NUTRITIONAL STRATEGIES TO REDUCE AMMONIA EMISSIONS FROM LAYING HENS

Kristjan Bregendahl[1] and Stacey Roberts
Iowa State University
Department of Animal Science
201 Kildee Hall
Ames, IA 50011-3150

Introduction

The development of a sustainable, profitable, and competitive egg-production system is becoming a challenging issue facing the laying-hen industry. The excretion and volatilization of nitrogen and the emission of volatile organic compounds of dietary origin are responsible for a large part of the environmental issues that have risen from the intensive poultry production. Especially for layer houses, ammonia is recognized as a major aerial pollutant and may adversely affect rural residential property values and the public's attitude towards intensive egg-production systems (Mackie et al., 1998; Herriges et al., 2003). Moreover, high levels of air-borne ammonia in poultry houses adversely affects egg production, worker health, and the public perception of the egg-production industry (Deaton et al., 1982; Morse, 1995; Mackie et al., 1998; Moore, 1998; Yang et al., 2000; Whyte, 2002). Especially during winter, the ammonia concentrations in many high-rise houses will exceed the levels recommended in industry guidelines (Liang et al., 2003; United Egg Producers, 2005). Moreover, Federal regulations (i.e., CERCLA[2] and EPCRA[3]) permit a maximum of 100 lb of ammonia be emitted per day. Thus, strategies to lower ammonia emissions from layer houses and manure-storage barns (containing manure from manure-belt houses) need to be identified and evaluated.

Where does ammonia come from?

Laying-hen diets that are formulated using proteinaceous ingredients such as soybean meal and meat-and-bone meal to meet the recommended levels of essential amino acids, contain relatively high levels of crude protein and excessive amounts of amino acids other than the first- and second-limiting amino acids (usually methionine and lysine, respectively). Because the birds have no storage mechanisms for amino acids consumed beyond the requirement for protein synthesis, the amino acids consumed in excess are deaminated and the amino acid–derived nitrogen is excreted in the urine mainly as uric acid (80%), ammonia (10%), and urea (5%) (Goldstein and Skadhauge, 2000). Once excreted, uric acid is readily converted to ammonia (NH_3) by a series of microbial enzymes present in the manure (Figure 1).

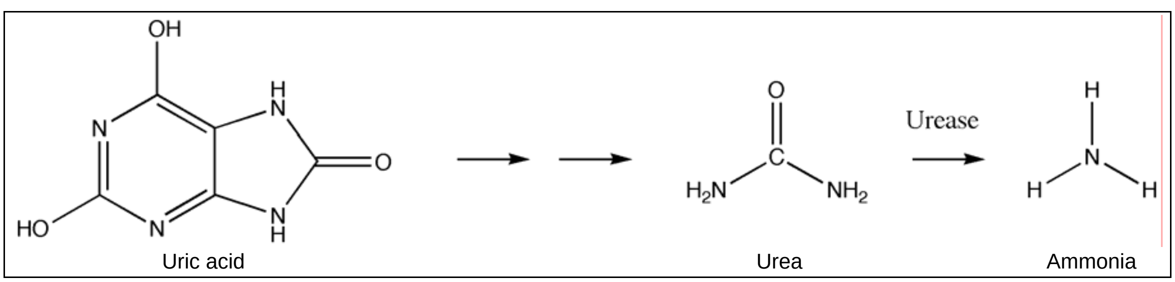

Figure 1. Conversion of uric acid to ammonia through a series of microbial enzymes, including urease.

[1] To whom correspondence should be addressed (515/294-5132, kristjan@iastate.edu).
[2] Comprehensive Environmental Response, Compensation, and Liability Act.
[3] Emergency Planning and Community Right-to-Know Act.

Selected strategies to reduce ammonia emission

There are multiple methods to reduce ammonia concentrations in laying-hen houses; these include mechanical, manure management, and dietary approaches. Increasing the ventilation rate will remove the ammonia from the building and lower the hens' exposure to ammonia. However, it may not always be practical to increase ventilation (e.g., in cold weather) and increasing the ventilation rate does nothing by itself to comply with the CERCLA and EPCRA regulations. Other mechanical and management approaches include planting tree buffers around the perimeter of the laying-hen house (Coletti and Tyndall, 2005) or moving the manure out of the house (as occurs in manure-belt houses). The manure itself can be treated either chemically (e.g., by acidification or addition of zeolite) or physically (by changing its surface-to-volume ratio or temperature) (Panetta et al., 2005; Xin et al., 2005). Although post-excretion strategies alone are effective in reducing ammonia emission, a combination of post- and pre-excretion strategies will be more effective in minimizing ammonia emission. Pre-excretion strategies include dietary manipulation, which can dramatically reduce the ammonia excretion from the birds and the manure. Such strategies can be divided into two not mutually exclusive categories based on the method of action: Lowering the nitrogen (uric acid) excretion and 'trapping' the ammonia in the manure.

Strategies to lower nitrogen excretion include phase feeding and formulating diets without a crude protein minimum using crystalline amino acids. The amino acid requirements of young hens are relatively high and decrease over time due to declining egg production and rate of body weight gain. When phase feeding is implemented, the dietary nutrient profile is adjusted over time to better reflect that needed by the hens. As a result, consumption of excess amino acids is reduced and, with it, is the excretion of uric acid and production of ammonia. Theoretically, a new diet should be formulated and fed every day, however, a more practical approach is to change the diet formulation at least four times during a production cycle.

The amount of nitrogen excreted by poultry can be reduced dramatically by not specifying a dietary crude-protein minimum and instead formulating the diet to meet the hens' amino acid requirements. Such 'low–crude-protein' diets can be obtained through a partial replacement of soybean meal with corn and crystalline amino acids or amino acid analogs. The inclusion of individual crystalline amino acids in the diet allows for a more precise formulation, more closely matching the content of dietary amino acids with that needed by the hens (Figure 2). As a result, the diet contains less excess amino acids (in relation the hens' needs), meaning that fewer amino acids are deaminated and less nitrogen converted to uric acid and excreted. A three to five percentage-unit reduction in the dietary crude protein content has resulted in up to a 60% reduction in the total nitrogen excretion from broilers and laying hens (Summers, 1993; Summers and Leeson, 1994; Aletor et al., 2000; Bregendahl et al., 2002; Keshavarz and Austic, 2004) with concomitant reductions in ammonia emission (Latimier and Dourmad, 1993; Liang et al., 2003). Although the reduction in the dietary crude protein content is typically only around one percentage unit (e.g., from 17 to 16% crude protein) in practical laying-hen diets, the ammonia emission is reduced by 8–10% (Kerr and Easter, 1995; Liang et al., 2003).

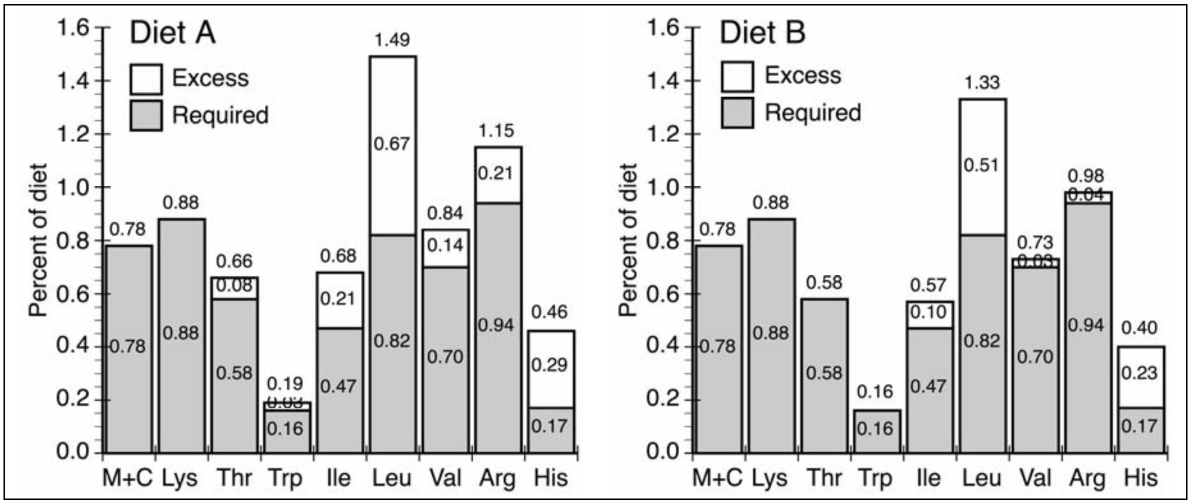

Figure 2. Amino acid contents of two diets formulated using corn, soybean meal, and DL-methionine (Diet A; 18.1% crude protein) or formulated using corn, soybean meal, DL-methionine, L-lysine·HCl, and L-threonine (Diet B; 16.1% crude protein). Note that both diets meet the amino acid requirements, but that Diet B has fewer excess amino acids.

As mentioned previously, ammonia emission can be reduced from laying hens by minimizing the excretion of uric acid and, therefore, ammonia emission. However, some ammonia production is inevitable and additives can be added to the diet to sequester or trap it. Among these additives is zeolite, a type of mineral with a porous or lattice-like structure, which when included in the diet binds ammonia in the feces and prevent it from being emitted into the air. Another strategy is to acidify the diet through addition of gypsum ($CaSO_4$) or calcium benzoate, or by lowering the dietary electrolyte balance[4] (Canh et al., 1998b). The acidic diet will result in acidic manure, causing ammonia (NH_3) to be converted to ammonium (NH_4^+). Because of the electrical charge, ammonium is more water soluble and not readily emitted into the air. Results from experiments conducted at Iowa State University indicate that feeding a low-protein diet fortified with gypsum and zeolite reduces ammonia emission from laying hens by 40% (Xin et al., 2005).

Dietary inclusion of fermentable fiber shifts partitioning of nitrogen excretion from urea and uric acid in the urine to microbial protein in the feces (Canh et al., 1997; Canh et al., 1998c). Because dietary fermentable fiber is not digested, it serves as an energy source for microbial growth in the large intestine. The nitrogen used in the (increased) microbial protein synthesis comes partly from nitrogen that diffuses from the blood across the intestinal wall—nitrogen that would otherwise have been excreted as uric acid. Although the combined nitrogen excretion in the urine and feces may not change with consumption of fermentable fiber, the fecal nitrogen is in the form of microbial protein, which is less likely than uric acid to be converted to ammonia and emitted into the air (Canh et al., 1997). Additional benefits of the microbial fermentation of the dietary fermentable fiber include production of volatile fatty acids, which lowers the pH of the manure. Indeed, for each unit decrease in pH, ammonia emissions from pig slurry decreased by 45% (Canh et al., 1998a). On the other hand, dietary inclusion of fermentable fiber may decrease the apparent nutrient digestibility and, therefore, may increase total nitrogen excretion (Canh et al., 1997). Moreover, because of the microbial fermentation of the dietary fiber, more odorous volatile compounds may be excreted from the hens fed fermentable fiber (Canh et al., 1998c). Nevertheless, Canh et al. (1998c) showed that dietary inclusion of fermentable fiber in the form of sugar-beet pulp decreased ammonia emissions from pig slurry.

The efficacy of dietary fermentable fiber in preventing ammonia emission from manure has not been investigated with laying hens. The objective of the study described below was therefore to determine if inclusion of fermentable fiber in laying-hen diets would reduce ammonia

[4] Calculated as the dietary contents of $Na^+ + K^+ - Cl^-$ and expressed in units of milliequivalents (mEq).

emissions from manure by shifting nitrogen excretion from uric acid in the manure to more stable microbial protein and by reducing manure pH.

Effect of fibrous feed ingredients on ammonia emissions from laying hens[5]

Materials and Methods

A total of 256 Hy-Line W-36 hens, 45 weeks of age, were allotted to the dietary treatments, which included a control diet and three fiber-containing diets (Table 1). The three fiber ingredients were chosen based on their availability in the Midwest; corn distiller's dried grains with solubles (DDGS) was included at 10% of the diet, whereas soybean hulls and wheat middlings were each included in amounts sufficient to supply an equal amount of neutral detergent fiber as that supplied by the 10% corn DDGS. All diets were formulated to contain equal amounts of digestible methionine+cystine, digestible lysine, metabolizable energy, calcium, and phosphorus.

Table 1. Composition and chemical analysis of diets.

Item	Control	Soy hulls	Wheat midds	Corn DDGS
Ingredient (%)				
Soy hulls	—	4.80	—	—
Wheat midds	—	—	7.30	—
Corn distiller's grain with solubles	—	—	—	10.00
Corn	62.82	56.55	54.93	51.90
Soybean meal (48% CP)	18.52	18.43	17.62	18.37
Limestone	8.96	8.90	8.98	9.00
Meat and bone meal (50% CP)	5.00	5.00	5.00	5.00
Vegetable oil	2.27	3.88	3.85	3.65
Dicalcium phosphate	0.27	0.28	0.21	0.14
Methionine hydroxy analogue	0.17	0.19	0.17	0.13
Sodium bicarbonate	0.20	0.12	0.10	—
Salt (iodized)	0.19	0.25	0.24	0.21
Trace-mineral premix	0.30	0.30	0.30	0.30
Vitamin premix	0.30	0.30	0.30	0.30
Celite[1]	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Metabolizable energy (N-corrected), kcal/kg	2,840	2,840	2,840	2,840
Linoleic acid, %	1.47	1.34	1.43	1.69
Crude protein (total), %	16.94	16.77	17.05	18.37
Neutral detergent fiber, %	9.20	11.21	10.73	11.67
Calcium, %	4.00	4.00	4.00	4.00
Phosphorus (non-phytate), %	0.37	0.37	0.37	0.37
Dietary electrolyte balance (K+Na–Cl), mEq/kg	191	191	191	191
Isoleucine (digestible), %	0.60	0.59	0.60	0.64
Lysine (digestible), %	0.73	0.73	0.73	0.73
Methionine (digestible), %	0.39	0.40	0.39	0.38
Methionine + cystine (digestible), %	0.61	0.61	0.61	0.61
Threonine (digestible), %	0.54	0.53	0.53	0.56
Tryptophan (digestible), %	0.18	0.18	0.18	0.19
Valine (digestible), %	0.70	0.69	0.70	0.75

[1]Indigestible marker.

Hens were housed two per cage (96 in^2/hen), which each were equipped with one nipple waterer and a plastic self-feeder; hens had ad libitum access to feed at all times. Egg production was recorded daily and feed intake was measured once per week throughout the 12-week study, after which egg mass (= egg production × egg weight) was calculated. Six weeks into the study, manure samples were collected and analyzed for contents of total nitrogen, uric acid, acid

[5] Results from this study have been presented in part at the 2005 Iowa Egg Industry Symposium and in the 2006 Iowa State University Animal Industries Report.

insoluble ash, pH, and dry matter. The manure excretion was calculated using acid insoluble ash as an indigestible marker. Ammonia emission was measured from manure collected over a 24-hour period, pooled within diet, and stored at –20˚C prior to analysis using ammonia-emission vessels described by Xin et al. (2005). Data were analyzed by analysis of variance (ANOVA) appropriate for a randomized complete block design and results from each of the three fiber diets were compared to that of the control diet using contrasts. P-values ≤ 0.05 were considered significant, whereas P-values ≤ 0.10 were considered a trend. All procedures were approved by the Iowa State University Institutional Animal Care and Use Committee.

Results and Discussion

Including soy hulls, wheat midds, or corn DDGS in the diets for laying hens reduced ($P < 0.05$) the total ammonia emission and the rate of ammonia emission from manure by up to 50% (Figure 3). This reduction in ammonia emission could seemingly not be attributed a shift in the partitioning of nitrogen excretion from uric acid to microbial protein as described by (Canh et al., 1997), because both the excretion of total and uric-acid nitrogen were unaffected ($P > 0.10$) by the dietary treatments (Figure 4). Instead, a reduction in manure pH, likely stemming from an increased content of microbially produced volatile fatty acids, caused a shift from ammonia (NH_3) to the more water-soluble ammonium (NH_4^+) and thereby reducing ammonia emission (Figure 5).

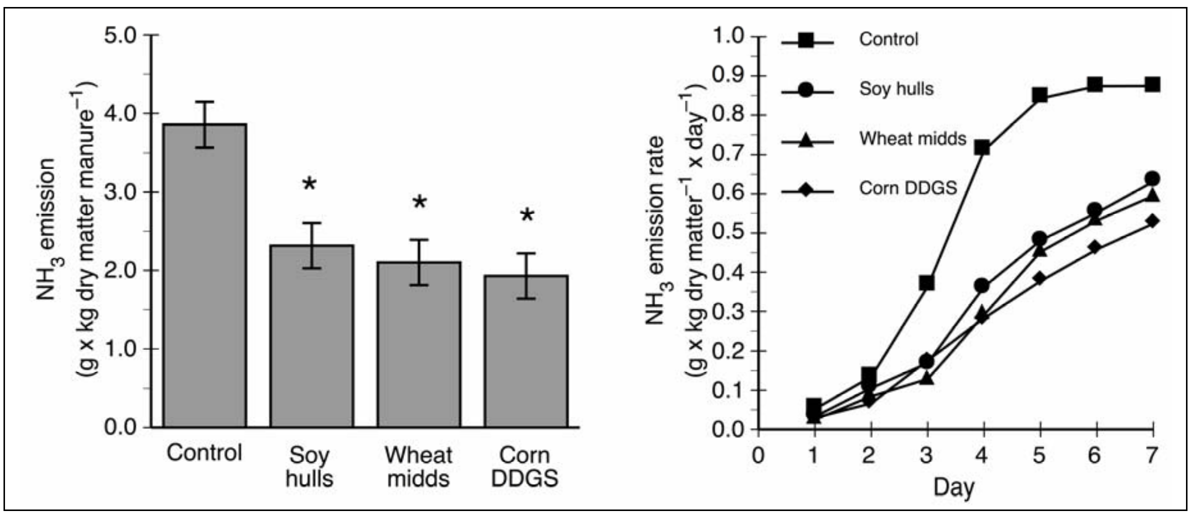

Figure 3. Total ammonia emission from manure over seven days and daily ammonia emission rate. Means ± pooled SEM, n = 6. *Different from control ($P < 0.05$).

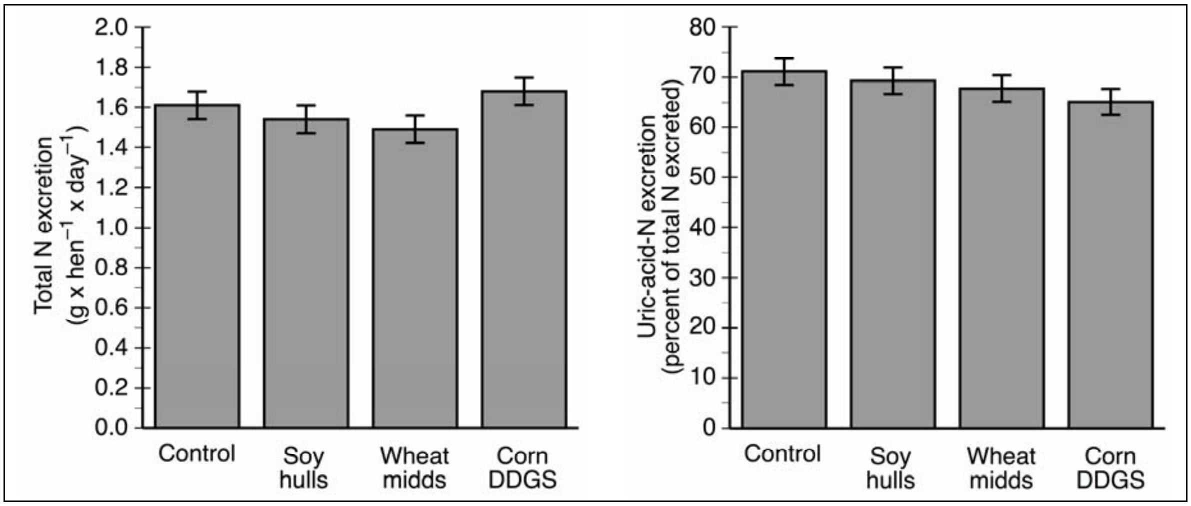

Figure 4. Excretion of total nitrogen and excretion of uric-acid–nitrogen as a percentage of total nitrogen excreted. Means ± pooled SEM, n = 32. There were no effects (P > 0.10) of the dietary treatments.

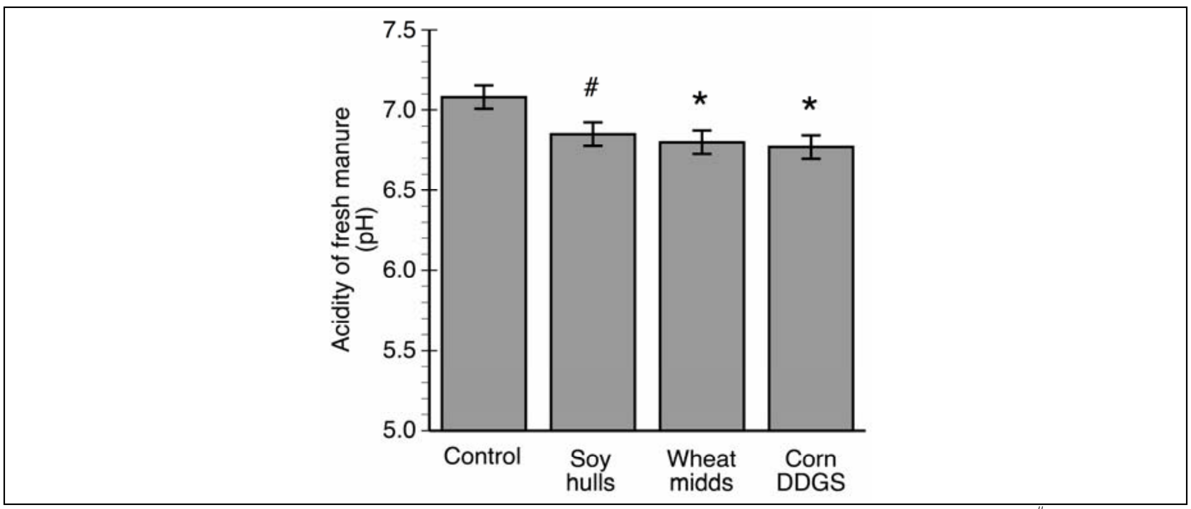

Figure 5. Acidity (pH) of fresh manure. Means ± pooled SEM, n = 32. *Different from control (P < 0.05), #different from control (P < 0.10).

The incorporation of fermentable fiber (from soy hulls, wheat midds, or corn DDGS) in the laying-hen diets did not significantly affect egg production or egg mass (Figure 6). However, the egg weight of hens fed the soy-hull diet was higher than that observed for control-fed hens (Figure 7). No differences (P > 0.10) were observed among the treatments with regard to egg composition (i.e., percentages of solids, yolk, albumen, and shell; data not shown).

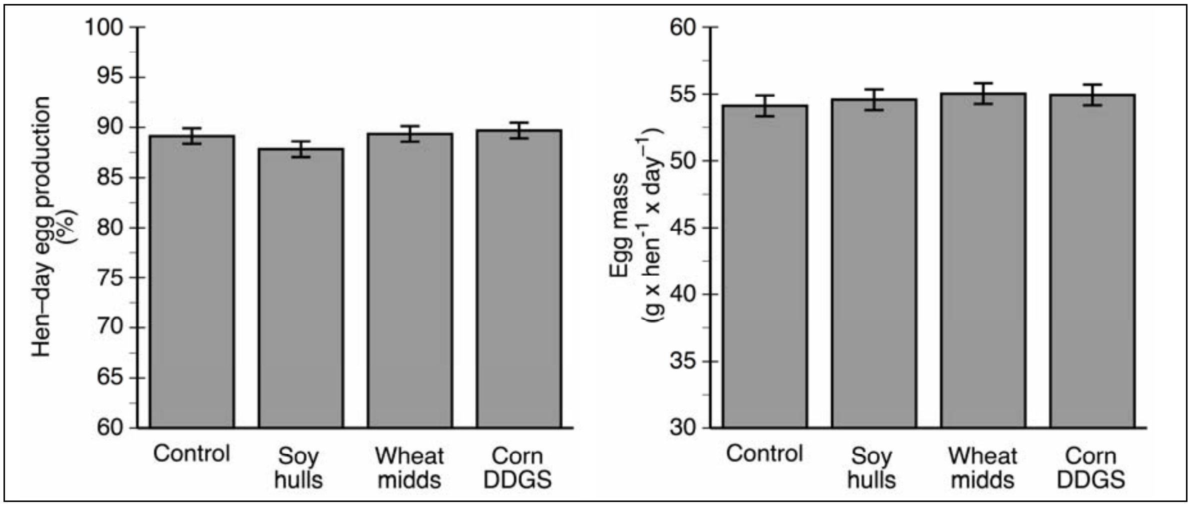

Figure 6. Hen–day egg production rate and egg mass. Means ± pooled SEM, n = 32. There were no effects ($P > 0.10$) of the dietary treatments.

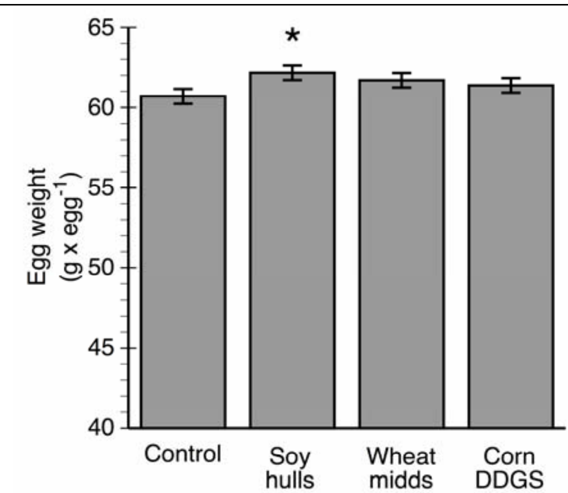

Figure 7. Egg weight. Means ± pooled SEM, n = 32. *Different from control ($P < 0.05$).

Care was taken in the diet formulation to equalize the energy and nutrient content among the diets; however, hens fed the fiber diets consumed more feed than the control-fed hens (Figure 8), potentially because the energy values for the soy hulls, wheat midds, and corn DDGS were overestimated. Yet, the differences were not sufficiently large to elicit differences in feed efficiency ($P > 0.05$). In part because there were no differences ($P > 0.10$) in the apparent digestibility of the diet dry matter, the slightly higher feed consumption rate of the fiber-fed hens tended ($P < 0.10$) to cause an increase in dry matter manure production (Figure 9).

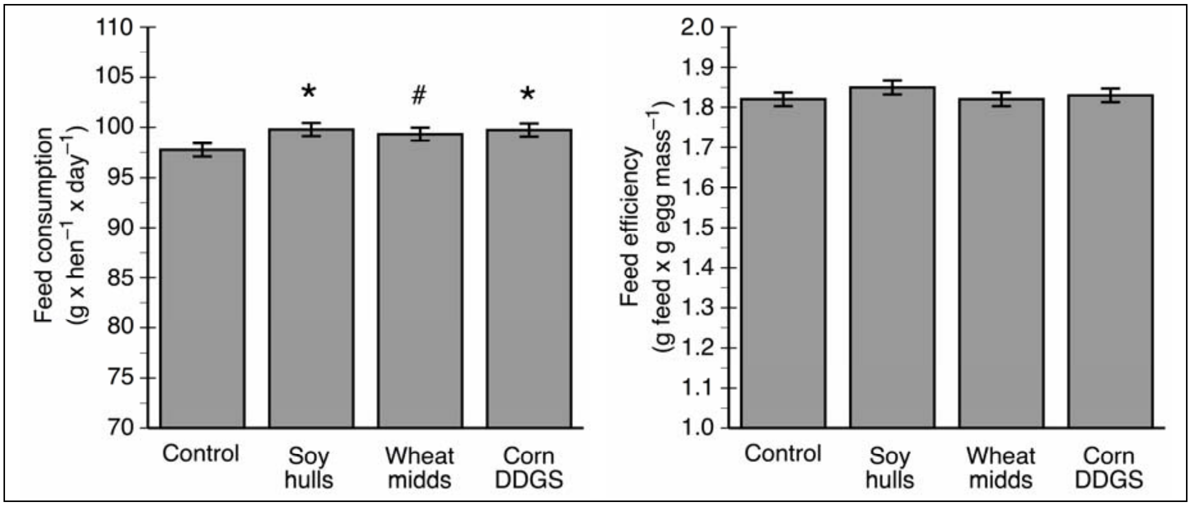

Figure 8. Feed consumption and feed efficiency. Means ± pooled SEM, n = 32. *Different from control ($P < 0.05$), #different from control ($P < 0.10$).

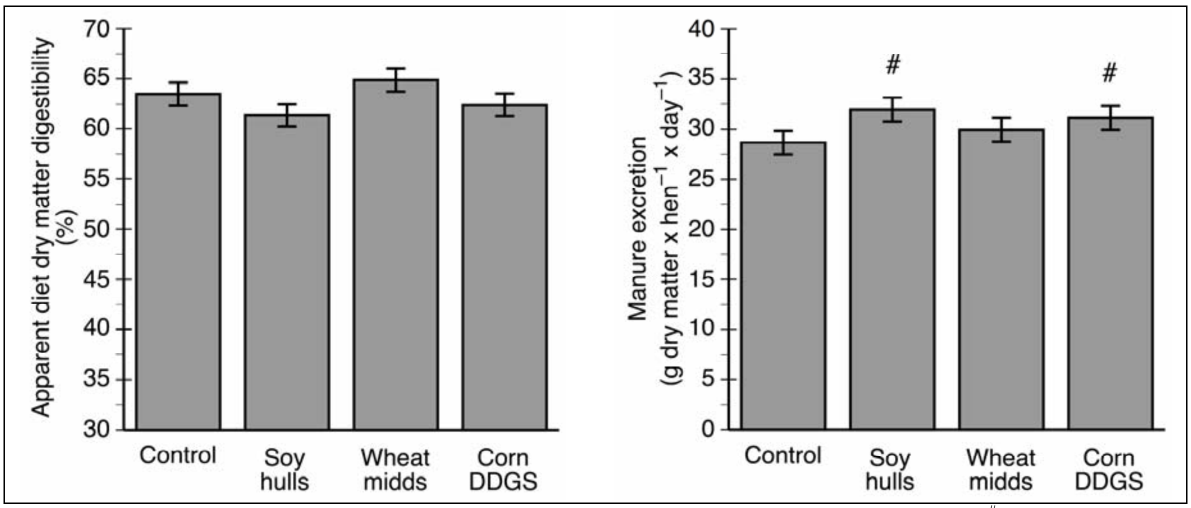

Figure 9. Apparent diet dry matter digestibility and excretion of manure. Means ± pooled SEM, n = 32. #Different from control ($P < 0.10$).

In summary, including either 5% soy hulls, 7% wheat midds, or 10% corn DDGS in laying-hen diets did not significantly change egg-production or egg-quality parameters, but reduced the ammonia emission by up to 50%. More research is needed to investigate effects of the fibrous diets on manure excretion and dry matter content as well as to further elucidate the mechanism by which the dietary fiber reduces ammonia emission and at what inclusion rate the ammonia emission is affected.

Acknowledgements

The study was conducted by Stacey Roberts in partial fulfillment of a M.S. degree in Animal Nutrition under the supervision of Dr. Bregendahl. Funding for the study was provided by the Midwest Poultry Federation and Novus International through grants to Drs. K. Bregendahl, H. Xin, B. Kerr, and J. Russell. In-kind donations by Rembrandt Enterprises, Inc., Rembrandt, IA (hens), Feed Energy Company, Des Moines, IA (vegetable oil); and ADM, Des Moines, IA (fiber ingredients) are appreciated, as is the help of the staff at the Iowa State University Poultry Science Research Center and in the labs of Drs. Bregendahl, Xin, Kerr, and Russell.

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