slow or even stop. Although maintaining very dry litter may minimize NH_3 production, it can increase dust.

Reducing odor, particulate, and ammonia emissions from mechanically ventilated houses

The emissions of odor and gases during storage and land application of broiler litter can vary significantly over time. In contrast, emissions from housing are relatively constant, which facilitates their control. A variety of technologies can be used to disperse or capture and, in some cases, treat particulate matter, gases, and odors emitted from poultry houses. Windbreak walls are well-suited for use 10 to 20 feet downwind of the exhaust fans on tunnel-ventilated buildings. The wall frame is usually constructed from wood and then either covered with plastic or chicken wire, which is filled with crop residues. Windbreak walls work by slowing down the rate of airflow from exhaust fans. This causes odorous dust to settle and odorous gases to deflect upward and become diluted when they are mixed with fresh air. Shelterbelts of trees or other vegetation offer protection from wind and snow and, if planted strategically in front of tunnel ventilation exhaust fans, can act as natural windbreaks and aid in odor dispersion, though their effects on dust and NH_3 and other gases have not been well characterized.

Air from mechanically ventilated houses can be exhausted through biofilters where microorganisms growing under moist conditions on shredded wood and compost or other residues can break down NH_3 , hydrogen sulfide and volatile organic

compounds, and reduce odors. However, two aspects of biofiltration may limit its use to treat emissions from broiler houses. First, the high airflow rates associated with tunnel ventilation may make biofiltration too expensive, especially during warm weather. To help minimize costs, there is work under way to develop a diversion system such that air is only filtered when most needed (summer and/or nights). Second, the biofilter media creates airflow resistance. Tunnel ventilation systems operate best when there is no pressure difference between the inlet and outlet fans and if not designed to accommodate the static pressure associated with a biofilter, it may be difficult to achieve sufficient air exchange unless the media is maintained such that compaction is limited. Evaporative cooling pads placed downwind of birds and upwind of exhaust fans inside tunnel-ventilated buildings act as washing walls because as air passes through these structures, dust and some gases are “scrubbed” from the air and absorbed by the water. They have been shown to reduce dust and NH_3 levels in the air emitted from tunnel-ventilated swine buildings without causing significant air restriction or increasing water use excessively.

Litter moisture

Ammonia volatilization increases as litter moisture increases. Strategies that promote drier litter will conserve litter N by decreasing volatilization. Drier litter also reduces animal health and product quality problems associated with wet litter; additionally, it reduces odor. Management factors that minimize wet litter conditions include: proper site drainage around houses; the use of high quality (not excessively wet) bedding materials; the installation and maintenance of adequate bedding/litter depth; the management of nipple drinkers; the proper design and operation of cooling and ventilation

systems; and the maintenance of uniform bird density throughout the house. Daily management of the nipple watering system with respect to proper line height and pressure, routine line sanitation, and replacement of leaky or worn components is critical in reducing excessively wet litter. Although a litter moisture concentration of approximately 25% is generally considered optimum, excessively dry litter can exacerbate dust production, the transport of odorous compounds attached to dust particles, and cause respiratory problems in the flock as well as on field personnel.

Proper storage, handling, and application of poultry litters are also important to minimize the potential for NH₃ volatilization and for increases in litter water-soluble P that impact water quality. A recent study by McGrath et al. (2005) showed that wet storage of litters doubled water-soluble P, regardless of whether phytase was used in the diet or not. Litters stored under wet conditions also produced higher concentrations of soil water-soluble P and of runoff dissolved P than did litters stored dry. Therefore, storing litters in a manner that keeps them as dry as possible is another important litter management tool.

Limiting nutrient losses from field applications of poultry litter

Traditionally, most poultry litter has been applied to nearby cropland. However, poultry litter is inherently more difficult to manage and apply with precision than inorganic fertilizer. Extra precautions are needed to minimize nutrient losses. The keys to minimizing nutrient loss are similar to those for inorganic fertilizer but are logistically more difficult for poultry litter due to the low N:P ratio, the low overall nutrient density, and the variable physical characteristics of unprocessed

litter relative to inorganic fertilizer. As a result, many options that are available for applying inorganic fertilizers cannot be easily used with poultry litter. The only readily available option for applying poultry litter is surface broadcasting, while equipment for subsurface and band applying of both liquid and granular forms of inorganic N and P is widely available. The lack of subsurface application techniques for poultry litter is a critical challenge because it leaves tillage as the only practical method for incorporating poultry litter into the soil.

Consistent research findings on nutrient transport from crop fields have indicated that the availability of soluble nutrient sources on the soil surface is a primary factor to controlling the potential for soluble nutrient losses in surface runoff. Because a major fraction of N and P in poultry litter can be water soluble, surface applications can result in elevated nutrient losses in surface runoff. Increased losses in surface runoff-dissolved P as a result of surface applications of poultry litter can be expected even in fields where soil P concentrations are low. In addition, a major fraction of NH₃ in poultry litter can be lost to the atmosphere if poultry litter is not mixed into the soil soon after application. Tilling as soon as possible after application reduces the risk for elevated dissolved N and P losses in surface runoff as well as the potential for volatilization losses of NH₃. Unfortunately, tillage also increases the potential for soil erosion and the loss of particulate nutrient forms. Until recently, efforts to reduce nutrient losses in surface runoff have been focused almost exclusively on reducing soil erosion by minimizing or eliminating tillage. But it is now clear that applying poultry litter in no-till settings can lead to increases in dissolved nutrient losses that more than offset reductions in particulate nutrient losses from elimination of tillage. The issue of balancing the potential for

increased soil erosion due to tillage against the potential for increases in dissolved nutrient losses when nutrients are applied in no-till settings must be addressed on a site-by-site basis.

The following steps should be taken to minimize nutrient losses associated with applications of poultry litter to cropland:

1. Follow the main principles (rate and timing) of nutrient management: test litter to determine nutrient content; apply nutrients based on crop needs; calibrate application equipment; and apply nutrients as closely as possible to periods of maximum uptake by crops.
2. Minimize incidental application of poultry litter to noncrop areas. Broadcast applications can result in spreading of poultry litter beyond field boundaries. This is especially important in areas where extensive surface drainage has been installed because spreading along field edges can result in poultry litter being applied directly to waterways.
3. Incorporate poultry litter as soon as possible after application on sites with potential for surface runoff. If poultry litter must be applied well ahead of crop planting, delay final seedbed preparation until just before planting to maintain soil roughness and to minimize runoff. Minimize application frequency on sites with high erosion potential. Use good soil and water conservation BMPs (e.g., buffer strips) to reduce soil loss by erosion.
4. Use cover crops to reduce nitrate leaching. Poultry litter and other organic nutrient sources tend to increase the release of nitrate late in the summer. Cover crops can take up much of this nitrate and therefore reduce leaching losses the following winter. If poultry litter must be applied in the fall, cover crops are especially

important for controlling nitrate leaching.

AGRONOMIC AND ENVIRONMENTAL MANAGEMENT OF BROILER LITTER

Nitrogen management

Broiler litter is an excellent source of N for nonleguminous crops, with a total N content of about 4% (80 lb total N per dry ton). Litter contains about 80% organic N (mainly uric acid and urea) and 20% inorganic N (mainly $\text{NH}_3\text{-N}$). The organic N in litter is mineralized (converted to plant available ammonium-N and then nitrate-N) by soil microorganisms. About 60 to 70% of the total organic N added when litter is applied will be available for crop uptake in the first year of litter application. Therefore, about 3 to 5 tons of broiler litter can provide sufficient plant-available N for most grain and vegetable crops. Litter applications to leguminous crops, such as soybeans, are not recommended because legumes can obtain adequate N for optimum yields through biological N fixation. Research has also shown that litter organic N mineralizes rapidly to nitrate-N in warm, moist soils, often within the first month after application. Therefore, to prevent nitrate-N from leaching below the crop rooting zone and to groundwater, it is important to apply litter as closely as possible to the time of crop planting. It is also recommended that soil and plant N testing be used to monitor the amount of N available from litters. Diagnostic tests such as the pre-sidedress soil nitrate test (PSNT), the leaf chlorophyll meter, and the corn stalk nitrate test can determine if an adequate amount of N is available to crops

from a litter application. Steps should also be taken to prevent NH_3 volatilization (loss into the atmosphere) from land-applied litters, because this represents the loss of a valuable plant nutrient and also can have negative effects on air quality. Incorporation of litter within one to two days is needed to prevent significant NH_3 losses. Chemical amendments added to litter in the broiler production house can help prevent NH_3 volatilization as well. In summary, the best management practices (BMPs) needed to use broiler litter N efficiently are reasonably well-developed, but should be more widely implemented, for example through additional technical assistance and education programs. Particular emphasis should be placed on the expanded use of diagnostic N tests (e.g., PSNT), that are well known to increase N use efficiency. Important future research areas are the need for innovative BMPs to prevent NH_3 loss and the use of remote sensing technologies to monitor and direct N management practices rapidly at large scales.

Phosphorus management

Phosphorus is a vitally important plant nutrient that is present at higher concentrations in monogastric manures (swine manure and poultry litter) than in ruminant manures. Litter generated by broilers fed typical industry diets contains about 1.5 to 2.0% P on a dry weight basis (~ 60 to 80 lb P_2O_5 /ton, "as-is" basis). "Modified" broiler diets, such as those that feed closer to animal nutritional requirements and use phytase correctly to make plant-based forms of P more available are now widely used on Delmarva and generate litters that contain approximately 30% less P than litter from typical pre-phytase diets. Recent research has shown that, regardless of diet type, litter P is mainly composed of calcium phosphate (Ca-P) and phytic acid. Because Ca-P is readily soluble in

the moderately acidic soils of Delmarva, litter is an excellent source of plant-available P. Agronomic management of litter P is straightforward. In brief, soils should be tested for plant-available P and litters should be applied at P rates that optimize crop yields; good soil and water conservation BMPs should be used to prevent P loss by soil erosion. In the mid-Atlantic region, a soil test P value (Mehlich 3 soil test) of 30 to 50 ppm is adequate for most crops. The major nutrient management challenge with broiler litter has always been that when litters are applied to meet crop N needs (the longstanding approach), more P is added than removed in crop harvest. This has resulted in decades of overapplication of litter P and in an ensuing buildup of P in many soils on Delmarva to concentrations that cause environmental concern. Soil "saturation" with P increases the potential for eutrophication of surface waters, both from erosion of P-rich soil particles and from the loss of dissolved P in runoff and leaching waters. This has led to regional requirements for "P-based" nutrient management plans for "high P" soils.

All mid-Atlantic states recommend use of the P Site Index to identify fields where "P-based" management is needed. The P Site Index is a risk assessment tool that characterizes the risk of P loss into water by using site properties (e.g., erosion, runoff, drainage, and proximity to surface water) and P management practices (soil test P and type, rate, and method of P source application). The P Site Index makes it possible to identify fields where N-based management can continue or where, in order to protect water quality, no applications of litter P or applications at rates that equal crop P removal should be made. Adopting "P-based" management often means that broiler producers have excess litter on their farms. This has led to an increased effort to find alternatives to land application of litter, such as the

production of pelletized litters that can be exported to nutrient-deficient areas or the use of litters as bio-energy sources. Future research priorities for litter P management include the development of innovative BMPs that reduce nonpoint P pollution from P-saturated soils, improvements in watershed scale models that quantify effects of implementing BMPs on P loss to water, and continued efforts to identify alternative uses for litters.

Trace elements in litters

Broiler litters contain trace elements that are essential for plant growth, such as boron, Cu, Mn, and Zn, and some (e.g., As) that are important for animal health but not needed by plants. Arsenic, Cu, and Zn can also have undesirable effects on

water quality and human and ecosystem health. Therefore, questions have been raised about the potential environmental and ecological impacts associated with the long-term accumulation of trace elements in soils from litter applications to soils. Widespread environmental problems from land application of trace elements in broiler litter have not been extensively documented to date. This is a critical area for future research because of the importance of trace elements to broiler nutrition and health. Research should focus on the fate, cycling, and transport of As, Cu, and Zn in litter-amended soils. Particular areas of emphasis are the soil and environmental parameters that affect trace element retention and mobility in soils and aquifers and bioavailability in terrestrial and aquatic ecosystems.

FOR FURTHER INFORMATION

Websites

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