Efficient Feed Nutrient Utilization to Reduce Pollutants in Poultry and Swine Manure

K. H. Nahm

Feed and Nutrition Laboratory, College of Natural Resources, Taegu University, Gyong San, 712-714, South Korea. email: nahmikh@taegu.ac.kr

ABSTRACT: High-density livestock facilities lead to a concentration of livestock wastes and subsequent leakage of pollutants into the environment, resulting in public concern about their effects. Nitrogen (N) and phosphorus (P) are the most harmful components of animal manure, but odor from the manure itself and the livestock facilities is also a problem. Improving the nutrient efficiency of the livestock helps to decrease excretion of these environmental contaminants. Pigs and chickens are the main animals used in studies to improve nutrient efficiency to reduce excretion of environmental contaminants. Addition of feed supplements and modifying feeding programs to improve nutrient efficiency can result in significant decreases in the N, P, odor, and dry matter (DM) weight of manure. Examples of these methods include the following. (1) The addition of synthetic amino acids and reducing protein contents resulted in N reductions of 10 to 27% in broilers, 18 to 35% in chicks and layers, 19 to 62% in pigs, and a 9 to 43% reduction in odor from pigs. (2) Enzyme supplementation resulted in a 12 to 15% reduction in DM weight of broiler manure. (3) Phytase supplementation resulted in P reductions of 25 to 35% in chickens and 25 to 60% in pigs. (4) The use of growth-promoting substances resulted in a 5 to 30% reduction in N and a 53 to 56% reduction in odor from pigs. (5) Formulating diets closer to requirements (diet modification) reduced N and P by 10 to 15% each in chickens and pigs, and odor by 28 to 79% in pigs. (6) Phase feeding reduced N and P excretion by chicken and pigs from 10 to 33% and 10 to 13% each, as well as odor in growing and finishing pigs by 49 to 79%. (7) Use of highly digestible raw materials in feed reduced N and P excretion by 5% in chickens and pigs. Certain feed manufacturing techniques (grinding feed grains and proper particle size, feed uniformity in rations, or expanding and pelleting) when done properly can significantly reduce N, P, and odor contents and DM weight of chicken and pig manure. Feed with proper grinding reduced 27% of N in finishing pigs and 22 to 23% reduction of N in piglet fed with pelleting, 60% reduction of NH$_3$ emission fed with finely ground Zeolites in pig, and a 26% reduction of DM weight in finishing pigs fed with proper grinding were reported, but further research is needed in this area. Coordinating actual feed analytical results with production technique modifications is needed to reduce environmental contamination by animal manure, but specialists may need to be consulted for the successful implementation of these efforts.

KEY WORDS: enzymes, feed manufacturing, manure, nutrient efficiency, phase feeding, pollutants, protein levels.

I. INTRODUCTION

Public concern about environmental pollution from intensive swine and poultry production is increasing. Environmental pollution is defined as contamination
with poisonous or harmful substances to human beings, animal production, and other organisms (Williams, 1995).

The primary livestock excreta of concern in agriculture is manure. Animal manure is primarily a mixture of urine and feces, and it contains undigested dietary components, endogenous end products, and indigenous bacteria from the lower gastrointestinal tract (GIT), which contain a variety of organic compounds, complex to simple in nature, inorganic compounds, and, potentially, feed additives, depending on the make up of the diet (Sutton et al., 1999).

Much of the concern for pollution from animal manure involves nitrogen (N) pollution of ground water and run off into surface water and phosphorus (P) pollution of ground and surface water via soil erosion and run off. Although odors are generally considered a swine problem, all livestock producers may have to address the changing public attitude toward rural air quality eventually (Hamilton and Arogo, 1999). N, P, and some metals in livestock manure are feed nutrients, but environmental pollutants are caused by feed nutrients in the manure. Nutrient excretion is a result of the inefficiencies associated with digestion and metabolism (Coffey, 1996).

Without appropriately addressing these critical eco-nutritional issues, the livestock and poultry industries will be faced with major public opinion and regulatory problems that could limit the potential for growth. There are many methods of reducing environmental pollution by reducing excreta N, P, and odor contents and dry matter weight of manure. The focus of this article is on improving manufacturing techniques along with feed testing to improve feed nutrient efficiency and therefore reducing manure pollutants. Various feed supplements and modified feeding systems that have been developed for the same purpose are also introduced here.

II. STRATEGIES TO IMPROVE FEED NUTRIENT EFFICIENCY FOR REDUCING POLLUTANTS IN MANURE

A. Ways to Increase Feed Nutrient Efficiency

More attention should be placed on feeding diets with minimal nutrient excesses. Until recently, diets have been often formulated with relatively large excesses of nutrients, with little attention being paid to the excretion patterns of nonutilized nutrients (Farrell et al., 1998; Morse et al., 1992). Provided proper attention is paid to nutrient management, animal excreta can be used as fertilizers, soil amendments, and feed ingredients (Nahm, 2000). Furthermore, the contents of N, P, odor, and dry matter contents in livestock manure can be reduced by paying careful attention to diet composition — for example, by applying the concept of ideal protein, supplementation with synthetic amino acids, addition of various
enzymes, including phytase, lowering the protein and P contents, and the use of highly available sources of supplementary P and vitamin D (Nahm, 2000).

Scientists have reported the potential reduction of N, P, odor (measured by NH$_3$ emission reduction), and excreta weights in chickens and pigs (Table 1). Methods have mainly involved adding supplements to the feed and modifying the feeding programs. Supplements that have been found to be beneficial include: synthetic amino acids and reduced protein levels, enzymes, phytase, and growth-promoting substances. Modifications to feeding programs that have been studied include: formulations closer to requirements (including diet modification), phase feeding, and the use of highly digestible raw materials in the ration.

When feed rations were formulated to maintain the appropriate levels of each amino acid rather that just the total protein content, there was improved feed efficiency as well as reductions in manure pollutants. For example, in one research study (Blair et al., 1999), there was a reduction of 10 to 27% of the N content of broiler manure by using synthetic amino acids and reducing protein content. A similar reduction of 18 to 35% was seen in chicks and layers (Blair et al., 1999; Farrell, 2000; Summers, 1993), and in pigs there was a reduction of 19 to 62% (Bridges et al., 1995; Carter et al., 1996; Cromwell and Coffey, 1995; Hobbs et al., 1996; Pierce et al., 1994).

By supplementing rations with enzymes, a reduction in manure dry matter content of 12 to 15% (broiler) could be expected (Wyatt and Harker, 1995). Phytase supplementation reduced P contents of manure up to 25 to 35% in chicken (Federation Europeenne des Fabricants d'Adjuvants pour la Nutrition Animale — FEFANA, 1992; Lobo, 1999) and up to 25 to 60% in pigs (Cromwell and Coffey, 1995; FEFANA, 1992; Jongbloed et al., 1992; Kornegay and Harper, 1997; Michel and Frosoth, 1999). When somatotrophin was used as a growth promotant, N content of pig manure was reduced 5 to 30% (FEFANA, 1992; Williams et al., 1987). The amount of ammonia gas emission of pig manure was reduced by 53 to 56% when sarsaponin extracts were fed to pig (Sutton et al., 1992).

When feeding systems were adopted to provide formulations that were closer to the nutrient requirements, a 10 to 15% reduction of N and P contents of chicken manure resulted (FEFANA, 1992). Recent research into dietary modification has resulted in the reduction of NH$_3$ emission of 28 to 79% in pig manure (Canh et al., 1998a; Canh et al., 1998b; Hankins et al., 2000; Kay and Lee, 1997; Sutton et al., 1999).

Phase feeding in chicks and pigs reduced N content 10 to 33% (FEFANA, 1992; Henry and Dourmad, 1993; Koch, 1990; Sutton et al., 1997) and NH$_3$ emission in growing and finishing pig manure by 49 to 79% (Boisen et al., 1995; Sutton et al., 1997; Turner et al., 1996; Van der Peet-Schwering et al., 1996). According to scientists (FEFANA, 1992; Henry and Dourmad, 1993; Koch, 1990; Sutton et al., 1997), phase feeding also resulted in a 10 to 13% reduction in the P content of pig manure. The use of highly digestible raw materials in chicken and
| TABLE 1  
Reducing Concentration of Various Pollutants in Animal Manure Through 
Supplements and Feeding Programs |
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<td>Factors</td>
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<td>Odor (N(_2) emission)</td>
<td>Dry matter</td>
<td>Experimental animal used</td>
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<td>Synthetic amino acids and reduced protein Intake</td>
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<td>Diet modification</td>
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<td>Phase feeding</td>
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pig formulations has resulted in a 5% reduction each in manure N and P contents (FEFANA, 1992).

B. Odor in Animal Agriculture and Diet Manipulation

Odor has been described as the number one problem associated with animal pollution (Lyons, 1995). And odor and N pollution are closely related because both are mainly produced by crude protein (CP) (Coelho, 1994). Offensive odors from livestock facilities consist of many (ranging from 30 to more than 200) volatile odorous compounds, including hydrogen sulfide and ammonia (Hobbs et al., 1995; O’Neill and Phillips, 1992; Shurson et al., 1999; Spaelstra, 1980). Sutton et al. (1999) reported that primary odor-causing compounds evolve from excess degradable proteins and lack of specific fermentable carbohydrates during microbial fermentation.

Solutions to odor control have been studied in masking agents, enzyme and bacterial preparations, feed additives, chemicals, oxidation processes, air scrubbers, biofilters and new ventilation systems, but research relating the effects of the swine diet on manure odors has been scarce (Sutton, 1999). However, dietary manipulation is an opportunity for improvement to reduce nutrient excretion as well as to improve odor control (Coffey, 1992).

A large part of the N losses is associated with inefficiencies of digestion and absorption, so providing diets with highly digestible amino acids may reduce the amount of N excretion. Hobbs et al. (1996) demonstrated that reducing dietary protein concentration reduced several of the odor-producing compounds. When nutritionally adequate, low sulfur starter diets are fed, total sulfur and sulfate excretion can be reduced approximately 30% without compromising energy and N digestibility or pig performance (Shurson et al., 1999). Furthermore, this study shows that a reduction in total sulfur consumption and excretion can lead to a reduction in hydrogen sulfide gas and odor, but not affect ammonia levels in nursery facilities. Sutton et al. (1999) reported that ammonia emissions were reduced by 28 to 79% through diet modification, and limited research on reduction of other odorous volatile organic compounds through diet modifications is promising. They added that continued nutritional and microbial research to incorporate protein degradation products, especially sulfur-containing organics, with fermentable carbohydrates in the lower gastrointestinal tract of pigs will further control odors from manure.

III. IMPROVING NUTRIENT EFFICIENCY THROUGH MANUFACTURING STRATEGIES TO REDUCE POLLUTANTS

Decreasing the excretion of excess nutrients may be achieved by determining the content of nutrients in feedstuffs and improving feed manufacturing tech-
niques. Determining the nutrient content in feedstuffs is discussed in the section on testing of the complete feed. Feed processing, especially grinding, increases the surface area of the feed that is exposed to the animal digestive system. Processing is also known to facilitate mixing, improve feed density, reduce dustiness, improve palatability, extend “shelf life” and alter nutrient makeup (Jensen et al., 1965; Nahm et al., 1998; Peisker, 1994; Wilson and Beyer, 1997).

A. Effect of Grinding and Particle Size on Feed Efficiencies

Prior to mixing, grain is ground to increase the surface area and subsequently improve the digestion rate, to decrease segregation and mixing problems, and to assist in processes such as extrusion or pelleting (Nir, 1996), and grinding to the proper size can improve a herd’s feed efficiency and be more cost efficient (Norton, 1999). Reducing particle size from 1000 to 400 μm improved nutrient digestibility and lowered average daily feed intake, which resulted in a 26% decrease in daily dry matter excretion and a 27% decrease in daily N excretion in the manure of finishing pigs (Wondra et al., 1995c). While in another study, a particle size less than 600 μm was suitable for corn used for meal and pelleted diets. It has also been shown that uniform particle sizes provide improved nutrient (dry matter, N and gross energy) digestibilities (Wondra et al., 1995a, 1995b). In poultry, particle size preference has been shown to vary with age, the preference for larger particles increases as the bird become older, and it may be related to beak dimensions (Bartov, 2000). In broilers, the positive effect of mesh coarseness on performance is seen even after the feed was subsequently pelleted and phytate P utilization of corn by broilers improved by increasing the particle size (Kasin and Edwards, 1998). The effect of corn or hard and soft grain sorghum particle size on growth performance and nutrient utilization in broiler chicks has been investigated (Cabrera et al., 1994). As particle size was reduced, energy required to grind increased, and production rate decreased. Corn required more energy to grind and had lower production rate than the sorghums. Growth rate, daily feed consumption, and gain/fed were not affected by treatment.

The effects of grain particle size on nutrient digestibility have been studied (Owsley et al., 1981). In ileal cannulated pigs, as the particle size was reduced, the upper gastrointestinal digestibility of N, DM, gross energy (GE), starch and most amino acids was increased. When the particle size of barley was reduced by 14% (789 vs. 676 μm) for starter pigs, their average daily gain (ADG) and gain to feed (G/F) improved by 5% (Goodband and Hines, 1988). Improved G/F and DM, GE and N digestibility were noted when the particle size of corn and grain sorghum was reduced (Ohh et al., 1983). Extensive particle size reduction may not improve the performance of pigs fed wheat. In starter pigs fed diets with wheat ground to 860 or 1710 μm average particle size, the average daily gain and G/F were similar (Seerley et al., 1988).
The development of esophageal ulcers, stomach lesions, and keratinization in pigs has been correlated to fine grinding of feeds (Hedde et al., 1985). Fine grinding (less than 600 μm) of corn and two grain sorghum genotypes negatively affected stomach morphology, but the improved performance in these animals may make fine grinding acceptable (Cabrera et al., 1993). This study also showed that smaller grain particle size dramatically reduced DM and N excretion.

The influence of mill type (hammer mill vs. roller mill) on finishing pig performance and stomach morphology has been investigated by Wondra et al. (1993). Growth performance was not affected by mill type, but when corn was ground by a roller mill, pigs showed greater digestibilities of DM, N, and GE, while they also excreted 18% less DM and 13% less N than pigs fed hammer mill ground corn.

B. Feed (Nutrient) Uniformity and its Effect on Nutrient Excretion and Animal Performance

Improper mixing of feeds results in reduced uniformity of the diet, leading to poor animal performance and increased nutrient excretion into the environment. Analytical results from 26 sow feed samples and 17 finishing feed samples were summarized by Spears (1996). Single samples were taken from each farm and analyzed by the North Carolina Feed Testing Laboratory. The mineral concentrations in the different feeds varied substantially. The mineral contents of the feeds were in excess of the requirements suggested by the National Research Council (NRC, 1998). The use of excess nutrients in order to avoid nutrient deficiencies when formulating diets accounts for variability in ingredient composition and accuracy of diet mixing, but it also increases nutrient excretion and diet cost. Nahm et al. (1998) noted that the livestock and poultry industries must be aware that if microingredients of feed such as vitamins, amino acids, trace elements, enzymes, growth promotants, and drugs are not properly distributed in the feed, there is a resultant adverse effect on animal performance. There is a greater importance for feed uniformity in very young animals and animals with a short digestive tract, hen compared with older or larger animals that consume larger amounts of feed less often (Nahm and Carlson, 1998). In pig, Miner et al. (1997) found that the application of 1 to 4% (w/v) finely ground clinoptilolite to dairy slurry, immediately before spreading through a sprinkler system, reduced NH3 emission rates by up to 60%. Even though the importance of diet uniformity is intuitive, there is very little credible research that relates diet uniformity to animal performance (Behnke, 1996).

In a survey of commercial feed mixers, over 50% did not meet the industry standard of a coefficient of variation (CV) of less than 10% when methionine or lysine was used as a tracer (Wicker and Poole, 1991). The results were similar when farm feed mixers were surveyed (Stark et al., 1991). That survey
indicated that 42% of participants had CVs of less than 10% (67% were between 10 and 20% and 11% had CVs greater than 20%). The tracer in this study was salt.

Although the accepted industry standard for mix uniformity of a complete diet is a CV of 10% or less, it has been shown that broiler chicks had maximum growth performance with a diet that had a CV of 12 to 23%, depending on the method of analysis (McCoy et al., 1994). Nursery pigs have been reported to require feed mixed to a CV of at least 12% to maximize performance (Traylor, 1997). In both of these studies, P excretion was decreased when phytase was added to the chicken and pig diets.

Johnston and Southern (2000) determined the effect of varying mix uniformity of phytase on growth performance, mineral retention and bone mineralization. They found that P excretion increased linearly as phytase CV increased and P excretion tended to be higher for chicks fed the CV 103 (calcium - Ca 0.9% + aP 0.35% + 0 or 1200 FTU phytase units) treatment than those fed the CV0 (Ca 0.9% + aP 0.35% + 600 FTU phytase units). Ca and P excretion was numerically higher for the CV 69 (Ca 0.9% + aP 0.35% + 200 or 1000 FTU phytase units) treatment than for the CV 103 treatment.

The nutrient availability in animal feedstuffs may be increased through the use of enzymes. The actions of feed enzymes include any or all of the following: (1) supplement to the endogenous enzyme production of the host; (2) nutrient availability in the feed may be improved; (3) digestibility of the indigestible fiber materials may be improved; and (4) the antinutritional factors in feed ingredients may be decreased (Scott, 1991).

The CVs of the enzyme application improves with increased mixing of the liquid enzyme in the finished feed. Improvements in CVs have been seen during the transfer of the feed from the mixing screw, to the bin on the farm and to the feed hopper in the poultry house. It is recommended that finished feed be sampled immediately after blending/mixing to determine how well the feed mill is applying the enzyme. The quantity of enzyme is as important as the consistency of application. Although adequate field performance has been noted with CVs of 15 to 20% (Classen, 2000), the effectiveness of feed enzymes is significantly affected by the type of ingredients, cultivars, types of soils, diet ingredients, types of feed processing, age of animal, etc. (Duncan, 1973).

Every enzyme has a mode of action and a specific assay, although uniformity of these assays is an industry problem for a variety of reasons. The determination of the complete enzyme levels in feed is suspect because of the small quantity of enzyme in the feed, as well as the presence of soluble inhibitors or the possibility of the enzyme binding to substrate (Classen, 2000). Therefore, the primary method used to determine the quality of an enzyme as a feed additive must be biological testing under commercial manufacturing and animal production conditions (Nahm, 1992; Classen, 2000).
C. Expanding/ Pelleting Processes

The process of expanding is a typical High-Intensive-Short Term (HIST) process involving an expander, which is a simplified and low-cost extruder having its own technical specification. The expander is used in industrial manufacturing of a compound as a pressure conditioner before the pellet mill in order to improve the pellet quality.

Multiple beneficial effects can be obtained through expanding. Nutrient digestibility is increased by expanders, including N digestibility resulting in reduced N excretion. They also are responsible for inactivation of antinutritional factors like protease inhibitors, denaturation of the tertiary protein structure, removal of resistance to proteolytic enzymes, which decreases hydrolysis time in the gastrointestinal tract (Coelho, 1994). Expanders are also involved in improving the hydrolysis, gelatinization, and melting of starch and polysaccharides, which includes the decrease in crystallinity and depolymerization of starch molecules, resulting in improved digestibility. Fat-splitting enzymes are inactivated by expanders, and this reduces the potential for fat oxidation. Expanders inactivate several pathogenic organism such as Salmonella and E. coli (Delort-Laval, 1993).

Because of the correlation between starch modification and pellet quality, the nutritional importance of the starch modification by expanding can be used as benefit too in comparison to the conventional pelleting. Fancher et al. (1996) reported improved growth and feed conversion in male turkeys fed expanded diets compared with diets that were only pelleted. Beyer (2000) found that these parameters are improved by 5 to 10% when expanded diets are compared with conventionally pelleted rations in broiler trials. Edwards et al. (1999) demonstrated steam pelleting of corn, soybean meal or diets containing these ingredients, as well as extrusion of this diet did not increase phytate phosphorus utilization by broiler chicks. Moreover, extrusion of the diet decreased Ca, P, and phytate P retention, and its ME value.

Pelleting of feed has the potential to improve feed efficiency and reduce nutrient excretion. Wondra et al. (1995) reported that dry matter and N excretion in feces were decreased 23 and 22%, respectively, by pelleting. Feed efficiency was improved 6.6% in that study. Summarizing eight trials on pelleting diets for swine, Hancock et al. (1996) concluded that pelleting improved average daily gain (ADG) 6% and feed efficiency 6 to 7%. A 2% reduction in feed wastage can reduce the N and P in manure approximately 3% (based on a N and P retention of 35%) (Van Heugten and Van Kempen, 1999).

Broiler performance is affected more by addition of a beta-glucanase to a barley based diet when the feed is pelleted rather than a mash (Belyavin, 1994). Regardless of how phytase is added to the diet, inactivation of the enzyme is still a concern. Exogenous phytase addition can be done after expansion and/or pelleting (Aicher, 1998), which avoids heat inactivation of the enzyme. When properly stabilized enzymes are used, heat and pelleting trials show good enzyme recovery.
even at high temperatures (Classen et al., 1991). A large number of commercial trials have shown that enzyme supplemented feeds pelleted at temperatures of 71 to 90°C (160 to 195°F) improved animal performance, indicating the survival and presence of added enzyme activities. Heat-stable enzyme products are available, but methods to assay the enzyme stability remaining after the pelleting process has not been agreed upon (Bedford, 1993). Enzyme stabilization through improved production technology has allowed some dry enzyme products to be pelleted after conditioning at up to 88°C (190°F) and liquid enzymes to be stored in the feed mill up to 4 months prior to feeding (Lobo, 1999).

Some improvements seen with the extrusion process include improved digestibility of nutrients by rupturing cell walls, changing the chemical and physical properties of carbohydrates and proteins, and reductions in the protein and fat contents of corn, but there were no changes seen in the concentrations of various amino acids. The use of extruded corn in the diets of young pigs improved energy utilization, but there was no effect on lysine or nitrogen utilization (Herkelman et al., 1990). The trypsin inhibitor content of soybean meal is reduced by extrusion, but urease activity and utilization of lysine by young pigs were not affected (Rodhouse et al., 1992). Steam pelleting or extrusion of corn, soybean meal or diets containing these ingredients did not increase phytate P utilization by broiler chicks (Edwards et al., 1999).

Certain heat-sensitive nutrients may be destroyed by expanders, but Coelho (1994) indicated that research showed this to be an insignificant concern. However, McEllhiney (1989) reported that feed formulations need to account for decreases in vitamin A potency of 29.3% due to regrinding, and another 12.9% decrease when reground mash is pelleted. A 17.9% loss of vitamin A was seen when feed was pelleted alone, without regrinding, but when it was reground, the loss increased to 38.4%. Pelleting of feed has been shown to increase the lysine requirement in growing turkeys compared with turkey fed similar diets in mash form, especially when lysine levels were marginal in the formulations (Jensen et al., 1965). Because pelleting increased the productive energy of the diet, Beyer (2000) speculated that more lysine was required because the requirement of some nutrients is related to the level of other nutrients available to the bird. If pelleting increases the feed conversion by 10%, then the theoretical requirement for lysine in growing turkeys, for example, would be 1.43% compared with mash at 1.3% (NRC, 1994). Further research is still needed on the effect of feed form on the nutrient content of feed. Feed form may influence certain nutritional requirements and has been shown to interact with bird behavior, management, and anatomical changes. Growth, feed conversion, and product quality may all be improved by properly manufactured feed. The determination of the effect of feed conditioning and processing on nutrient availability is needed to increase the precision of feeding programs to reduce costs. Efficiency could be increased by refinements in crumble quality, pellet diameter, and pellet length. Least cost feed formulation needs to evaluate the resulting impact on feed quality and bird performance.
IV. IMPROVING NUTRIENT EFFICIENCY BY TESTING THE COMPLETE FEED

Successful quality control programs must include sending finished rations for laboratory analysis. It is important to verify that the steps to improve efficiency have been accurate and whether the feed will do its job in the livestock herd. First, a representative fed sample is needed. A sample should be kept back, labeled with the date, and stored in an air tight container for the least 1 year.

A reliable laboratory should be chosen for sending the sample. Results should be reported within 3 days and should include contents of nutrients such as protein, fat, and fiber. Sometimes the limited number of amino acids, vitamins, trace minerals, and others are included along with specialist’s advice for farmers on how best to apply the analytical data (Nahm, 2000). There is an acceptable analytical variation for each nutrient.

There are two types of analytical methods used for quality control program in laboratories, which are the wet chemistry method and the dry chemistry method. Near Infrared Reflectance Analysis (NIRA) is a good example of dry chemistry method. NIRA may be the answer for proving rapid and accurate digestible energy and amino acid values for use in feed formulation.

V. CONCLUSION

Recently, the reduction of pollutants in animal manure has been approached through research into improving nutrient efficiency, mainly with pig and chicken test subjects. Nutrient efficiency has been improved through supplements (extended use of amino acids and related compounds, use of enzymes, and use of growth promotants) and modifying feeding programs (formulations closer to requirements, phase feeding, and increased use of highly digestible raw materials). These methods lead to a reduction of DM, N, P, and trace mineral contents as well as decreased odor of animal manure.

Feed manufacturing techniques, including grinding methods to provide proper particle sizes and feed uniformity or expanding and pelleting techniques, must be studied to improve feed efficiency and reduce manure pollutants as well as done in a cost-effective way. Specialists also need to provide improved feed formulations based on analytical results of samples taken from the farms, which will result in reduced manure pollutants from poultry and swine.

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