INVITED REVIEW

A Review of the Capacity for Nutritional Strategies to Address Environmental Challenges in Poultry Production

W. Powers*[1] and R. Angel†

*Michigan State University, Department of Animal Science, 2209 Anthony Hall, East Lansing 48824;
and †University of Maryland, Department of Animal and Avian Sciences, College Park 20742

ABSTRACT Poultry production faces increasing environmental challenges, in the United States and globally. Although the environmental impact of poultry production has been decreased, regulatory and social pressures mandate that further improvements be made to decrease the pollution potential even more. Concerns over air and water quality to date have been related primarily to nutrient issues, specifically N and P. Air emission concerns include N and sulfur emissions. More recently, states have addressed emissions of volatile organic compounds. Although no regulations have been developed that are targeted at food production, greenhouse gas emissions are receiving a great deal of attention in the United States. Nutrient-related water quality concerns have focused on N and P contributions to ground and surface waters, respectively. To address nutrient-related air and water quality concerns, nutritional strategies have focused on reducing nutrient excretions. These strategies have been very successful. However, strategies beyond just reducing nutrient excesses will be needed to meet future challenges that are not nutrient-related. Challenges such as pathogens, antimicrobials, and endocrine-disrupting compounds have received considerable attention recently. The purpose of this review is to provide an overview of the findings from nutrition research with respect to reducing environmental impact and to identify areas that merit attention in the near future, recognizing that many of the emerging environmental issues are not nutrient-related.

Key words: poultry production, nitrogen, phosphorus, nutrient excretion

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INTRODUCTION

Environmental issues continue to be a challenge for livestock and poultry production. Globally, and even within the United States and North America, the issues vary considerably. Although parts of the United States and northern Europe are currently focused on emissions of N to the atmosphere, the western United States is focused on volatile organic compounds, whereas Australia and New Zealand have their attention directed at greenhouse gases. In much of the United States, the emphasis is on effects of P on water quality, whereas arid regions of the western United States are concerned about salinity in soils, and many regions of the world have greater restriction of N than P with respect to water quality regulations. Regardless of location, standards for compliance are getting greater, and the breadth of issues to address gets wider each year in spite of little change in profit margins and producers alike.

Nutritional strategies have achieved success in providing a partial solution for several of the prominent environmental issues (Sutton et al., 1999; van Kempen, 2001; Beauchemin and McGinn, 2005). Adoption of nutritional strategies often results in a cost-savings or break-even situation. Nutrition strategies focus on reducing nutrient excretions, thereby improving the whole-farm nutrient balance of an operation. An imbalance occurs when the difference between nutrients brought into an operation are not equal to the nutrients exported from the operation. In cases in which imports exceed exports, reducing the inputs such as feed nutrients helps to provide more balance. Nutrient excretions have direct implications for both water quality and air quality concerns. However, although nutritional strategies can play an important role in reducing the environmental impact of poultry production, such strategies may not provide sufficient mitigation nor be able to address some of the emerging environmental challenges that the industry will face. The purpose of this manuscript is to provide a critical review of avail-

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[1] Corresponding author: wpowers@msu.edu

able data that demonstrates how nutritional strategies address environmental challenges and to identify emerging challenges that may or may not be suitable for mitigation through nutrition.

CURRENT CHALLENGES

Environmental concerns related to poultry production have focused on water quality impacts that result from, primarily, manure storage and land application of manure. Air emissions from poultry operations arise from housing facilities, manure storage areas outside of the house, egg wash water storage facilities, and land where manure and wash water are applied.

Mitigation strategies to minimize environmental impacts include nutritional strategies, the primary strategy being to minimize feeding nutrients in excess of dietary needs. The principle behind the strategy is that nutrients consumed beyond what are utilized for production are excreted where they can then leach into groundwater after application to land, move into surface waters when attached to sediment, or be volatilized into the atmosphere.

Nitrogen

Nutritional strategies employed to address N losses to the environment have focused on dietary CP content in the past and amino acid (**AA**) composition in more recent research. Reducing CP content of broiler diets by less than 2 percentage units, or 13% reduction in N intake, resulted in greater than an 18% decrease in litter N content (Ferguson et al., 1998). Angel et al. (2006a) fed a 4-phase and a 6-phase feeding program to broiler chickens. Formulated protein concentrations were 22.1, 20, 17.2, and 16.6% for the 4 control diet phases, respectively, whereas those for the 6-phase diets were 22.0, 18.6, 18.1, 17.3, 15.8, and 15%, respectively. Synthetic sources of Lys, Met, Ile, Val, Trp, and Arg were included in the 6-phase program, whereas only Met and Lys were included in the 4-phase program, resulting in greater CP in the 4-phase program. Consumption of N was 5.1% less, and litter N content was decreased 16.6% as a result of feeding the 6-phase diets. In a recent study by Applegate et al. (2008), turkey toms were fed diets containing 2 (Lys and Met) vs. 3 (Lys, Met, and Thr) amino acids and fed at either 100 or 110% of the NRC (1994) AA recommendations. Diets were formulated to maximize soybean meal inclusion when formulated with 2 supplemental AA, thereby resulting in 2.0, 1.5, 1.4, and 1.0% units more CP than diets containing 3 supplemental AA at 4 to 8, 8 to 12, 12 to 16, and 16 to 20 wk of age, respectively. Differences in N intake resulted in 7% more N in litter ($P = 0.067$) in birds fed 100% NRC AA versus those fed 110% NRC AA. Similarly, birds fed 3 versus 2 supplemental AA had 10.8% less N in litter. No performance differences were observed between treatments.

Elwinger and Svensson (1996) fed broilers diets containing 18, 20, or 22% CP and measured NH_3 emissions from the litter bed and observed a linear trend of increasing NH_3 emission when increasing dietary CP content was observed. Total N losses in the houses averaged 18 to 20% of total N input. However, Ferguson et al. (1998) observed no difference in house NH_3 concentrations. Generally, as a guide, for each 1 percentage unit reduction in dietary CP, estimated NH_3 losses are decreased by 10% in swine and poultry (Aarnink et al., 1993; Jacob et al., 1994; Blair et al., 1995; Kay and Lee, 1997; Sutton et al., 1997). Variation does, however, occur. Powers et al. (2007) observed a 15% reduction in NH_3 emissions as a result of reducing crude protein by 2.0 percentage units. As animals are fed closer to true N requirements, further reductions in dietary CP may result in less-pronounced reduction in N excretion and NH_3 losses. Thus, this issue becomes how close to requirements the industry can economically achieve while accounting for the unknown variation in raw materials that are used in the diet.

Feed additives have been used to decrease N losses to the environment. Most of them have focused on N losses to the atmosphere. Kim et al. (2000) observed a 30% reduction in NH_3 emissions associated with growing pig diets containing a combination of phosphoric acid and calcium sulfate and lesser reduction in emission (17%) compared with diets containing a combination of monocalcium phosphate, calcium sulfate, and calcium chloride. Similarly, Wu-Haan et al. (2007) observed a 39% reduction in NH_3 emission from rooms where laying hens were offered a diet containing 6.9% of a gypsum-zeolite mixture and slightly decresed CP. In 3 separate trials, daily NH_3 emissions from hens fed the gypsum-containing diets (185.5, 312.2, and 333.5 mg/bird) were less than emissions from hens fed the control diet (255.0, 560.5, and 616.3 mg/bird; $P < 0.01$). Bird performance was not different as a result of the treatments, suggesting that the strategy, if economical, is a practical mitigation strategy. However, as a result of the gypsum inclusion, across trials, daily emissions of hydrogen sulfide from hens fed the gypsum-containing diet were 4.08 mg/bird compared with 1.32 mg/bird from hens fed the control diet ($P < 0.01$). The rationale for this is that the inclusion of gypsum in the diet increased dietary S content by 4- to 6-fold. The trade-off of decreasing NH_3 emissions while increasing hydrogen sulfide emissions needs to be considered carefully, factoring in local and state regulations as well as environmental objectives of the operation.

Postexcretion or engineering controls can be employed to address discharges to water and air. Litter additives are often used to decrease air emissions (Moore et al., 1995, 1996; Do et al., 2005) or bind nutrients (Felton et al., 2004; Do et al., 2005; DeLaune et al., 2006; Maguire et al., 2006). A review of recent developments is outside the scope of this review; however, there are some amendments that can be fed. Kithome et al. (1999) observed that application of a layer of 38%

zeolite placed on the surface of the composting poultry manure decreased NH_3 losses by 44%. However, Amon et al. (1997) observed greater NH_3 concentration and emission when clinoptilolite was used in broiler houses compared with houses without the addition of clinoptilolite. In an Environmental Protection Agency report, Moore et al. (1996) reported 42% reductions in NH_3 from poultry litter when aluminum sulfate was added in bench-scale tests. As more manure additives are studied, their applicability as feed additives to control emissions from excreta should be considered.

Phosphorus

Research and field data have shown that poultry diets can be modified in several ways to decrease the concentration of P in excreta. When compared with P content of typical industry diets, feeding broiler chickens diets with P contents in line with nutrient recommendations can decrease P intake as well as the amount of P excreted (Waldroup et al., 2000; Bar et al., 2003; Dhandu and Angel, 2003; Yan et al., 2003; Angel et al., 2005, 2006a,b). Similarly, feeding laying hens (Boling et al., 2000a,b; Keshavarz, 2003) and turkeys (Roberson et al., 2000; Hocking et al., 2002; Thompson et al., 2002) diets that contain P at recommended concentrations decreases the amount of P fed and excreted. In conjunction with feeding closer to requirements, the addition of phytase to improve P availability (Selle and Ravindran, 2007) and thus dietary P use by poultry can substantially decrease P excreted (Yan et al., 2003; Keshavarz and Austic, 2004; Angel et al., 2005, 2006a,b; Panda et al., 2005; Roberson et al., 2005; Liu et al., 2007). Use of other feed additives such as 25-hydroxycholecalciferol (Angel et al., 2005, 2006b; Fritz and Waldroup, 2005) and citric acid (Martinez-Amezcua et al., 2006) has shown promise in increasing the availability of the phytate P found in the plant-based ingredients that make up the majority of poultry diets.

There is substantial scientific literature available on P requirements of broilers but less on the P requirements of layers and turkeys. Unfortunately, there are large differences among the recommendations given. For example, in 19 papers published since the literature that was used by the NRC (1994), different values for the P requirements in starter phase broiler diets are provided (Angel, 2006). Nonphytin P (**nPP**) or available P requirements for male broilers in the starter phase (hatch to 21 d) ranged between 0.20 and 0.40% with an average of 0.36%, for females or straight-run (unsexed birds) broilers (7 papers) from 0.29 and 0.45% with an average of 0.38%. Even if one tries to remove the effect of growth rate in the different experiments by giving the requirement as milligrams per gram of growth, the reported differences in requirements remain large. For example, in male broilers, the average recommendation for body weight gain was 5.8 mg of nPP/g of growth (SD = 1.2). There is a debate as to which term should be used when referring to P: available P, nPP, or a different term such as retainable P proposed by Coon et al. (2007).

When reviewing P requirement literature, one salient fact becomes obvious. It is difficult to make comparisons between studies. In P requirement research as well as phytase efficacy work, certain information that has a large impact on the results has to be included in the published work. Information that needs to be included is as follows: animal breed, strain and age, start and end weight, replication and birds/replicate, pen size and animal density, actual mortality and whether the data are corrected for mortality, prior nutrition (especially as it pertains to Ca, P, and vitamin D), age of the breeder flock where chicks came from, feed consumption, formulated and analyzed diet Ca and P, and, if possible, phytate P. Also of importance are diet information specifics that cover formulated diet vitamin D, ME, fiber, all vitamins and microminerals, the amount of each ingredient used, formulated and analyzed diet protein and fat, and light schedule used. Feed additive (coccidiostats, antibiotics, growth-promotants, pro- or prebiotics) information to provide includes the product name, active ingredient, and inclusion level. Details of prevailing environmental conditions, vaccination program used, and finally, if floor pen work is conducted, type of litter used, and whether it has previously been used should also be included.

Selle and Ravindran (2007) reviewed the extensive scientific literature on the impact of phytase for increasing the availability of P for poultry. Despite the number of scientific papers that have been published on this topic, a consensus on the efficacy of the different phytases has not been reached. In summarizing 3 battery trials (11 to 21 d or 12 to 22 d of age), Angel et al. (2002) reported that the range in phytase concentrations needed to obtain a 0.1% sparing effect of nPP was 781 to 1,413 U of phytase/kg of diet when using a microbial phytase source. When the dietary Ca was fixed at 0.7%, the additional nPP spared with 500 U of phytase/kg of diet averaged 0.065% (as calculated from additional toe ash obtained in comparison with graded concentrations of monocalcium phosphate). Others have reported a sparing effect of the same microbial phytase of 0.1% with 750 U of phytase/kg of diet (Yi et al., 1996). The experimental design and diet nutrients are 2 factors that will impact efficacy, and thus, it must be clarified that the sparing effect published in most studies applies only to the conditions of the particular study that derived that value. Driver et al. (2005) stated that it is impossible to determine or specify one single equivalency for a phytase. These authors found large effects of dietary Ca:P ratio on the sparing effect of phytase. Most research has maintained a constant Ca concentration within each study. Variations in the reported efficacies of each phytase abound, and it is difficult under practical situations to give a moderately accurate efficacy value to the different phytases.

In addition to the variation in quality of information related to efficacy of phytase, there is no international standard assay for expressing phytase activity (Selle and Ravindran, 2007). This void leads to confusion when analyzing different phytase sources, especially when the same designation of units (phytase units) is used across procedures Differences in the specifics of the assays (such as buffer, pH, temperature used) can induce a 3- to 4-fold difference in the measured phytase units (Ward and Campbell, 2007). The confusion has only increased in the last couple of years as new *Escherichia coli*-derived phytases have come on to the marker for commercial use. These new enzymes appear to have greater impact on making available other nutrients that can be bound to the phytate molecule such as amino acids, minerals, and carbohydrates (Cowieson et al., 2006; Pirgozliev et al., 2007; Selle and Ravindran, 2007).

Some questions have been raised about the use of phytase in broiler diets, because some research and field data (DeLaune et al., 2001) suggest 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. This resulted in concentrations of diet available P that were greater than those needed by the broiler. When consumed available P exceeds the needs of the broiler, P is excreted in a more soluble form, increasing litter water-soluble P. When phytase is included in diets deficient in P, at phytase concentrations that liberate phytate P to make the diet adequate in P, no significant increases in litter-soluble P occur (Maguire et al., 2003; Angel et al., 2006b). 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 decreased, but when P is not decreased enough in the presence of phytase, litter-soluble P increases (Angel et al., 2005). 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 safety margin.

Consistent implementation of phytase to improve P availability from P that allows for lower levels of inorganic P sources in the feed has been lacking. This is not surprising given the lack of consensus among research publications related to phytase efficacies and P requirements. Use of phytase in all poultry diets is below 50% in the United States (N. E. Ward, DSM Nutritional Products, personal communication). Under research conditions, diet P reductions of 21%, in the presence of dietary phytase have decreased litter total P by 39% (Angel et al., 2006b). Survey work on 50 broiler farms in the Delmarva peninsula (comprising the eastern shore of Maryland, southeastern Delaware, and northeastern Virginia), before the use of phytase and 2 yr after phytase use was implemented, showed that under commercial conditions, broiler litter P was decreased by 30% when diet P was decreased by 10% (Angel and Powers, 2006). In surveying the diets and comparing Ca and P concentration with average published recommendations (Angel, 2006), P concentrations in many commercial diets exceed current recommendations by 25%. The extent of overfeeding exceeds the perceived formulation safety margin needed for P (10%). Today, with better diet management that includes feeding closer to requirements and appropriate use of phytase, the broiler industry has the potential to decrease P intake by 40% and excreta P by 70%, as compared with 2002 industry concentrations (Angel and Powers, 2006). The most promising diet management strategy is the use of moderately high concentrations of available P in the prestarter and starter phase combined with no added inorganic P in the finisher and withdrawal phases (Yan et al., 2003; Angel, 2007). 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 decreased further and broilers are fed closer to their P needs, the potential for deleterious effects on animal productivity and processing yields increases.

Microminerals

To meet nutritional requirements, several microminerals are supplemented in poultry diets. These include the following: Fe, Cu, Mn, Zn, I, and Se. When added to diets at close to requirement concentrations, excreted concentrations are minor and pose no environmental concern. Some minerals such as Cu and Zn are included for the bacteriostatic, bacteriocidal or antifungal, or both, properties at concentrations well above the needs of the bird (Southern and Baker, 1983; Pesti and Bakalli, 1996). The positive aspects of oversupplementation of Zn and Cu do not seem to have any direct environmental effects but are potentially phytotoxic (Alva et al., 2000) and decrease the efficacy of phytase and P retention (Banks et al., 2004). Average concentrations of Cu and Zn in poultry litter have been reported to be 390 and 377 mg/kg (Gupta and Charles, 1999). The environmental risk of these heavy metals is largely dependent upon the ability of the soil to adsorb and desorb these elements and the potential for leaching or soil loss to water by erosion.

Arsenic

Arsenic, as the organic molecules 3-nitro-4-hydroxyphenylarsonic acid (roxarsone) or p-aminobenzenearsonic acid (arsanilic acid), is often included in poultry diets for its coccidiostatic properties. Average broiler consumption of roxarsone, when utilized at maximal dosages (as regulated by the US Food and Drug Administration) of 45 g/ton of feed (Nachman et al., 2005), would result in 170 mg of roxarsone/bird or 48 mg of As/bird (2.6-kg bird, 1.7 feed:gain ratio to 42 d of age, assuming 5-d withdrawal). To prevent resistance build-up, coccidiostat drugs are rotated during the year, thereby limiting the use and eventual excretion of As. There are several values given for concentration of As in poultry litter ranging from 14 to 47 mg/kg (Gupta and Charles, 1999; Anderson and Chamblee, 2001; Arai et al., 2003; Garbarino et al., 2003; Rutherford et al., 2003) reported as an average litter As concentration and 11.8 to 27 mg/kg (Morrison, 1969) reported specifically in litter from houses fed roxarsone. Roxarsone is predominantly excreted intact, as 3-nitro-4-hydroxyphenylarsonic acid. However, when it reaches the soil, it is rapidly converted into arsenate (**As^{5+}**) by soil microorganisms (Rutherford et al., 2003). Depending on soil hydration, when As^{5+} is placed into a low-oxygen environment, soil microorganisms can also readily convert As^{5+} to arsenite or methylate of As^{5+} to dimethylarsinate (Rutherford et al., 2003).

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 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, arsenite (Garbarino et al., 2003). 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 fully recovered from poultry manure-amended soils due to oxidative and reductive transformations, and the possibility exists for volatilization as methanoarsonates (Rutherford et al., 2003). The extent of this transformation is relatively small and has not been quantified.

FUTURE CHALLENGES

Many of the environmental challenges to date have focused on nutrient issues, thereby making nutritional strategies a suitable means of addressing the issue. However, topics currently raised as potential challenges of the future are not as susceptible to mitigation that revolves around nutritional strategies.

Energy Use and Greenhouse Gas Emissions

Energy use has received considerable attention as supplies and sources of fossil fuels are questioned, energy prices are increasing, and environmental issues are increasing. With that come the environmental issues related to fossil fuel consumption, such as greenhouse gas production and carbon footprint (Moroto-Valer et al., 2002). Even renewable energy production faces environmental challenges such as ecosystem diversity (Tsur and Zemel, 2007). Energy use in food production will likely face greater scrutiny in the future as consumer awareness of energy use issues continues to increase. Although Wu-Haan et al. (2007) observed a change in methane production as a result of feeding diets containing gypsum to laying hens (18% reduction), an explanation for the effect is not apparent and is therefore difficult to promote currently as a strategy. Ruminant animal production is certainly more directly linked to greenhouse gas emissions (Monteny et al., 2006); however, this issue is one that will face poultry production as well (Wang and Huang, 2005), and resources need to be directed at answering questions and developing and implementing solutions.

Pathogens

Pathogens in the environment are a prominent concern of consumers and citizens. Considerable work is underway to identify sources of pathogens (human vs. animal; Scott et al., 2003). In the future, more emphasis may be placed on controlling the release of pathogens by using treatment technologies to trap or destroy pathogens. Pathogen destruction may be required in some situations before land application of excreta or litter, or both. Manure or litter storage alone does not completely destroy pathogens; however, biological or chemical treatments such as composting, thermophilic anaerobic digestion, or liming demonstrate some pathogen destruction (Spiehs and Goyal, 2007). Dietary modification using organic acids (Byrd et al., 2001; van der Wolf et al., 2001), direct-fed microbials (Muralidhara et al., 1977; Nisbet et al., 1999), and yeast (Spring et al., 2000; Naughton et al., 2001) has shown inconsistent results as a means of controlling specific pathogens from swine and poultry but suggests that there is merit in pursuing diet modification as a tool in the future.

Antibiotics

In addition to their concerns regarding pathogens, the general public is very much aware of antibiotic use in food production. Although antibiotic use as a growth-promotant has waned considerably (Singer and Hofacre, 2006; Castanon, 2007), pressure to make greater reductions is likely to occur. Proliferation and transport of antibiotic-resistant bacteria will continue to be prominent challenges to be addressed by the poultry industry, and the need for mitigation strategies to further decrease the need for antibiotic use is warranted. Although the ecosystem impacts of antibiotic-resistant bacteria and pathogens are less documented than the human health impacts of exposures, both topics are of interest to regulatory agencies.

Endocrine-Disrupting Compounds

Recently, endocrine-disrupting compounds (**EDC**) have started to receive scrutiny both from regulatory agencies as well as the general public (Nichols et al., 1997; NRC, 1999). Endocrine-disrupting compounds are a class of compounds either synthesized or present naturally in nature that are suspected to have adverse effects in animals and humans. The primary source of EDC in manure is the animal itself. Natural hormones produced by animals are shed in manure and may persist in ecosystems (Herman and Mills, 2003). They affect organisms primarily by binding to hormone receptors and disrupting the endocrine system by either mimicking natural hormones or by interfering with their binding (Colborn et al., 1993). 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 (Fisher et al., 2005). Testing for these compounds in food products, litter, and water is still a developing science. As defined, EDC include pesticides, herbicides, plant phytoestrogens, and other chemicals that interact with endocrine systems.

In broiler production, EDC can both enter and leave the production cycle. The main concern currently is on those that leave the production system. Broilers can produce EDC in the form of steroid hormones that are excreted into litter. The steroids of greatest concern are estrone and 17ß-estradiol, because they are often found in the environment at concentrations above the lowest effect levels. Research has shown that broiler litter contains estrogen (17ß-estradiol), estrone, and testosterone in measurable concentrations and that these EDC persist in litter (Nichols et al., 1997; Shore and Shemesh, 2003; Fisher et al., 2003). According to 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 8.2 d) due primarily to microbial and fungal action (Jurgens et al., 2002). These researchers looked at the impact of these naturally occurring steroids in poultry litter on fish, and the results suggests that, with time in waterways, steroids degrade to levels that are not high enough to cause any negative effects. (Fisher et al., 2005).

Agronomic practices can affect the loss to surface and groundwaters of EDC in the same manner as other litter or soil contaminants that are water-soluble (Nichols et al., 1997). Conventional tillage, as compared with no till, greatly decreases losses to water of steroid hormones from soils where litter has been applied (Nichols et al., 1997). Use of chemical binders such as alum in litter can decrease steroid transport into waterways from litter applied to soils (Nichols et al., 1997). Some research has been done on the effect that age, sex, and reproductive status have on the excretion of steroids in poultry (Shore et al., 1993). These researchers reported that estrogen was 14 and 65 µg/kg in litter from male and female broilers, respectively, whereas manure from laying hens contained 533 µg/kg. As EDC come under regulatory control, a better understanding of the impact of age and growth rate on excretion of EDC by poultry will become more important.

CONFLICTING OBJECTIVES

One of the greatest challenges in meeting environmental objectives is that, in addition to federal regulations, there are state-specific regulations. When regulations are reviewed and revised, the breadth of the regulation often increases, with greater concerns addressed. As one issue is addressed, it may be at the expense of another, thereby producing unintended consequences (Siegford et al., 2008). Work by Wu-Haan et al. (2007) illustrates this point. Although NH_3 emissions from birds fed a diet containing gypsum were decreased by almost 40%, hydrogen sulfide emissions increased 3-fold. Unintended consequences can occur when employing nutritional strategies and engineering strategies alike. For example, composting of litter may decrease odor problems associated with land application; however, gross NH_3 emissions (NH_3 lost during the compost process plus NH_3 lost after land application) potentially are greater than if litter was land-applied and rapidly incorporated without prior composting (Jeong and Kim, 2001; DeLaune et al., 2004). Pasture-raised poultry production may decrease the concentration of excreta in one location as a result of decreased bird numbers per unit area, but gross nitrous oxide emissions can be considerable in grass systems (Petersen et al., 2004). To avoid unintended consequences, a system-wide approach is needed to evaluate mitigation options.

LIMITS TO NUTRITIONAL STRATEGIES

As discussed above, nutritional strategies can have a large impact on decreasing N and P inputs into a farm. As inputs decrease while staying above requirements for optimal economic and environmental productivity, excretion of nutrients decreases. Because biological systems are not 100% efficient in converting that which is fed into body tissues, there is a limit on how much of an impact nutritional strategies can have on concentration of excreted nutrients. Indeed, reaching that limit may not be economically feasible. In a review of poultry literature published between 1985 and 2003, Applegate et al. (2003) reported that the N retention in broilers averaged 60.2%, 56.8% in turkeys and 45.6% in laying hens. For P, an average retention for broilers before 32 d of age was 49.3% and for broilers after 32 d of age was 41.0%. For turkeys, average P retention was 48.0% and for laying hens 29.1%. Although improvements can be made with strategies such as those discussed throughout, there are limits as to what is achievable.

Some dietary additives are not used currently by the industry due to high cost. However, this may change as other ingredients become more expensive. Shirley and Edwards (2003) added a commercial phytase at concentrations ranging from 95.75 to 12,000 U/kg of diet. They found an improvement in P retention as phytase concentration increased beyond commercial concentrations of 1,500 U of phytase/kg of diet. Phosphorus retention was 50.0, 65.4, and 79.9% in the negative control, 1,500 and 12,000 U of phytase/kg of diet, respectively. Nitrogen retention improved from 54.8 to 74.5% and 77.7% in the negative control, 1,500 and 12,000 U of phytase/kg of diet, respectively. Because of ingredient prices, the level of enzyme inclusion may increase over current practices. This has the potential to improve digestibility of the diet and thus improve nutrient use, thereby lowering nutrient excretion. Greater ingredient prices may also increase the use of AA that, to date, have not entered into a least cost formula, providing for further reductions in N intake and excretion. Nutritional strategies alone will not address all environmental challenges; however, nutritional strategies play an important role in achieving environmental objectives.

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