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# COMPARISON OF TWO METHODS FOR ESTIMATING BROILER MANURE NUTRIENT EXCRETION: BIOLOGICAL MASS BALANCE VERSUS MODEL BASED ON MASS BALANCE APPROACH

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## ABSTRACT

In the absence of actual biological data on total excreted nutrients, development of models is needed to predict these values. Models are usually constructed based on relationships that have been determined biologically and that allow for estimation of values. Estimation of nutrient excretion has become necessary due to the recent emphasis on environmental management and regulation of animal feeding operations. Because of the impact that new environmental regulations will have on animal production it is important to determine if model estimates are accurately predicting biological nutrient excretion rates. A broiler chick total excreta collection by age period trial was conducted to determine actual excretion of dry matter (DM), nitrogen (N) and phosphorus (P). Values obtained in this trial were compared to the latest broiler model developed and proposed by the American Society of Agricultural Engineers (ASAE). The new proposed ASAE model overestimates DM, N and P excretion by 19.4, 14 and 13%, respectively as compared to numbers obtained from a total collection trial in broiler chicks up to 2.36 kg of body weight fed an average industry diet. The apparent overestimation in nutrient excretion levels in the proposed ASAE model reflects variability inherent at the commercial production level. These overestimations are within what would be expected when average production levels (variable) are being used compared to levels obtained from one controlled battery trial.

**KEYWORDS.** Broiler chickens, mass balance, excreta, nitrogen, dry matter, phosphorus.

# INTRODUCTION

Estimation of nutrient excretion based on models has become necessary due to the recent emphasis on environmental management and regulation of animal feeding operations that rely on predictions of nutrient excretion. As federal, state, and local governance and regulation increase in the nutrient management arena, the accuracy of nutrient excretion models is imperative for the success of animal agriculture in these circumstances. To determine the accuracy of a prediction model, the testing of that model's predictions against data obtained through biological testing is necessary. In general prediction models are necessary when the data needed is not available from direct biological testing. Numerous models exist that estimate nutrient excretion (ASAE, 2002; NRC, 2003). The NRC (2003) model is based on a process-base mass balance approach. Excreted N in this model is calculated by subtracting the quantity of N produced in the animal from the quantity of N consumed in the feed. This model assumes broilers are fed to meet NRC (1994) nutrient recommendations and used the body weight and feed efficiencies as given in the NRC (1994). The NRC (2003) model thus is using broiler information published between 1942 and 1990 for amino acid requirements and between 1952 and 1983 for P requirements. This model also uses only a three-phase feeding program when industry has moved to a four or five phase feeding program. There clearly are differences in the efficacy of nutrient use, growth and skeletal development between current broilers and those of more than 10 years ago (Havenstein et al., 1994a and b; Williams et al., 2000). NRC (1994) gives the weight of a male broiler at 49 days of age as 2.59 kg when 2001 industry average weights are closer to 2.3 kg and were 1.82 kg in 1982 (Lec, 2003). Genetic as well as diet and management changes have affected the ability of present broiler strains to convert nutrients to gain and allow for higher weights at earlier ages. Models need to reflect current practices when predicting current nutrient excretion levels.

The magnitude of the potential impact of using older performance and diet values can be substantial if one considers that at 42 d of age weight of a 1957 bird strain used for meat (Athens-Canadian random bred strain) was 508 g as compared to 2132 g for a 1992 commercial broiler strain (Arbor Acres). The present day commercial strains of broilers have been selected for rapid growth, efficient utilization of feed, breast yield, and bone development (Havenstein et al., 1994a and b; Williams et al., 2000). Mineralization of bone as well as bone formation of a present day commercial Ross meat strain of broilers has been shown to be different from its precursor strain of the year 1972. Bone ash content was lower in modern selected birds and mineral content was lower in the current Ross bird as compared to its 1972 precursor (Williams et al., 2000). These differences in mineralization would translate into lower mineral content in the carcass.

Because data is not available on retention of nutrients throughout growth, models make use of biological relationships usually determined in animal experiments of finite duration and generally based on one sex (Table 1). For example, in a limited list of published values for N retention the age of the birds used varied between 18 to 25 and 38 to 46 days of age. Only one reference uses female broilers. In the early age phase, N retention reported varied between 47.3 (Ravindran et al., 2000) and 55.1% (Huyghebeart and De Groote, 1997). At the older ages the range in reported numbers was between 38.8 (Dozier et al., 2001) and 43.2% (Bonnet et al., 1997) in males with females having a much lower retention of 24.5% (Dozier et al., 2001). With such limited information on female N retention, the model will tend to reflect male retention numbers. Differences exist in protein as well as amino acid content of the diets used in the published work that may influence retention. These differences are especially evident in the earlier age phase with protein varying between 21.4 (Ravindran et al., 2000) and 23.04% (Qian et al., 1997). Similar differences are seen when looking at a selected list of literature P retention values (Table 1). Selected P retention literature values generally reflect retention of P in males early in the growth phase (11 to 25 days of age) with very few P retention values for birds at the end of the growth phase. Retention levels for P vary between 34.1 (Ravindran et al., 2000) and 60.3% (Lan et al., 2002) in birds ranging between 11 and 25 days of age and fed diets that were similar in total as well as available or non-phytate P content and contained no added phytase. Most of the retention values available in the literature are apparent retention values derived from excreta collection studies. Apparent nutrient retention is derived from subtracting excreted nutrient from consumed nutrient and does not account for either endogenous losses or losses of the nutrient that are not accounted for in the excreta. Of importance is the loss of volatilized N from the excreta into the atmosphere mainly as ammonia but also as other volatile nitrogenous compounds such as nitrous oxide or nitric oxide. Thus the apparent N retention determined using excreta, where volatile N is not accounted for overestimates N retention.

Given that models will use mean retention values from different published studies, some of the variability inherent in the data set used will influence the predicted or estimated excretion levels when the model is applied. Since published retention values cover only part of the production phase, models use these values to reflect retention for a whole age or growth phase and in broiler models disregard retention sex effects. Knowing some of the limitations associated with using models to estimate excreted nutrients, the objective of this paper is to compare the estimated broiler DM, N, and P excretion by two different models with actual excretion determined in a broiler trial.

**Table 1. Examples of selected broiler nitrogen (N) and phosphorus (P) retention literature values published in the last seven years**

| Reference | Age, d | Sex | Diet Protein, % | N Retention, % | Diet P, % | P Retention, % |
|---|---|---|---|---|---|---|
| Bonnet, et al., 1997 | 38 to 42 | male | 20.8 | 43.2 | | ND[1] |
| Qian et al., 1997 | 18 to20 | male | 23.04 | 54.2 | | ND |

| | | | | | | |
|---|---|---|---|---|---|---|
| Huyghebaert and De Groote, 1997 | 21 to 25 | male | 21.54 | 55.1 | | ND |
| Dozier et al., 2001 | 45 to 46 | male | 20.0 | 38.8 | | ND |
| | | female | 20.0 | 24.5 | | ND |
| Lan et al., 2002 | 11 to 13 | male | | ND | 0.46 (nPP)[2] 0.69 (tP)[3] | 60.3 |
| | 18 to 20 | | | | | 51.2 |
| Li, et al., 2000 | 17 to 21 | male | | ND | 0.45 (aP) 0.74 (tP) | 44.6 |
| Kilburn and Edwards, 2001 | 13 to 15 | NP[4] | | ND[1] | 0.45 (aP)[5] 0. 71( tP) | 47.6 |
| Ravindran et al., 2000 | 21 to 25 | male | 21.4 | 47.3 | 0.45 (aP) 0.74 (tP) | 34.1 |
| Zyla et at., 2000 | 15 to 20 d | NS | | NP | 0.41 (nPP) 0.70 (tP) | 42.24 |
| Viveros et al., 2002 | 19 to 21 | male | | | 0.45 (nPP) 0.71 (tP) | 51.5 |
| | 40 to 42 | | | | 0.37 (nPP) 0.63 (tP) | 55.34 |

[1]ND = Not determine. [2] Non-phytate phosphorus (nPP). [3] Total phosphorus (tP). [4] NP = Not provided or specified. [5]Available phosphorus (aP).

Mass Balance Broiler Experiment

A broiler experiment was done where Ross 308 male broilers were raised in battery pens. Fifteen pens of birds were fed a control diet that reflected industry nutrient levels. Levels formulated were 21, 19, 17.5 and 16.5% protein in the starter, grower, finisher and withdrawal phases, respectively. The levels of non-phytate P formulated were 0.45, 0.35, 0.35 and 0.30% in the starter, grower, finisher and withdrawal phases, respectively. Feed consumption was measured (feed offered minus wastage) by phase and excreta collected in its totality every day. At the end of each phase, all the birds in three pens were fasted for 16 hours to minimize intestinal digesta content, killed and frozen. The carcasses (including feathers and viscera) were ground, freeze-dried and then ground again using a freeze grinder. Excreta were weighed as collected by phase, freeze-dried and ground. Feed, carcasses and excreta were analyzed for DM, N and P. For the purpose of this paper only the excretion numbers will be used. Pen values for excreta DM, N and P were regressed against body weight. Best fit for all measurements was linear regression. Average weight of the birds at the end of the experiment (43 days of age) was 2072.99 grams. Average N content in the carcass was 3.1% and average N consumed was 113.7 grams. These birds excreted an average of 893.57 g of DM, 39.92 g of N and 11.94 g of P.

Estimated Excretion Based on Nutrient Excretion Models

In a different paper in this proceeding (Applegate et al., 2003) the details of the new proposed broiler model are outlined. This model bases nutrient excretion on industry average feed formulation, average performance and published nutrient retentions based on animal experiments (Table 2). The estimated excreted DM, N, and P based on the proposed model are given in Table 3 for a typical broiler (2.36 kg body weight).

**Table 2. Profile of peer-reviewed publications (1985-present) used to derive retention values used in the broiler chick model in new ASAE Standards (from Applegate et al., 2003)**

| | Average Retention , % | Minimum | Maximum | # reports |
|---|---|---|---|---|
| Dry matter | 68.6 | 52.2 | 74.5 | 10 |
| Nitrogen | 60.2 | 44.0 | 73.5 | 11 |
| Phosphorus < 32 days | 49.3 | 34 | 64.1 | 22 |
| Phosphorus >32 days | 41.0 | 36 | 51.0 | 5 |

**Table 3. Manure nutrient excretion per bird to market based upon average diet formulation, average performance, and average published nutrient retention (from Applegate et al., 2003)**

| | Assumed | Assumed | | Assumed | ------ Excretion, grams/bird--------- | | |
|---|---|---|---|---|---|---|---|
| Specie | Market weight, kg | Market age | Nutrient | Retention, % | Average | Low | High |
| Broiler[1] | 2.36 | 47.7 days | DM | 68.64 | 1269.3 | 1181.7 | 1361.9 |
| | | | N | 60.2 | 53.18 | 52.44 | 53.92 |
| | | | P | 49.3 < 32 days | | | |
| | | | | 41.0 > 32 days | 15.82 | 14.58 | 17.25 |

[1]Represents 95.8% of broilers marketed July 2002 (662 million birds or 1.53 billion kg live weight). A four diet-feeding program is assumed. High and low values were determined from the variance of growth and diet formulation of the top 25% of broiler companies during this period.

A second model, proposed by NRC (2003) for N is based on NRC (1994) growth and efficiency values and on typical carcass N content values (NRC, 2003) of 2.6, 2.5, and 2.3% N in starter, grower, and finisher birds, respectively. Based on this model the estimated N excretion for a 7 week-old broiler weighing 2.25 kg is 96.5 g of nitrogen. It is important to note what information is being used in the model. The data used in the model is: based on a carcass balance or true balance; on consumptions and N content in feed according to NRC (1994) (overestimates as compared to today's commercial broiler) and on an average carcass N of 2.4% derived primarily from a reported carcass N determined on 56 day old female broilers (Santoso et al., 1995).

Comparison of Estimates of Nutrient Excretion Based on the Models with the Broiler Mass Balance Trial Results

The models as set have different end weights (2360 gram bird for the proposed ASAE model and 2250 gram bird in the NRC (2003)) and these end weights also differ from the end weight obtained in the broiler trial of a 2073 gram bird. With these different end points it is impossible to compare resulting excretion estimates. When end bird weight is set at 2360 grams the nutrient excretion predictions on a per bird basis are: 1269.3 and 1010.77 grams of DM, 15.82 and 13.73 grams of P and 53.18, 103.58, and 45.76 grams of N for the proposed ASAE model, NRC (2003) model and the mass balance trial, respectively (Table 4).

The biggest difference is seen with the NRC (2003) model but if the assumptions of the model are reviewed to reflect more current N consumption numbers and the N content of carcass is corrected to reflect N content of a carcass with feathers and viscera (3.1% vs 2.4% N carcass content the model uses currently) then the prediction would be for 56.35 grams of N excreted per 2360 grams bird. This number would include any nitrogen lost to the environment through volatilizations as compared to the other numbers (ASAE proposed model and mass balance trial) where N losses to the environment were not quantified which will overestimate retention and underestimate excretion. Other reports on N content in carcass agree with the values obtained in the broiler balance trial. Values of 3.9% in 16 days old unsexed broiler chickens (Van Der Hel et al., 1992) and of 3.2% in male broiler chicks weighing 1083 grams (Brady et al., 1978). In another study, Havenstein et al. (1994b) reported a 2.9% N content in the featherless, eviscerated carcass.

**Table 4. Model estimates of nutrients in excreta versus mass balance trial results**

| | Excreted Nutrients, grams per bird | | | |
|---|---|---|---|---|
| | Body weight, g | Dry matter | Nitrogen | Phosphorus |
| Proposed ASAE Model | 2360 | 1269.3 | 53.18 | 15.82 |
| NRC (2003) Model | 2250 | | 96.5 | |
| Mass Balance Trial | 2073 | 893.57 | 39.92 | 11.94 |
| | | | | |
| Estimate to equal body weight | | | | |
| Proposed ASAE Model | 2360 | 1269.3 | 53.18 | 15.82 |
| NRC (2003) Model | 2360 | | 103.58 | |
| Mass Balance Trial | 2360 | 1010.77 | 45.76 | 13.73 |

## CONCLUSION

The differences between actual (mass balance trial) versus ASAE proposed model estimates are 19.4% for DM, 14% for N, and 13% for P with the ASAE proposed model estimates overestimating excretion for DM, N, and P. A prediction model use for a wide variety of field conditions (different feed formulations, different bird strains, different management and different environmental conditions) must be based on estimates that reflect some of the field variation.

The limitations of the ASAE proposed broiler excretion model are that it is primarily set for male broilers', the model currently does not allow for setting different target weights and thus its application under different end points is limited; and the model currently does not allow for changes in feed formulation or feed intake.

Use of the regression equations derived from the broiler trail in conjunction with feed consumption and feed nutrient content information may provide the ability for case-by-case analysis to estimate nutrient excretion. These estimates would have to be given a margin of safety for application to field conditions of approximately 15%. With this margin of safety, the nutrient excretion levels obtained from the broiler trial are very close to those predicted by the proposed ASAE model.

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