Nitrogen Emissions from Broilers Measured by Mass Balance Over Eighteen Consecutive Flocks

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ABSTRACT Emission of nitrogen in the form of ammonia from poultry rearing facilities has been an important topic for the poultry industry because of concerns regarding the effects of ammonia on the environment. Sound scientific data is needed to accurately estimate air emissions from poultry operations. Many factors, such as season of the year, ambient temperature and humidity, bird health, and management practices can influence ammonia volatilization from broiler rearing facilities. Precise results are often difficult to attain from commercial facilities, particularly over long periods of time. Therefore, an experiment was conducted to determine nitrogen loss from broilers in a research facility under conditions simulating commercial production for 18 consecutive flocks. Broilers were reared to 40 to 42 d of age and fed diets obtained from a commercial broiler integrator. New rice hulls were used for litter for the first flock, and the same litter was recycled for all subsequent flocks with caked litter removed between flocks. All birds, feeds, and litter materials entering and leaving the facility were quantified, sampled, and analyzed for total nitrogen content. Nitrogen loss was calculated by the mass balance method in which loss was equal to the difference between the nitrogen inputs and the nitrogen outputs. Nitrogen partitioning as a percentage of inputs averaged 15.29, 6.84, 55.52, 1.27, and 21.08% for litter, caked litter, broiler carcasses, mortalities, and nitrogen loss, respectively, over all eighteen flocks. During the production of 18 flocks of broilers on the same recycled litter, the average nitrogen emission rate was calculated to range from 4.13 to 19.74 g of N/kg of marketed broiler (grams of nitrogen per kilogram) and averaged 11.07 g of N/kg. Nitrogen loss was significantly ($P < 0.05$) greater for flocks reared in summer vs. winter. Results of this experiment have demonstrated that the rate of nitrogen volatilization from broiler grow-out facilities varies significantly on a flock-to-flock basis.

Key words: nitrogen, mass balance, ammonia, emissions, broiler

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INTRODUCTION

Proper manure management to prevent the loss of nutrients from poultry production facilities has long been a challenge for poultry producers. As poultry operations have become larger and more concentrated over the last few decades, the result has been a greater concentration of nutrients in the form of waste products such as manure (i.e., litter) and gaseous emissions. The nutrient of concern with gaseous emissions is nitrogen (N) in the form of ammonia (NH_3). The volatilization of NH_3 into the atmosphere has become an important issue because of concerns regarding negative environmental impacts of excessive NH_3 releases. Ammonia has been implicated as contributing to N saturation of soils and ecosystems, eutrophication of surface waters, acidification of soils, forest decline, loss of ecosystem biodiversity, and contributing to air pollution through the formation of fine particulate matter ($PM_{2.5}$) (Draaijers et al., 1989; Aneja et al., 2001; Krupa, 2003; National Research Council, 2003; Erisman and Schaap, 2004).

Concerns regarding NH_3 emissions from poultry operations have been further exacerbated by federal legislation that requires the reporting of releases of NH_3 into the atmosphere. The Comprehensive Environmental Response, Compensation, and Liability Act and the Emergency Planning and Community Right-to-Know Act both require operations to report releases of 100 lb or more per day to the Environmental Protection Agency. Although the purpose of these laws was to protect the public from continuous hazardous waste emissions and accidental releases of large quantities of hazardous materials, environmental and animal activist groups have used this legislation to bring litigation against poultry producers for NH_3 emissions. Much debate has centered around issues such as how this legislation applies to agricultural operations and how a producer determines when the 100 lb/d threshold has been surpassed. As a result, considerable amounts of research in recent years have been devoted to the measurement of NH_3 emissions from poultry operations. The most common approach has been to mea-

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sure NH_3 concentrations in air exhausted from poultry housing and multiply by the ventilation rate of the facility. Direct measurement of NH_3 in the air is often difficult and requires expensive equipment (Wheeler et al., 2000). Accurate estimation of ventilation rate is also critical. Errors in calculating ventilation rates or NH_3 concentrations could dramatically affect the estimation of NH_3 emission rates (Worley et al., 2002). Wathes et al. (1997) stated that this methodology could result in emission rate estimates with an accuracy of ±20%. Day to day fluctuations in NH_3 release within broiler houses and variations in conditions between houses on the same farm have been found to contribute to the variability of past research (Wheeler et al., 2003). Variations in NH_3 emission rates have also been reported between summer and winter flocks (Redwine et al., 2002). In addition, most of the data published in the past has been collected in Europe and may not accurately reflect NH_3 production from broiler facilities in the United States. Lacey et al. (2003) reported an emission rate of 12.8 g of NH_3/h per AU (1 Animal Unit = 500 kg of live weight) for broilers in Texas. This value was much higher than previously published values, which ranged from 1.9 to 8.5 g NH_3/h per AU (Table 5 in Lacey et al., 2003).

The variability of reported NH_3 emission rates can be attributed to a large set of factors that could impact NH_3 volatilization. Ammonia is formed from the breakdown of nitrogenous waste products in poultry manure (undigested proteins and uric acid) by exogenous enzymes produced by microorganisms. Factors that exhibit direct control over these processes have been identified as pH, temperature, and moisture (Elliott and Collins, 1982; Carr et al., 1990). Ammonia release is depressed at pH <7 but is very high at pH >8 (Reece et al., 1979). Therefore, in a commercial broiler grow-out facility, pH would seldom be a factor in determining NH_3 volatilization since the pH of broiler litter is normally greater than pH 8 unless acidifying agents have been applied to the litter (Reece et al., 1979; Moore et al., 1996, Lacey et al., 2003). This fact leaves temperature and moisture as the 2 most important factors affecting the variability of NH_3 volatilization in a commercial setting. As a result, many other factors such as housing design and management, bird age and health status, drinker management and maintenance, litter age and management, and ambient weather conditions outside poultry housing could all influence temperature and moisture conditions within commercial facilities.

Many methods that could be used to estimate NH_3 emissions from animal operations were reviewed by Phillips et al. (2000). One of the methods discussed was the mass balance technique. This method calculates emission or loss to the environment by the difference between all inputs and measurable outputs to the system under study. Using this technique, NH_3 emissions could be estimated by performing a mass balance for nitrogen. One critical assumption is that all losses of N would be in the form of NH_3. This is most likely not the case because some N will be inevitably lost in other forms (nitrous oxide, dust, etc.) Wathes et al. (1997) estimated N_2O emissions for broiler houses to be 0.59 g of N_2O/h per AU. Thus, a mass balance for N establishes an upper limit for the estimation of NH_3 emissions after adjusting the N loss by a factor of 17/14 to account for the difference in molecular weight between N and NH_3. If sufficient data were available, this upper limit could also be adjusted for other nitrogenous losses to calculate a more accurate NH_3 emission rate. Phillips et al. (2000) also stated that the mass balance technique would have limitations because of the estimation of animal weight accumulation and feed consumption. However, if these obstacles were overcome, then an accurate accounting of all inputs and outputs would allow for a complete nitrogen mass balance. The National Research Council (NRC, 2003) has recommended the use of mass balance accounting of nutrients in animal production systems as a means to accurately estimate total emissions of volatile nutrients such as N. In our review of the literature, it was found that few complete N mass balance studies have been performed in the past. Two such mass balance studies were done by Elwinger and Svensson (1996) and Patterson et al. (1998). Elwinger and Svensson (1996) reported total N losses to average between 18 to 20% of total N input for broilers in experimental pens, and Patterson et al. (1998) estimated N loss to average approximately 18% from commercial broiler housing in Pennsylvania. However, in both cases broiler carcass N was not directly measured, and N retained in the carcasses was calculated based on previously published values for carcass N content.

The research discussed in this paper was conducted with several objectives in mind: 1) measure N content of all solid phase inputs and outputs without using assumed values in calculations, thus allowing for a complete and accurate N mass balance for commercial broilers reared under simulated commercial conditions to determine the fate of N inputs, 2) calculate N emission rates over several consecutive flocks, 3) examine the impact of litter reuse on N loss, 4) measure N excretion rates from commercial broilers, and 5) determine what portion of excreted N in broiler manure is volatilized and lost from the litter.

MATERIALS AND METHODS

Accurate measurement and sampling can often be difficult to accomplish in a commercial setting because of the large scale of the operations, variables that are often beyond the control of the researcher, and the ability to be present at all times. Therefore, the design of the current research was focused on replicating commercial conditions as closely as possible in a research facility that would allow accurate data collection and monitoring of activities at all times. In this manner, the data obtained would not only be as precise as possible but also applicable to the commercial broiler industry. Close cooperation with a commercial broiler integrator was maintained throughout the experiment. All materials [day-old chicks (Cobb-Vantress, Siloam Springs, AR), feed, litter] used in this study were obtained directly from a commercial broiler integrator. Eighteen consecutive flocks were reared on the same recycled litter as is often done in commercial production in the United States (Malone, 1992; Bowers et al., 2002; Chamblee and Todd, 2002).

Housing and Equipment

The building (house) used for this project was similar in construction to many commercial broiler grow-out facilities in the United States. The house had solid side walls and was mechanically ventilated at all times. Evaporative cooling pads were used in hot weather to cool the birds, and natural gas furnaces were used for supplemental heating in the winter. Electric infrared brooder lamps were also used during the first week of chick placement for supplemental heat. Thermostats were used to turn brooder lamps off if the desired maximum temperature of 35°C was reached. The ventilation fans were controlled by a cycle timer to provide minimum ventilation. A thermostat override also controlled the fans to remove excess heat from the building if the maximum set point temperature was reached at any time. The fans would then run until the temperature dropped back to below the maximum set point. The override thermostat was set at approximately 32°C at chick placement and was reduced by approximately 2°C each week. Conditions within the house were checked daily. Thermostat settings were adjusted if needed based on outside temperature and weather conditions to provide an adequate environment for the birds. Each pen was equipped with nipple drinker lines and tube-style pan feeders that were filled manually. Light intensity of 21.5 lumen/m^2 (2.0 ft) candle was provided to chicks for 24 h/d for the first 3 d of brooding. Lighting was then reduced to 23 h/d for the remainder of the grow-out period at an intensity of approximately 3.22 lumen/m^2 (0.3 ft) candle.

Litter Management

The house was concrete-floored, which is different from commercial housing that most often consists of dirt flooring. However, this type of floor was necessary for the accuracy of litter collection and weighing. Dirt flooring could have introduced extraneous material into the litter, confounding data collection and litter analyses. At the initiation of the research, clean rice hulls were added to 4 large pens to a depth of 7.5 to 10 cm (3 to 4 in). This amount was similar to commercial conditions and was adequate to prevent any contact between the concrete floor and the birds. After each flock of birds was removed, caked litter (cake) was removed from the pens using a silage fork and disposed of. Loose litter remained in the pens and was subsequently used for the next flock. This was done to mimic the removal of cake in commercial production by mechanical litter management equipment. No additional litter material or amendments were added to the recycled litter at any time throughout the study. Litter was allowed to build up, as is commonly done in commercial production, for 9 consecutive flocks. After flock 9, equal amounts of litter were removed from the original 4 pens and evenly distributed into 3 pens for flocks 10 to 18.

Broiler Management

In flock 1, 504 straight-run broilers were reared in the 4 pens of approximately 3.2 × 3.0 m (10.5 × 10 ft), yielding a stocking density of 780 cm^2/bird (0.84 ft^2/bird). In flock 2, the number of birds placed was increased to 520, yielding a stocking density of 753 cm^2/bird (0.81 ft2/bird). In flock 3 to 9, bird placement was increased to 562 birds, yielding a stocking density of 697 cm^2/bird (0.75 ft^2/bird), which was the bird density used by the commercial cooperator in this study. After flock 9, a total of 420 birds were used in the 3 remaining pens in this study with the same stocking density as flocks 3 to 9. Stocking densities of 0.73 to 0.98 ft^2/bird were previously reported in similar studies (Patterson et al., 1998; Worley et al., 2002). Mortalities were removed from the pens daily and recorded. Feed and water were provided ad libitum. A multiphase feeding regimen consisting of 4 diets provided by the commercial integrator was fed to the birds for 40 to 42 d. Diets were changed at the bird ages directed by the commercial integrator. All care for the birds was carried out in accordance with animal care and use guidelines and approved Animal Use Protocol 2001-228, Texas A& M University System.

Data and Sample Collection

In this mass balance study, the weight of all inputs and outputs was accounted for as accurately as possible. The difference between the inputs and outputs was then assumed to be lost from the facility to the environment. The weight of all litter added to the pens prior to placement of flock 1 was recorded (to the nearest 0.005 kg). The weight of cake removed from each pen after each flock was also recorded. After cake removal, the remaining loose litter was then shoveled into plastic barrels, weighed, and returned to the original pen. The ending weight of the litter in each pen then became the starting mass for the next flock. Litter mass was calculated on a dry matter basis so that variation in moisture content would not affect N mass calculation. Litter samples were also collected immediately prior to chick placement at the beginning of each flock.

The mass of all birds and feed entering and leaving the facility was also measured. Day-old chicks were weighed in groups of 50 chicks before placement into the pens, and market-age broilers were weighed in groups of 10 as they were removed from the pens at 40 to 42 d of age. Market-age broilers were removed from the pens after a 4- to 6-h feed withdrawal period. In flocks 2 through 18, 12-d-old chicks and 12 market-age broilers from each flock were selected at random, euthanized, and retained for laboratory analysis. All feed for each pen was weighed prior to feeding, and any unconsumed feed was removed and subtracted from the total for that pen. Samples of all feeds (multiple phases) for flocks 2 to 18 were collected

Table 1. Flock data for nitrogen mass balance study, flocks 1 to 18

Begin date (mo/yr)	End date (mo/yr)	Flock	Ending no. of birds	Days of age	Ending BW (kg)	Feed conversion (kg:kg)	Mortality (%)	Carcass N[1] (%)
7/01	8/01	1	481	41	2.17[hijk]	1.59[f]	4.56[bcd]	NC[2]
9/01	10/01	2	511	40	2.18[hij]	1.63[def]	1.73[d]	8.39[cd]
11/01	12/01	3	540	40	2.27[defg]	1.65[de]	3.91[bcd]	8.63[abc]
1/02	2/02	4	525	41	2.33[bcd]	1.75[a]	6.61[b]	8.01[e]
2/02	4/02	5	526	41	2.14[ijk]	1.71[abc]	6.38[b]	8.28[de]
4/02	5/02	6	546	40	2.22[fgh]	1.63[def]	2.84[cd]	8.19[de]
6/02	7/02	7	545	41	2.15[ijk]	1.67[cd]	3.02[cd]	8.15[de]
7/02	9/02	8	547	41	2.11[k]	1.67[cd]	2.68[cd]	7.80[e]
9/02	10/02	9	546	41	2.34[bc]	1.61[ef]	2.83[cd]	8.23[de]
11/02	12/02	10	397	41	2.28[cdef]	1.64[def]	5.47[bc]	7.80[e]
1/03	2/03	11	364	41	2.25[efg]	1.68[bcd]	13.37[a]	8.84[a]
2/03	4/03	12	393	42	2.40[b]	1.74[ab]	6.44[b]	8.42[bcd]
4/03	6/03	13	401	41	2.21[ghi]	1.64[def]	4.52[bcd]	8.36[cd]
6/03	7/03	14	415	41	2.16[hijk]	1.66[cde]	1.20[d]	8.18[de]
8/03	9/03	15	405	41	2.13[jk]	1.67[cde]	3.58[bcd]	8.14[de]
9/03	10/03	16	412	42	2.31[cde]	1.77[a]	1.90[cd]	8.00[e]
11/03	12/03	17	398	40	2.30[cde]	1.68[bcd]	5.24[bc]	8.43[bcd]
1/04	2/04	18	369	42	2.47[a]	1.68[bcd]	12.13[a]	8.71[ab]
Average					2.24	1.67	4.91	8.27
Pooled SEM					0.024	0.020	1.221	0.111

[a–k]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]Average of 12 market-age broiler carcasses (dry-matter basis).

[2]NC = Data not collected.

for laboratory analysis. Carcass and feed samples were not collected for flock 1 because the initial objective for flock 1 only involved litter production rates. However, flock 1 protocol did specify the mass of all birds produced and all feed consumed to be quantified. Therefore, to complete the N mass balance for flock 1, bird carcass and feed composition data from flock 2 were substituted for the missing data in flock 1.

The N content of mortalities was estimated by calculating the average daily carcass N gain for each flock (based on d 1 and market-age carcass analysis) and then multiplying the daily carcass N gain by the number of days before bird death.

Sample Analysis

All samples were dried at 100°C for 24 h in a convection oven to determine moisture content. All subsequent laboratory analyses were then performed on a dry matter basis. Feed samples required no processing prior to drying. All litter samples were acidified with aluminum sulfate (10 litter:1 $Al_2(SO_4)_3$ by wet weight, adopted from Burgess et al., 1998). Reducing the pH of litter samples has been shown to prevent the volatilization of NH_3 during the drying process (Derikx et al., 1994; Burgess et al., 1998). Feed and litter samples were finely ground after drying. Chick and broiler carcasses were homogenized before drying. To facilitate homogenization, chick carcasses were heated in an autoclave at 100°C for 30 min, and broiler carcasses were heated at 120°C for 70 min. All carcass samples were sealed in autoclave bags to prevent the loss or addition of moisture. After cooling at refrigeration temperatures overnight, carcasses were homogenized using a large meat grinder. Carcasses were first passed through a 0.95 cm (⅜ inch) plate, and then through a 0.32 cm (⅛ inch) plate twice. This process sufficiently homogenized the entire carcass. All 12 chick carcasses were pooled for homogenization, but broiler carcasses were homogenized individually. Carcass samples were then dried as previously described and reground after drying using a small household type coffee grinder [Type 4041, Model KSM2(4), Braun GmbH, Kronberg, Germany]. All feed, litter, and bird carcass samples were analyzed for total N content by combustion method using a LECO FP-428 Nitrogen Determinator (LECO Corporation, St. Joseph, MI). The pH of litter samples was determined using a pH meter (Corning Model 430, Corning Corporation, Corning, NY) after mixing 3 g of litter with 60 mL of deionized water.

Statistical Analysis

All statistical analyses were performed by 1-way ANOVA using the GLM procedure of SAS (SAS for Windows, Version 8.01, SAS Institute, Cary, NC) with flock as the source of variation in the model and individual pens as replicates within flock. Means between flocks for each parameter were separated using the PDIFF option of the GLM procedure. Statistical significance between means was determined at $P < 0.05$. All calculations for the N mass balance were performed on a dry matter basis.

RESULTS AND DISCUSSION

Summaries of the data collected during this project are presented in Tables 1 to 3. In each table, the beginning and ending dates (month/year) are provided for each flock to document the time of year when each flock was reared.

Table 2. Nitrogen partitioning in broiler production,[1] flocks 1–18

Begin date (mo/yr)	End date (mo/yr)	Flock	Litter	Cake	All litter	Mortality[2]	Marketed broiler[3]	Loss
			(g of N/kg)					
7/01	8/01	1	11.20[abcd]	0.52[h]	11.72[defg]	0.48[cde]	29.05[e]	9.22[cdef]
9/01	10/01	2	10.73[bcd]	3.80[cde]	14.53[bcd]	0.37[cde]	28.99[f]	7.47[efg]
11/01	12/01	3	8.50[defg]	4.22[bcd]	12.71[cdef]	0.54[cde]	30.29[b]	7.34[efg]
1/02	2/02	4	10.23[cde]	3.60[cde]	13.84[cde]	0.79[cd]	28.99[f]	9.45[cde]
2/02	4/02	5	10.53[bcd]	1.80[fgh]	12.32[cdef]	0.83[cd]	29.77[c]	10.35[cde]
4/02	5/02	6	6.70[efgh]	2.78[ef]	9.48[fghi]	0.34[cde]	28.66[i]	12.45[c]
6/02	7/02	7	2.56[ij]	1.88[fg]	4.44[j]	0.46[cde]	29.18[d]	19.74[a]
7/02	9/02	8	10.23[cde]	1.25[gh]	11.48[defg]	0.42[cde]	29.21[d]	12.00[cd]
9/02	10/02	9	4.88[ghi]	3.50[de]	8.39[ghi]	0.32[de]	29.17[d]	14.66[bc]
11/02	12/02	10	15.02[a]	3.14[def]	18.16[ab]	0.66[cde]	28.55[j]	4.13[g]
1/03	2/03	11	14.62[ab]	3.43[de]	18.05[ab]	1.43[b]	29.00[ef]	7.83[defg]
2/03	4/03	12	13.95[abc]	4.91[bc]	18.86[a]	0.93[bc]	29.16[d]	5.25[fg]
4/03	6/03	13	2.25[ij]	4.48[bcd]	6.73[hij]	0.40[cde]	28.90[g]	15.48[bc]
6/03	7/03	14	–0.32[j]	4.55[bcd]	4.22[j]	0.17[e]	28.86[g]	18.71[ab]
8/03	9/03	15	3.36[hij]	2.44[efg]	5.80[ij]	0.74[cde]	28.47[k]	16.20[abc]
9/03	10/03	16	5.37[fghi]	5.09[b]	10.45[efgh]	0.36[cde]	28.47[k]	14.55[bc]
11/03	12/03	17	9.15[def]	5.37[b]	14.51[bcde]	0.88[bcd]	28.79[h]	8.21[defg]
1/04	2/04	18	4.72[ghi]	11.32[a]	16.03[abc]	2.53[a]	30.57[a]	5.13[fg]
Average			8.04	3.61	11.65	0.68	29.14	11.07
Pooled SEM			1.438	0.485	1.381	0.207	0.018	1.469

[a–k]Means within a column lacking a common superscript differ ($P < 0.05$).

[1]All analyses and calculations performed on dry matter basis.

[2]Flock 1 mortality and carcass N calculated using carcass N composition data from flock 2.

[3]Values calculated as grams of N per kilogram of live marketed broiler.

Starting litter moisture for new rice hulls in flock 1 was 9.44%. Litter and cake samples collected at the end of each flock ranged in moisture from 23.4 to 29.1% and 38.4 to 55.6%, respectively. The N content of new rice hulls at the beginning of flock 1 was 0.47% on a dry matter basis. New rice hulls had a pH of 7.05 at the beginning of flock 1. The pH rose to 8.59 by the end of the first flock, and continued to rise until flock 4 after which litter pH did not change. Litter pH, moisture, and total N values observed in this study were similar to litter characteristics observed in commercial facilities by Lacey et al. (2003) and Singh et al. (2004).

Broiler Performance

The broiler performance parameters of body weight, feed conversion, percent mortality, and broiler carcass N content on dry matter basis are presented in Table 1. Broiler carcass weight and composition are also important variables in completing the N mass balance. It is important to note that ending body weights and carcass N were not correlated in any consistent relationship. Mortality was within acceptable limits for all but 2 flocks (flocks 11 and 18). These 2 peaks in mortality both occurred during a grow-out period in the months of January and

Table 3. Broiler nitrogen excretion and loss of nitrogen from excreta

Begin date (mo/yr)	End date (mo/yr)	Flock	% of feed N excreted	Grams of N excreted	% of N lost from excreta
7/01	8/01	1	42.0[f]	45.3[g]	44.0[defg]
9/01	10/01	2	43.3[def]	48.0[efg]	34.0[ghij]
11/01	12/01	3	39.8[g]	45.5[g]	36.6[fghi]
01/02	2/02	4	44.3[cde]	54.2[b]	40.4[efgh]
2/02	4/02	5	42.9[ef]	48.4[ef]	45.9[defg]
4/02	5/02	6	43.5[def]	48.6[ef]	56.6[bcde]
6/02	7/02	7	45.4[abc]	52.0[bcd]	81.5[a]
7/02	9/02	8	44.7[cd]	49.4[def]	51.3[cdef]
9/02	10/02	9	44.2[cde]	53.8[bc]	63.0[bc]
11/02	12/02	10	43.7[def]	50.9[cde]	18.1[j]
1/03	2/03	11	46.4[ab]	58.2[a]	30.1[ghij]
2/03	4/03	12	44.9[bcd]	57.8[a]	21.7[ij]
4/03	6/03	13	43.5[def]	49.0[ef]	70.0[ab]
6/03	7/03	14	44.5[cde]	49.5[def]	81.8[a]
8/03	9/03	15	43.3[def]	46.9[fg]	73.6[ab]
9/03	10/03	16	46.9[a]	57.9[a]	58.2[bcd]
11/03	12/03	17	43.8[cde]	52.3[bcd]	36.0[fghij]
1/04	2/04	18	39.3[g]	52.3[bcd]	23.8[hij]
Average			43.6	50.9	48.5
Pooled SEM			0.58	1.05	6.18

[a–j]Means within a column lacking a common superscript differ ($P < 0.05$).

February and cannot be fully explained but may be related to breeder flock problems conveyed to the authors by the integrator following the start of each flock.

Variation in ending body weights can be largely attributed to seasonal effects. Winter flocks (flocks 4, 11, and 18) were significantly heavier than summer flocks (flocks 1, 7, 8, 14, and 15). Summers in Texas, as well as in other southern states where broilers are produced, can be very hot and humid and can result in heat stress to the birds even when evaporative cooling systems and high ventilation rates are used. This can result in reduced feed consumption and, consequently, lower ending body weights even though heat stress was not severe enough to cause increased mortality.

Flocks 11 and 18 had significantly higher carcass N than flocks 7, 8, 14, and 15. These differences are largely due to the differences in climatic conditions (summer vs. winter) among these flocks. Flock 4 did follow this same pattern and was not significantly different from the summer flocks. However, the average of winter flocks 4, 11, and 18 (8.52% N) was significantly greater than the average of summer flocks 7, 8, 14, and 15 (8.07% N; $P < 0.0001$).

Nitrogen Mass Balance

One of the main objectives of the current research was to conduct a N mass balance to accurately estimate N loss from a broiler production facility. This is accomplished by accurately measuring all N inputs and outputs of the production system, and the difference is calculated to be the amount of N lost to the environment. Day-old chicks and all feed entering the facility were considered to be all the N inputs. Day-old chicks represented less than 1% of all N inputs, and feed was calculated to be greater than 99% of all N inputs (data not shown). Measurable N outputs were marketed broilers, mortalities, cake, and litter that remained in the pens after cake was removed. Nitrogen partitioned into the various outputs is presented in units of grams of N per kilogram of live marketed broiler in Table 2.

The amount of N partitioned into the marketed broilers varied by relatively small amounts from flock to flock; however, because of the large number of flocks compared, statistically significant differences were observed. The body weight and N content of broiler carcasses were relatively consistent values. Therefore, the amount of N partitioned into the broiler carcasses was relatively constant, ranging between 28.47 and 30.57 g of N/kg. This fact validates the use of flock 2 carcass composition data to estimate carcass N for flock 1. Broiler carcasses contained between 7.8 and 8.7% N on a dry matter basis (Table 1). Partitioning of N into marketed broiler carcasses ranged from 51.5 to 59.5% of total N inputs with an average of 55.5% (Figure 1). These data are higher than the 51% estimated by Patterson et al. (1998). Nitrogen partitioned into mortalities displayed little variation because of the few numbers of bird carcasses involved in each calculation, but significant differences between flocks were observed.

Comparing data from all flocks reveals significant variation in N partitioning into the litter and the amount lost to the environment. Much of this variation can be attributed to climatic differences among the flocks (summer vs. winter season). Since the bird carcass categories of marketed broilers (carcasses) and mortalities were relatively constant, any change in the amount of N retained in the litter and cake (additively referred to as all litter) resulted in an opposite partitioning of N into the loss category. This inverse relationship can be easily observed in Figure 1. Therefore, when N retention in the litter materials was significantly lower in summer flocks compared with winter flocks, the amount of N loss was significantly greater in summer and lower in winter (Table 2). These findings are supported by previous research that has demonstrated NH_3 volatilization increases as temperatures increase from 20 to 35°C (Elliott and Collins, 1982). Redwine et al. (2002) observed similar results when comparing NH_3 emission rates of summer and winter broiler flocks in Texas. Warmer temperatures also stimulate microbial activity in the litter, thereby increasing the potential for the enzymatic degradation of uric acid and proteins to NH_3. Nitrogen loss per flock varied from 4.13 to 19.74 g/kg, or 7.91 to 36.65% of total N (g of N/kg) inputs.

It is also important to point out that litter age significantly affects N retention in the litter and, consequently, influences N loss. From the data in Table 2 and Figure 1, it can be concluded that in summer conditions litter that has been used for several flocks will not retain as much N as new litter. This trend can be observed in the differences in N partitioned into the all litter category for flocks 1, 7, 14, and 15. Flock 8 did not follow this trend and cannot be fully explained. Nonetheless, it does appear that older litter will retain less N than newer litter in warmer weather. This same trend can be observed for flocks reared at the end of the summer and the beginning of autumn. Less N was retained in the litter in flocks 9 and 16 for the same time period as flock 2. However, the opposite trend can be observed for flocks reared in cooler seasons. Flocks 4, 11, and 18 were reared during the same time period in January and February. Flock 11 retained significantly more N in all litters than flock 4. Nitrogen loss was also significantly less for flock 18 than flock 4. Similarly, flock 12 retained more N in the litter than flock 5 and, as a result, lost less N for the same time period of the year. Therefore, it appears that older litter may have more N retention ability than newer litter in cooler weather. This trend is difficult to explain, but may be related to litter C:N ratios and microbial activity. Elwinger and Svensson (1996) previously reported the C:N of wheat straw and wood shavings to be 99 and 526, respectively, at the beginning of a broiler study, but litter C:N was reduced to approximately 10 by the end of the study. In this study, lower C:N combined with cool temperatures could have reduced microbial activity in the litter in latter flocks compared with flocks reared on newer litter with higher C:N. Such a decrease in microbial activity would

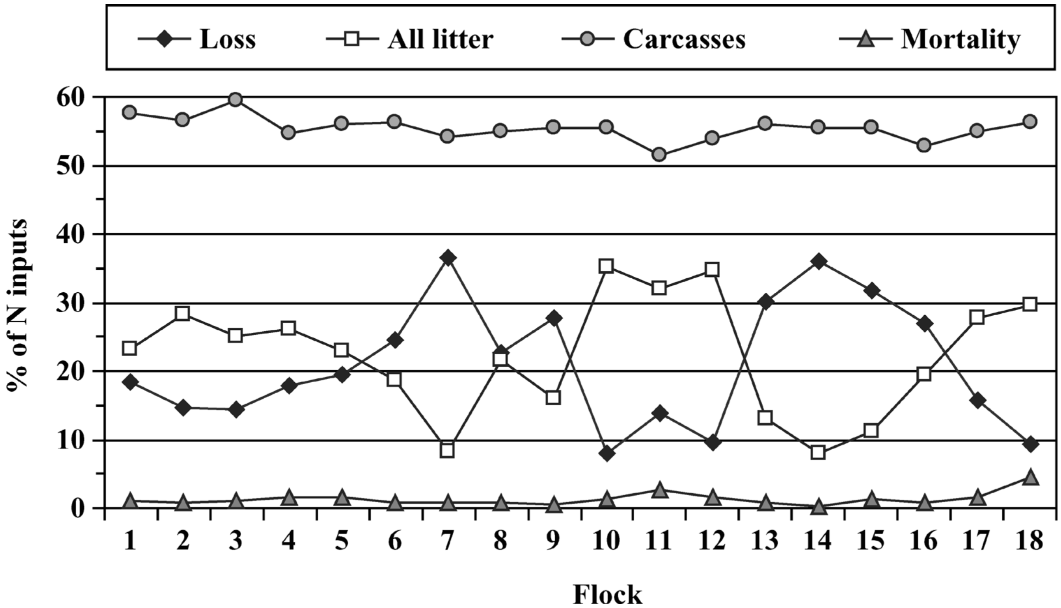

Figure 1. Percentage of N inputs partitioned into the outputs for 18 flocks of broilers.

most likely result in decreased liberation of N in the form of NH_3 from the litter.

Nitrogen Emissions

The terms nitrogen emission rate and ammonia emission rate are very closely related but are not used interchangeably in this discussion. The data presented do not represent a true ammonia emission rate because NH_3 was not directly measured. However, total N loss was accurately measured by the mass balance technique. The difference between total N loss and NH_3 loss is due to other nitrogenous losses such as dust and other nitrogenous gases (nitrous oxide, nitric oxide, etc.). Nitrogen losses as other gaseous forms are generally known to be very small (Wathes et al., 1997). Therefore, total N loss is approximately equal to NH_3 loss. If N losses calculated in this research were assumed to be 100% in the form of NH_3, then the N loss rates calculated would represent the maximum amount of NH_3 emission possible. The average rate of N loss was 11.07 g of N/kg over all 18 flocks. This is equivalent to 21.08% of all N inputs into the facility. These findings are similar to those of Elwinger and Svensson (1996), who reported N loss from broilers in 2 experiments to average 11.9 and 11.8 g of N/kg. Patterson et al. (1998) reported N losses to be approximately 18% from commercial broiler houses. Differences in results between those studies and this study can likely be attributed to differences in litter age and climate.

Nitrogen Excretion

In its final report on air emissions from animal feeding operations, the NRC (2003) proposed a process-based, mass balance approach to estimating total farm emissions of N-containing compounds rather than emissions factors. The first step in this process is the estimation of total manure N excretion. Based on the current research, it was possible to calculate N excretion by subtracting the N content of the bird carcasses (carcasses + mortalities) from the total N content of the feed. In addition, the percentage of excreted N that was volatilized could be calculated by subtracting the total N in all litter materials from the amount of N excreted. The percentage of feed N excreted by the birds, the average grams of excreted N calculated per bird, and the percentage of excreted N volatilized from the manure are presented in Table 3. The percentage of feed N excreted was relatively constant across all flocks, although significant differences were observed due to the sensitivity of the statistical test. Percentage of feed N excreted averaged 43.6% over all 18 flocks, thereby giving an average N retention rate of 56.4%. This value is lower than the average of 60.2% calculated by Applegate et al. (2003). However, when total excretion was calculated on a per bird basis, the average excretion rate of 50.9 g of N/bird was lower than the 51.3 and 53.2 g N/bird presented by Hutchings et al. (2001) and Applegate et al. (2003), respectively. Differences in feed N content, feed consumption rates, bird size at marketing, and carcass N values used in the calculations could explain these differences.

The percentage of N volatilized from the excreted manure varied significantly by season. Approximately 82% of excreted N was volatilized during summer flocks 7 and 14. In contrast, N loss from the excreted manure was only 18.1 and 23.8% in winter flocks 10 and 18, respectively. The average percentage of excreted N lost across all 18 flocks was 48.5%. This value was higher than the 24 and 40% estimated by Misselbrook et al. (2000) and Hutchings et al. (2001), respectively. These differences can likely be attributed to the difference in climate. Those estimates were made in Europe, whereas the current research was conducted in Texas where the climate is much warmer.

It is the intent that the data presented may be useful in estimating NH_3 losses from broiler grow-out facilities. Although these data do not determine what the NH_3 emissions may be on a given day, an accurate measurement of total N volatilization during broiler grow-out on a flock by flock basis was performed. The long duration and large number of birds used in this study have yielded data that encompass many environmental factors that affect N volatilization from broiler housing. This research has demonstrated that season is one of the most important factors contributing to the variability of N loss from broiler facilities. The factors of temperature and moisture (humidity) that greatly influence NH_3 volatilization are a reflection of weather conditions in each season of the year. Therefore, season will greatly influence estimation of NH_3 emissions and whether producers surpass the 100 lb/d threshold for reporting of emissions.

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