QUANTIFICATION OF LITTER PRODUCTION AND THE FATE OF NITROGEN IN COMMERCIAL BROILER PRODUCTION SYSTEMS

A Dissertation

by

CRAIG DANIEL COUFAL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2005

Major Subject: Poultry Science

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Approved by:

Chair of Committee,	John B. Carey
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ABSTRACT

Quantification of Litter Production and the Fate of Nitrogen in

Commercial Broiler Production Systems. (August 2005)

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Chair of Advisory Committee: Dr. John B. Carey

The environmental impacts of broiler production have recently gained considerable public attention due to concerns regarding the amount of ammonia (NH_3) released into the atmosphere from poultry facilities. Sound scientific data are needed to accurately estimate the production of manure waste products and gaseous emissions. This research project was undertaken to quantify nitrogen (N) loss through air emissions from a broiler grow-out facility over 18 consecutive flocks using the mass balance method. Measurement of litter and caked litter (cake) mass at the end of each flock allowed for the calculation of litter and cake production rates for broilers reared on recycled rice hull litter. Nutrient (nitrogen, phosphorus, and potassium) content of all litter materials was also measured. Broilers were reared in a research facility under simulated commercial conditions. All input materials (birds, feed, and litter) used in this study were obtained directly from a commercial broiler integrator to assure applicability to the broiler industry. The litter management technique of "top-dressing" was also investigated to determine its effects on N emissions and litter and cake production rates. Nitrogen emissions, litter and cake production rates, and nutrient density of litter materials were found to vary significantly between flocks reared at different times of the year. Nitrogen emissions were significantly greater for summer flocks than winter flocks. Average N loss over all 18 flocks was 11.07 g N/kg of marketed broiler (g N/kg). 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 18 flocks. Litter and cake production was lower in the summer compared to winter. Average litter, cake, and all litter (litter + cake) production was 153.3, 74.8, and 228.2 g of dry litter material/kg of marketed broiler. Litter and cake phosphorus and potassium content was elevated during summer flocks, while litter material N content decreased in summer flocks. Therefore, season of the year is an important factor that scientists and broiler producers must take into account when performing measurements and calculations, sampling litter materials and air emissions, and developing nutrient management plans.

DEDICATION

To all my family,

for their many years of encouragement, support, and love.

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I would like to express my sincere gratitude to my mentor and committee chairman, Dr. John Carey, for his many years of guidance, assistance, and wisdom. His help has made this difficult process much easier. I also thank the members of my advisory committee for their guidance and wisdom in preparing this manuscript. Special thanks to my friends and colleagues, Dr. Cesar Chavez and Paige Niemeyer, who helped me conduct this research. I also wish to express my thanks and appreciation to the staff of the Texas A&M University Poultry Research Center for their assistance, particularly Mr. Dale Hyatt and Mr. Melvin Carter. This research would not have been possible without the help of all these people.

I also thank all the members of my family for their special help and support throughout my educational years. I wish to recognize especially my mother, grandmother, and Uncle Fred for all their support and encouragement. I would like thank my grandparents for instilling in me the values and beliefs of hard work, dedication, honesty, and love of agriculture. And last of all, but most importantly, I want to thank my wife, Courtney. I cannot put into words the debt I owe her for her love, support, and understanding throughout the years of work and study. I could not have made it without her by my side.

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CHAPTER I

INTRODUCTION

The poultry industry is currently facing new challenges with respect to environmental impacts of manure management and nutrient[1] loss from poultry production facilities. Poultry operations continue to become larger and more concentrated, leading to a greater concentration of nutrients in the form of waste products such as manure (i.e. litter) and waste gas emissions. The term "litter" refers to the combination of manure and bedding material on the floor of a broiler grow-out facility (house), and is the largest waste by-product generated by the broiler industry (Malone, 1992). "Bedding material", usually wood shavings, sawdust, rice hulls, peanut hulls, sand, or some other absorbent material, is spread on the floor of a broiler house to absorb moisture from the manure and then release the moisture back into the air to be exhausted from the building. The nutrients in broiler litter of primary concern are nitrogen (N) and phosphorus (P), and the nutrient of primary concern with gaseous emissions is N in the form of ammonia (NH_3). Environmental impacts of broiler production have recently gained considerable attention with regards to the amount of ammonia released to the atmosphere. Sound scientific data is needed to accurately

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This dissertation follows the format of Poultry Science.

[1] The term "nutrient" in this document refers to the primary plant nutrients of nitrogen, phosphorus, and potassium.

estimate the production and content of these waste products so poultry producers can develop strategies to properly comply with current and future regulations regarding nutrient management planning and air emissions.

The first piece of information broiler producers need to know when preparing nutrient management plans is an estimate of the amount of litter that will be produced (accumulate) on a yearly basis. Published litter production rates for commercial broilers have been summarized in Table 1.1. Little data were found in the peer-reviewed journal literature regarding rates of broiler litter production, especially data concerning the amount of "caked" or "crusted" litter that was produced. Many of the references listed in Table 1.1 were obtained from extension service publications or reports from the states listed. Extension publications are often not peer-reviewed material. It is also important to note that the given litter production rates were not always in the same units and lacked much of the pertinent data necessary for unit conversion for appropriate comparison of data. Litter production rates appear to be most commonly reported as tons of litter on an "as is" or "wet" basis per 1,000 broilers. Other important information such as litter type, litter age, litter and broiler management practices, methods used for calculations and the date when the data was originally produced are often not specified in these extension publications. Data concerning the litter management technique of "top-dressing" were also not found in any literature. Malone (1992) discussed this practice based on calculations related to the density of sawdust, but no experimental or field data were presented. Malone (1992) also stated that the density of the starting litter material could also be a factor affecting litter production rates.

TABLE 1.1. Commercial broiler litter production rates on an "as is" basis

State	No. of Flocks[1]	Production Rate	Reference
Alabama	-	0.5-0.7 lb/lb market broiler	Mitchell and Donald, 1995
Arkansas	-	1-1.5 ton/1,000 broilers	Boles et al., 2004
Delaware	6	1.1 – 1.2 ton/1,000 broilers	Malone et al, 1992
Georgia	-	1.25 ton/1,000 broilers	Vest et al., 1994
Kentucky	6	140-150 tons/yr/house	Rasnake, 1996
Mississippi	5	1.6 ton/1,000 broilers	Chamblee and Todd, 2002
	10	1.0 tons1,000 broilers	
Pennsylvania			
Company A	2-3	1.65 ton/1,000 broilers	Patterson et al., 1998
Company B	1-2	1.07 ton/1,000 broilers	
Texas	-	1.0 ton/1,000 broilers	Feagley et al., 1998
Numerous State average	-	1.25 ton/1,000 broilers	NRAES, 1999

[1] Number of flocks reared on the same litter between complete house clean-outs

The nutrient content of broiler litter is also important information that broiler producers must know when completing nutrient management plans. Published values for nutrient composition of commercial broiler litter are summarized in Table 1.2. Again, it is important to point out that much of the data were from extension service publications and not peer-reviewed scientific journal articles. A great deal of variation, particularly in P concentrations, exists between the sources. It is also apparent that the number of flocks reared on the litter has a substantial influence on nutrient density of broiler litter. In addition, only two sources (Malone et al., 1992; NRAES, 1999) differentiated the nutrient density of “loose” litter versus “caked” litter. They showed substantial differences in P and K concentrations on an “as is” basis between loose and caked litter. In contrast, Malone (1992) stated that caked litter nutrient density (litter used for 6 flocks) averaged 15% greater (dry-weight basis) than loose litter. More research is needed to accurately determine the nutrient content difference between the two types of litter materials. It is also important to note that recently published data (Chamblee and Todd, 2002) showed substantially lower concentrations of P_2O_5 than data from older sources. This fact may indicate an average decrease in broiler litter P content in recent years, possibly due to changes in industry diet formulations or bird utilization of dietary P. Therefore, new research is needed to provide accurate and current data regarding nutrient content of broiler litters.

Issues related to the impact of broiler production on the environment have recently begun to address air emissions from broiler production facilities. Specifically, the release of NH_3 into the environment has come under question in recent years due to

TABLE 1.2. Commercial broiler litter moisture and nutrient composition data on an "as is" basis (lb/ton)

State	No. of Flocks[1]	% Moisture	Total N	P_2O_5	K_2O	Reference
Alabama	-	20	62	55	41	Mitchell and Donald, 1995
Alabama[2]						
Pine shavings	2	-	62	34	68	Bowers et al., 2002
	9	-	62	39	66	
Sand	2	-	17	9	16	
	9	-	49	27	45	
	22	-	71	30	52	
Arkansas	-	-	60	55	45	Boles et al., 2004
Delaware						
All companies	6	27	54	74	80	Malone et al., 1992
Company A	6	27	52	58	58	
Company A	18	32	64	80	74	
Cake	18	40	65	48	39	
Georgia	-	23	66	50	40	Vest et al., 1994
Kentucky	2	20	46	54	54	Rasnake, 1996
	5	20	56	65	63	
Mississippi	2	20	46	22	45	Chamblee and Todd, 2002
	5	20	60	29	59	
	28	19	67	29	65	
Pennsylvania						
Company A	2-3	25	66	63	47	Patterson et al., 1998
Company B	1-2	34	79	62	42	
Texas	-	-	40	68	48	Feagley et al., 1998
Numerous State average	-	24	59	64	41	Malone, 1992
States not specified						
Whole litter	-	21	71	69	47	NRAES, 1999
Cake	-	40	46	53	36	

[1] Number of flocks reared on the same litter between complete house clean-outs
[2] Reported by authors as total K and P, not K_2O and P_2O_5, respectively.

concerns regarding the negative environmental impacts of excessive NH_3 emissions. Atmospheric N compounds emitted from livestock operations have been implicated as causing N enrichment and eutrophication of surface waters contributing to the formation of acid precipitation, and as possible precursors to the formation of particulate material with diameter less than 2.5 microns ($PM_{2.5}$) in the form of ammonium nitrate and ammonium sulfate (Anderson et al., 2003; Baek et al., 2004). Loss of NH_3 from livestock facilities is typically expressed as an emission rate calculated by multiplying ventilation rate of the animal facility by the concentration of NH_3 in the emitted air. Ammonia emission rates reported for broilers on litter expressed as g NH_3/h/AU (1 AU= 500 kg live animal weight) are summarized in Table 1.3. As indicated by the data in the table, there are large differences in emission rates among the published reports. This variability leads to large differences in estimates of annual NH_3 production from broiler facilities. Direct measurement of ammonia production from broiler facilities is difficult, inaccurate, and expensive. Previous research efforts have focused on the creation of "models" to estimate the loss of NH_3 from poultry facilities. Often these types of studies measure NH_3 concentration in a small number of brief air samples, multiply NH_3 concentration by the ventilation rate of the facility, and extrapolate the data over a broad range of conditions. Such methodology can lead to large inaccuracies in the estimation of NH_3 production. The large variance in emission rates reported in the past is indicative of the difficulty and potential error associated with calculating emission rates from concentration and ventilation rate data. The overall accuracy of emission rates arrived at by these methods has been estimated to be no better than ± 20% (Wathes et al., 1997).

Worley et al. (2002) emphasized that small errors in NH_3 concentration measurement would result in large variation of results when concentration was multiplied by ventilation rate. They indicated a 1 ppm error in NH_3 measurement could result in a 9 kg (20lb) per day error in emission rate calculation per broiler house. Redwine et al. (2002), measured NH_3 emissions from tunnel ventilated broiler houses in Texas to range from 59 and 2105 g/hour in the summer and 38 and 1893 g/hour in the winter. Therefore, season of the year also appears to be an important factor in NH_3 production from broiler facilities, thereby adding more variation in NH_3 emissions and making accurate estimation even more difficult. It is also important to note that most of the published data on emission rates were generated in Northern Europe. Because of differences in broiler housing and production practices between European and American systems, these emission rates may not be applicable to US production. Recent studies by Lacey et al. (2003) found summer emission rates in Texas to be substantially greater than previously reported results.

The approach of this research was to utilize a mass balance technique to accurately quantify all solid-phase sources of N entering and leaving a broiler production facility. A mass balance study can provide an accurate measure of the fate of all N in a broiler production system. Any nutrient entering a broiler production facility ultimately has one of three fates. It can be utilized in building the tissues of the birds, be deposited in the litter as manure, or lost to the environment in the air and dust. By accounting for all non-volatile N (bound in bird carcasses and litter materials), the amount of N that escaped via volatilization can be calculated. Few complete N mass balance studies

TABLE 1.3. Published ammonia emission rates for commercial broilers

Location of Data Collection	Emission Rate[1]	Reference
UK	7.4	Sneath et al., 1996
UK	9.0	Wathes et al., 1997
UK	8.3	Groot Koerkamp et al., 1998
Netherlands	4.2	
Denmark	2.2	
Germany	7.5	
UK	6.2	Misselbrook, et al., 2000
Texas, USA	8.2	Lacey et al., 2002
Texas, USA	12.8	Lacey et al., 2003

[1] g NH_3/h/AU (1 AU=500 kg of live animal weight)

involving broilers have been previously reported. Elwinger and Svensson (1996) and Patterson et al. (1998) reported that approximately 19 and 18%, respectively, of the N inputs in the form of feed were lost to the environment. However, both studies did not directly analyze broiler carcasses for N content and used assumed carcass N values to calculate N content of market-age broilers.

The overall objectives of the current research were to 1) accurately measure the amount of litter, cake, and total litter materials produced during broiler production using recycled litter, 2) determine the nutrient content of the litter materials produced, 3) perform an accurate nitrogen mass balance to determine the amount of N lost to the environment during broiler production, 4) determine the effects of season on litter production rates and N loss, and 5) determine what effects the litter management technique of top-dressing would have on litter production, litter nutrient content, and N volatilization.

To accomplish these objectives, measurements in an actual commercial broiler rearing facility would be ideal. However, accurate measurement and sampling can often be difficult to accomplish in a commercial setting due to the large scale of the operations, variables that are often beyond the control of the researcher, and the ability of the researcher to be present at all times. Therefore, this research 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 would also be applicable to the commercial broiler industry.

CHAPTER II

NITROGEN EMISSIONS FROM BROILERS MEASURED BY MASS BALANCE OVER CONSECUTIVE FLOCKS

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 due to 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 (CERCLA) and the Emergency Planning and Community Right-to-Know Act

(EPRCA) both require operations to report releases of 100 pounds (lb) of NH_3 or more per day to the appropriate national and state and local authorities, respectively. Although the purpose of these laws was to protect the public from hazardous waste sites and accidental releases of large quantities of hazardous materials into the environment, 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 per day 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 measure 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 housing 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). Variation 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 had 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 NH_3/h per AU (1 AU=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 degradation of nitrogenous waste products in poultry manure (undigested proteins and uric acid). These processes are catalyzed by exogenous enzymes produced by microorganisms in the manure and litter. The pathway for the aerobic degradation of uric acid to NH_3 is summarized in Figure 2.1. The most important factors that exhibit direct control over this process have been identified as pH, temperature and moisture (Elliott and Collins, 1982; Carr et al., 1990). Ammonia release is depressed at pH less than 7, but is very high at pH greater than 8 (Reece et al., 1979). The pH of broiler litter in a commercial broiler grow-out facility is commonly greater than pH 8 (Reece et al., 1979; Moore et al., 1996, Carey, et al. 2000, Singh et al., 2004). Thus, pH would seldom be a factor in determining NH_3 volatilization under commercial conditions unless acidifying agents have been applied to the litter. This leaves temperature and moisture as the two 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.

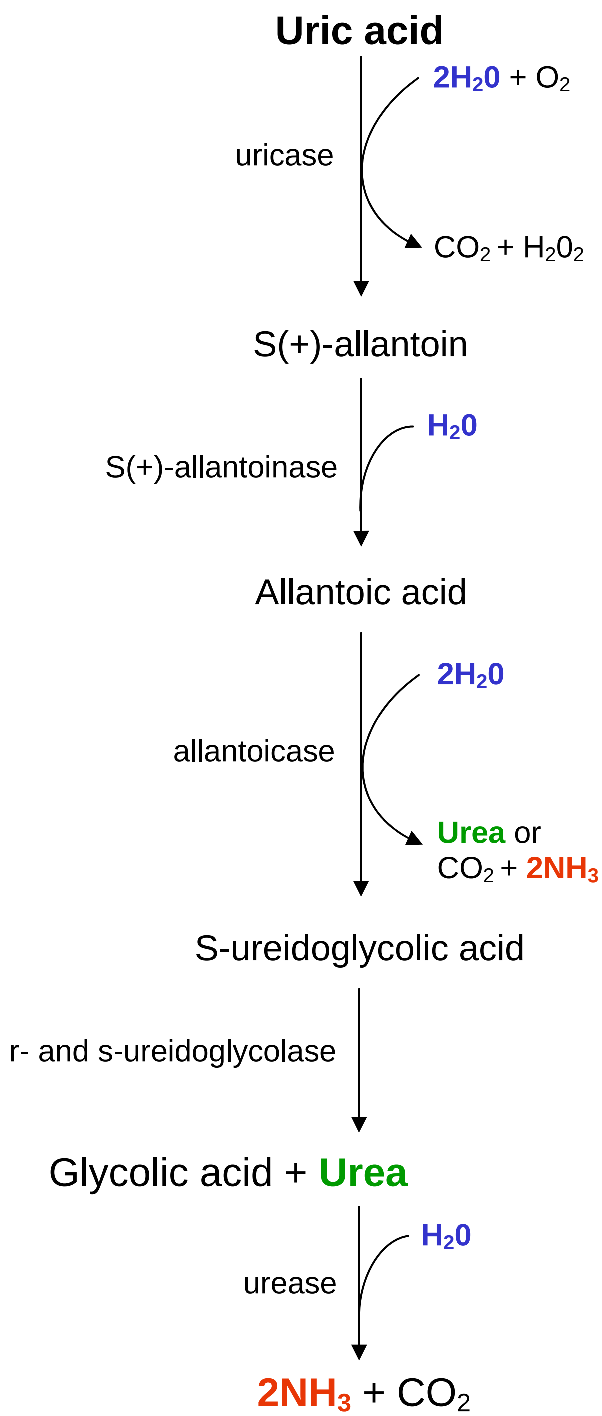

FIGURE 2.1. The aerobic degradation of uric acid to NH_3. (Adapted from Carlile (1984) and Nahm (2003)).

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 since some N will be inevitably lost in other forms (nitrous oxide, dust, etc.) Wathes et al. (1997) estimated nitrous oxide (N_2O) emissions for broiler houses to be 0.59 g 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 due to 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 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 season and litter age 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 of feed consumption and litter and cake materials can often be difficult to accomplish in a commercial setting due to 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 chick[2], 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 35ºC 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 32ºC at chick placement, and was reduced by approximately 2ºC each week. Conditions within the house were checked daily. Thermostat settings were adjusted if needed based on outside temperature and weather conditions to provide

[2] Cobb-Vantress, Siloam Springs, AR

an adequate environment for the birds. Each pen was equipped with a nipple drinker[3] line. The height of the drinker line was adjusted three or four times per week to keep the drinker line just above the top of the heads of the birds. Drinker pressure was also adjusted according to the manufacturer's recommendations. Pens were also equipped with tube style pan feeders that were filled manually. Feeder pan height and feed level in the pans was adjusted as needed to minimize feed spillage. Light 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 utilizes 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 four 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

[3] Ziggity Systems, Inc., Middlebury, IN

amendments were added to the recycled litter at any time. Litter was allowed to "build-up" as is commonly done in commercial production for nine consecutive flocks. After Flock 9, equal amounts of litter were removed from the original four pens and evenly distributed into two additional pens. Three of the six pens (two old and one new) continued to be managed as in Flocks 1 to 9 for the continuation of this experiment while the other three pens were top-dressed (to be discussed in Chapter V).

Broiler Management

In Flock 1, 504 straight-run broilers were reared in the four pens of approximately 3.2 m x 3.0 m (10.5 ft x 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 ft^2/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 three remaining pens in this study with the same stocking density as Flocks 3 to 9. Stocking densities of 0.73-0.98 ft^2/bd 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 multi-phase feeding regime consisting of four 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 (±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 and tracked on a dry matter basis so that variation in moisture content would not impact N mass calculation. Litter samples were also collected just 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 four- to six-h feed withdrawal period. In Flocks 2 through 18, 12 day-old chicks and 12 market-age broilers were selected at random, euthanized, and retained for laboratory analysis from each flock. Bird carcasses were not collected for Flock 1. 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 for laboratory analysis. Feed samples for Flock 1 were also not collected. This project was initiated as a litter study only. This is why carcass and feed samples were not collected in Flock 1. 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 was 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 100ºC 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 100ºC for 30 min, and broiler carcasses were heated at 120ºC 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[4]. All feed, litter and bird carcass samples were analyzed for total N content by combustion method using a LECO FP-428 Nitrogen Determinator[5]. The pH of litter samples was determined using a pH meter[6] after mixing 3.0 g of litter with 60 ml of deionized water.

Statistical Analysis

All statistical analyses were performed by one-way ANOVA using the GLM procedure of SAS[7] with flock as the source of variation in the model and individual pens as replicates within flock. Means between flocks for each parameter measured 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. As previously mentioned, feed, chick and broiler carcass samples were not collected for Flock 1. Corresponding values from Flock 2 were used to estimate the missing data points for Flock 1 to complete the N mass balance for Flock 1.

Results and Discussion

Summaries of the data collected during this project are presented in Tables 2.1 to 2.3. 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.

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[4] Type 4041, Model KSM2(4), Braun GmbH, 61476 Kronberg, Germany
[5] LECO Corporation, St. Joseph, MI
[6] Corning Model 430, Corning Corporation, Corning, NY
[7] SAS for Windows, Version 8.01, SAS Institute, Cary NC

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 at which time litter pH leveled off. 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, and percent mortality are presented in Table 2.1. Broiler carcass N content on a dry matter basis is also given. 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 related in any consistent manner. Mortality was within acceptable limits for all but two flocks (Flocks 11 and 18). These two peaks in mortality both occurred during a grow-out period in the months of January and February and can not be fully explained, but may be related to breeder flock problems conveyed to the author by the integrator following the start of each flock. Average mortality under commercial conditions was 3.1% according to data supplied by the integrator. Average mortality in this study was 4.91%. Not considering the outlier flocks of 11 and 18, average mortality for all other flocks was 3.93%. Feed conversion and ending broiler body weights were also similar to average performance data provided by the integrator.

TABLE 2.1. Flock data for nitrogen mass balance study, Flocks 1 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Ending # of Birds	Days of Age	Ending Body Wt. (kg)	Feed Conv. (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					0.02	0.02	1.22	0.11

[1] Average of 12 market-age broiler carcasses (dry matter basis)
[2] Data not collected
[a, b, …k] Means within a column lacking a common superscript differ ($P<0.05$).

Variation in ending body weights can most likely be 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.

Season of the year also significantly affected carcass N content. Winter Flocks 11 and 18 had significantly higher percent carcass N than summer Flocks 7, 8, 14, and 15. Winter 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) ($P<0.001$).

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, while feeds were 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

TABLE 2.2. Nitrogen partitioning in broiler production[1], Flocks 1 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Litter	Cake	All Litter	Mortality[2]	Marketed Broilers[2]	Loss
			(g N/kg)[3]					
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			1.44	0.49	1.38	0.21	0.02	1.47

[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.
[2] Values calculated as grams of N/kg of live marketed broiler.
[a, b, … k] Means within a column lacking a common superscript differ ($P<0.05$).

removed. Nitrogen partitioned into the various outputs is presented in units of g of N per kg of live marketed broiler (g N/kg) in Table 2.2.

The amount of N partitioned into the marketed broilers varied by relatively small amounts from flock to flock; however, due to 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 N/kg. Broiler carcasses contained between 7.8 and 8.7% N on a dry matter basis (Table 2.1). 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 2.2). These data are slightly higher than the 51% estimated by Patterson et al. (1998). Nitrogen partitioned into mortalities displayed little variation due to the few numbers of bird carcasses involved in each calculation, but once again significant differences between flocks were observed.

Comparing data from all flocks reveals significant seasonal variation in N partitioning into the litter and the amount lost to the environment. 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 2.2. Therefore, when N retention in the litter materials was significantly lower in summer flocks compared to winter flocks, the amount of N loss was significantly greater in summer and lower in winter (Table 2.2). These findings are supported by previous research that has demonstrated NH_3

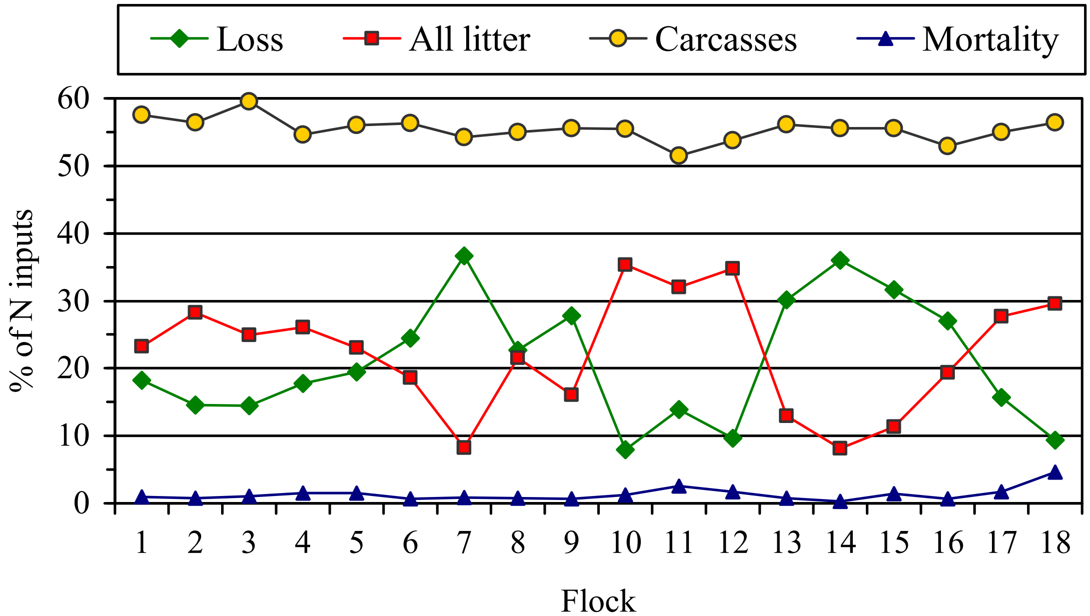

FIGURE 2.2. Percentage of nitrogen inputs partitioned into the outputs for 18 consecutive flocks of broilers.

volatilization increases as temperatures increase from 20ºC to 35ºC (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 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 2.2 and Figure 2.2, 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 can not 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 beginning of the 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 ratio 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 ratios combined with cool temperatures could have reduced microbial activity in the litter in latter flocks compared to flocks reared on newer litter with higher C:N ratios. Such a decrease in microbial activity would 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 "true" ammonia emission rates since 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 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 two experiments to average 11.9 and 11.8 g 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 g of excreted N calculated per bird, and the percentage of excreted N volatilized from the manure are presented in Table 2.3 for all 18 flocks. The percent of feed N excreted was relatively constant across all flocks, although significant differences were observed due to the sensitivity of the statistical test. Percent 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 retention rate 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 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.

TABLE 2.3. Broiler nitrogen excretion and loss of nitrogen from excreta, Flocks 1 to 18

Begin Date (m/y)	End Date (m/y)	Flock	% of feed N excreted[1]	g N/bird[2]	% of N lost from excreta[3]
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]
1/02	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			0.6	1.1	6.2

[a, b, … j] Means within a column lacking a common superscript differ ($P<0.05$).
[1] Manure N excretion = feed N – (carcass N – chick N + mortality N)
[2] Grams of manure N excreted per bird
[3] (N loss/manure N excretion)*100

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. While this data does 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 or not producers surpass the 100 lb/d threshold for reporting of emissions.

CHAPTER III

CORRELATIONS BETWEEN NITROGEN MASS BALANCE DATA FROM BROILERS AND CORRESPONDING METEOROLOGICAL DATA

Introduction

The main factors that influence the volatilization of NH_3 from poultry manure have been identified as pH, temperature, and moisture content (listed in decreasing order of importance) (Elliott and Collins, 1982). The volatilization of NH_3 from poultry manure has been shown to be rapid at pH values above 7.5 (Carr et al., 1990). As discussed in Chapter II, broiler litter in commercial facilities has been show to typically have a pH value greater than 8. Therefore, based solely on the factor of pH, NH_3 volatilization from broiler litter under commercial conditions would be rapid. However, the factors of temperature and moisture content must also be considered. The process of NH_3 release from the breakdown of uric acid in poultry manure is catalyzed by enzymes produced by microorganisms. Microorganism growth and proliferation are sensitive to temperature and moisture content (water activity). The chemical pathway for the breakdown of uric acid to NH_3 also requires the presence of water (Figure 2.1). As a result, the factors of temperature and moisture will greatly influence the formation of NH_3 in broiler litter. Without adequate temperature, moisture, and microbial enzymes present, the formation of NH_3 will be hindered regardless of litter pH.

Ambient climatic conditions outside a broiler house will inevitably influence temperature and moisture conditions within the house. Therefore, as weather conditions change with the seasons of the year, the volatilization of NH_3 from broiler litter will be influenced. Evidence of a relationship between nitrogen (N) loss and season has been discussed in Chapter II, although, no statistical analysis was performed to quantify this relationship. Attempting to include the factor of "season" into a statistical model is difficult and arbitrary at best. Regional differences in weather conditions within seasons can be drastically different and would introduce variability in comparison of results from one region to another. Assigning a seasonal classification to a flock of broilers based on "calendar seasons" is also difficult since the grow-out period of a flock of broilers may transcend the "change of season" on the calendar. In addition, ambient climatic conditions may not change when season changes according to the calendar. Therefore, it is more logical to study the relationship between N loss from a broiler facility and ambient weather conditions that correspond to the grow-out period.

The purpose of this experiment was to compare N loss data obtained from the N mass balance study in Chapter II with meteorological data corresponding to the grow-out period of each flock. In this manner, the influence of ambient temperature and moisture (humidity) on N retention in litter materials and N lost to the environment will be accessed.

Materials and Methods

Nitrogen mass balance data for 18 consecutive flocks of broilers reared on the same recycled litter was presented in Table 2.2. and is summarized in Figure 3.1. Since N partitioned into marketed broiler carcasses and mortalities did not exhibit large variation from flock to flock, those parameters were not considered for this analysis.

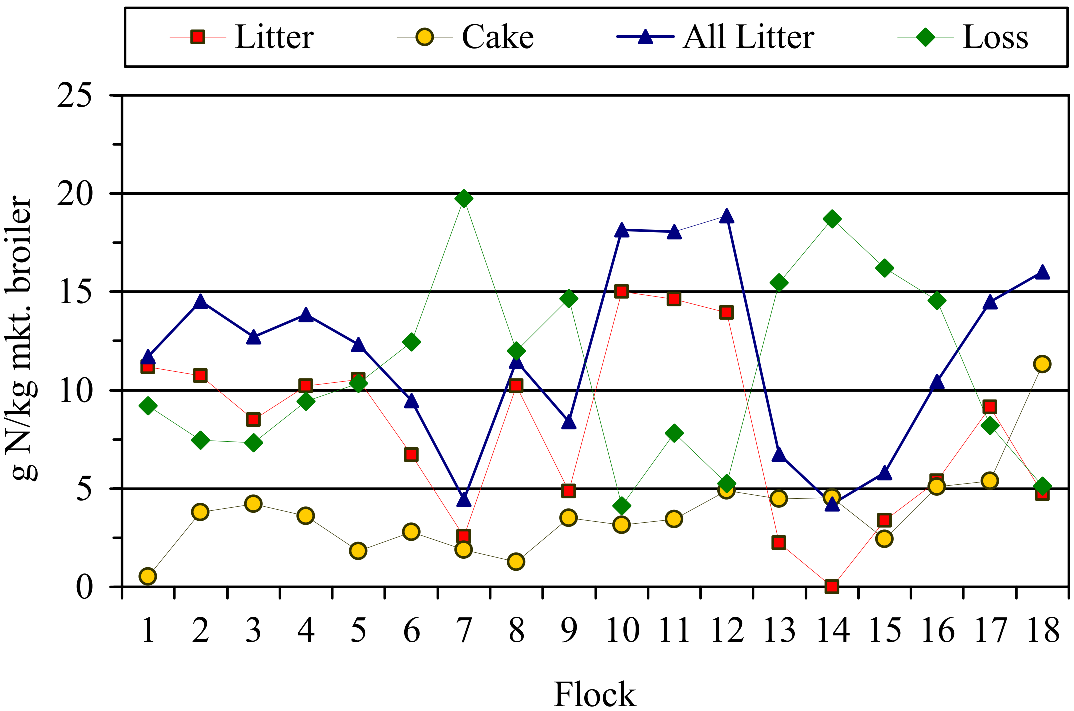

FIGURE 3.1. Nitrogen partitioned into the outputs for N mass balance study expressed as g N/kg of marketed broiler.

Easterwood Airport in College Station, Texas is located approximately 0.8 km from the Texas A&M University Poultry Research Center (TAMUPRC) where the nitrogen mass balance study was performed. Therefore, meteorological data collected at the airport weather station would accurately reflect weather conditions at the TAMUPRC. Meteorological data for each day during the grow-out period of each flock was obtained from the National Climatic Data Center website for College Station, TX (NCDC, 2005). Data for daily maximum dry bulb temperature, daily minimum dry bulb temperature, daily average dry bulb temperature, and daily average dew point temperature were downloaded directly into a Microsoft Excel® spreadsheet. Data for each meteorological variable was averaged over the 40 to 42-d grow-out period for each flock, and is summarized in Figure 3.2. From Figure 3.2, "seasonal" variation for each meteorological variable can be easily observed over the period the 18 flocks were reared. Daily average dry bulb temperature and daily average dew point temperature were used to calculate a daily average relative humidity (RH). Daily RH was then averaged for all days in each flock (Figure 3.3).

Pearson correlation coefficients between meteorological variables, N partitioned into litter, cake, all litter materials, and N lost to the environment were determined using the CORR procedure of SAS[8]. Correlations were determined for all 18 flocks grouped together and for various groupings of flocks to investigate the effect of litter age on correlations. Correlations were considered significant at $P<0.05$.

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[8] SAS for Windows, Version 8.01, SAS Institute, Cary NC

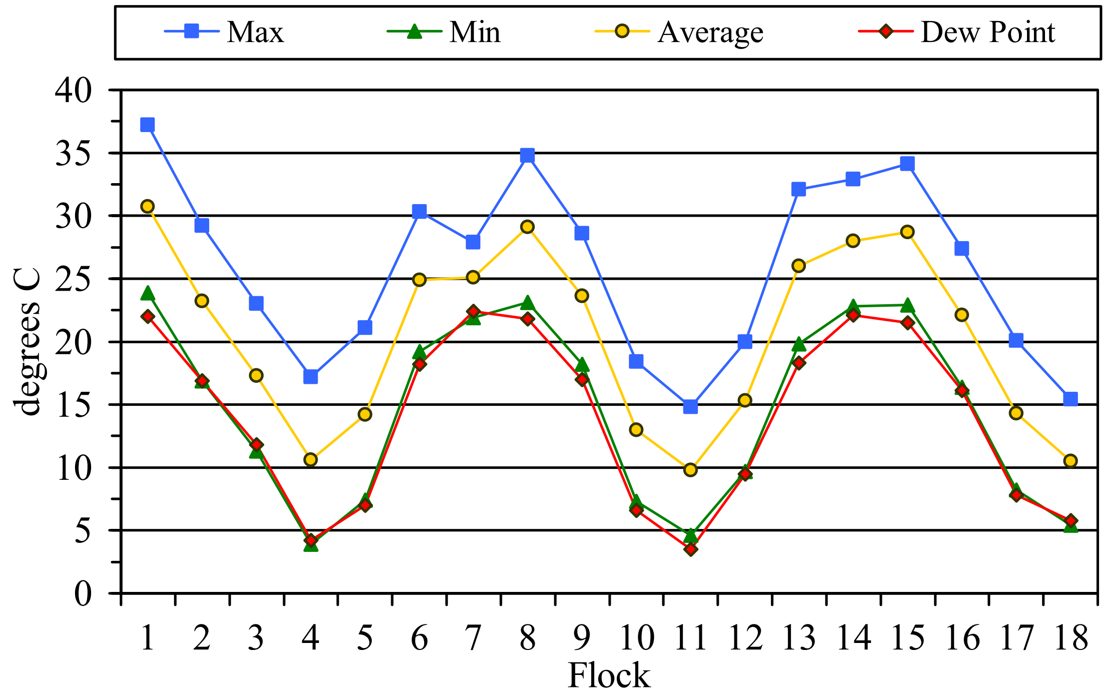

FIGURE 3.2. Meteorological data corresponding to Flocks 1 to 18. Each data point is the average of all days in each flock. Max = average maximum daily dry bulb temperature; Min = average minimum daily dry bulb temperature; Average = average daily dry bulb temperature; Dew point = average daily wet bulb temperature.

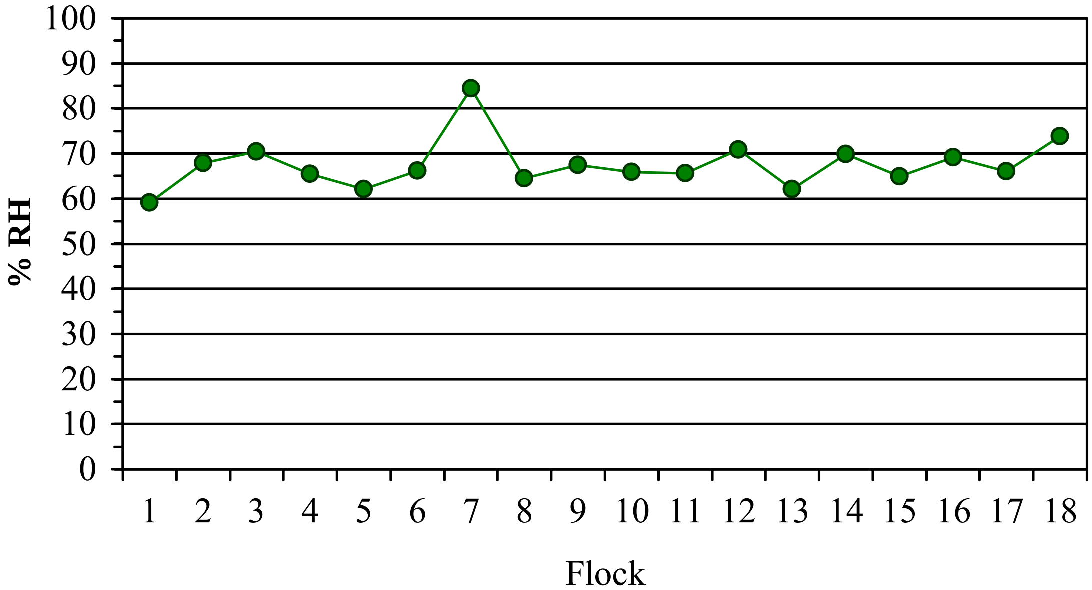

FIGURE 3.3. Average flock relative humidity calculated from average daily dry bulb temperature and average daily dew point temperature for Flocks 1 to 18.

Results and Discussion

Pearson correlation coefficients (r) between meteorological data, N partitioned into litter, cake, all litter materials, and N lost to the environment are presented in Tables 3.1 and 3.2. Table 3.1 gives the r between selected variables for all 18 flocks considered simultaneously. All litter N and N loss were moderately correlated to dry bulb and dew point temperatures with correlations being significant. Relative humidity was not significantly correlated to any N balance variables. This can be attributed to the fact that no consistent seasonal variation was observed for RH, while N balance variables did vary with season. Although no data on RH levels inside the broiler house were collected, it can be assumed that RH levels within the house will usually be elevated. This would be especially true in the hot weather conditions when the evaporative cooling system was used to cool the air entering the house. In cold weather, RH levels would also be expected to be elevated within the house as ventilation rates are reduced to retain heat in the house. Therefore, high RH would promote NH_3 formation year-round and would not be expected to contribute to the observed variations in N loss. The inverse relationship observed to in Chapter II between all litter N and N loss was found to have a strong, significant correlation (r = -0.95) for all 18 flocks. When N retention in all litter materials was low, N lost to the environment was high, and vice versa.

Correlation analysis on various groupings of flocks was performed to determine what influence litter age would have on correlations. It was determined that Flocks 1 to 5 yielded the poorest correlations, and Flocks 6 to 18 yielded the strongest correlations. Results of this analysis are given in Table 3.2. Non-significant correlations were

TABLE 3.1. Pearson correlation coefficients (r) between meteorological data, nitrogen partitioned into litter materials, and nitrogen lost to the environment in Flocks 1 to 18[1]

	All Litter N[2]	N Loss
Max. Temp.[3]	-0.73 (0.001)	0.64 (0.004)
Min. Temp.[4]	-0.78 (<0.001)	0.72 (0.001)
Ave. Temp.[5]	-0.75 (<0.001)	0.69 (0.002)
Dew Point[6]	-0.79 (<0.001)	0.73 (0.001)
Relative Humidity	-0.18 (0.483)	0.23 (0.353)
Litter N	0.87 (<0.001)	-0.81 (<0.001)
Cake N	0.28 (0.252)	-0.32 (0.203)
All Litter N		-0.95 (<0.001)

[1] Numbers in parentheses are P-values for test of significant correlation between corresponding variables
[2] All Litter N = litter N + cake N
[3] Max. Temp. = average maximum daily dry bulb temperature
[4] Min. Temp. = average minimum daily dry bulb temperature
[5] Ave. Temp. = average daily dry bulb temperature
[6] Dew Point = average daily wet bulb temperature

TABLE 3.2. Effect of litter age on Pearson correlation coefficients (r) between meteorological data, nitrogen partitioned into litter materials, and nitrogen lost to the environment[1]

	Flocks 1 to 5		Flocks 6 to 18	
	All Litter N[2]	N Loss	All Litter N	N Loss
Max. Temp.[3]	-0.35 (0.564)	-0.20 (0.750)	-0.84 (<0.001)	0.81 (0.001)
Min. Temp.[4]	-0.31 (0.609)	-0.30 (0.629)	-0.90 (<0.001)	0.88 (<0.001)
Ave. Temp.[5]	-0.33 (0.591)	-0.25 (0.682)	-0.87 (<0.001)	0.85 (<0.001)
Dew Point[6]	-0.27 (0.660)	-0.32 (0.599)	-0.90 (<0.001)	0.88 (<0.001)
Relative Humidity	0.62 (0.263)	-0.79 (0.115)	-0.18 (0.550)	0.23 (0.459)
Litter N	-0.05 (0.932)	0.52 (0.371)	0.89 (<0.001)	-0.81 (0.001)
Cake N	0.76 (0.138)	-0.66 (0.228)	0.34 (0.253)	-0.43 (0.140)
All Litter N		-0.44 (0.458)		-0.97 (<0.001)

[1] Numbers in parentheses are P-values for test of significant correlation between corresponding variables
[2] All Litter N = litter N + cake N
[3] Max. Temp. = average maximum daily dry bulb temperature
[4] Min. Temp. = average minimum daily dry bulb temperature
[5] Ave. Temp. = average daily dry bulb temperature
[6] Dew Point = average daily wet bulb temperature

observed between all temperature variables and N mass balance variables in Flocks 1 to 5. All litter N and N loss were also not significantly correlated in the first five flocks. In Flocks 6 to 18, strong, significant correlations were observed between all temperature variables and all litter N and N loss. All litter N was negatively correlated with temperature while N loss was positively correlated with temperature. Therefore, as temperature increases, the amount of N inputs partitioned into the litter materials decreases. Conversely, as temperature increases, the amount of N inputs lost to the environment also increases. Such results would be expected since it has been previously shown that NH_3 volatilization increases with temperature (Elliott and Collins, 1982; Carr et al., 1990). The correlation between average daily temperature and N loss in Flocks 6 to 18 was r = 0.85. The differences in r between the analysis for Flocks 1 to 5 and 6 to 18 indicate that litter age is an important factor influencing N retention in the litter and, therefore, N loss. These differences in correlations related to litter age are easily observed when average daily temperature is plotted against N loss (Figure 3.4). The correlation between average daily temperature and N loss in Flocks 1 to 5 was not significant. This fact demonstrates that litter age has a greater influence on N loss than temperature with newer litter. Litter age was also found to influence the correlation between cake N and RH. In Flocks 1 to 5, cake N and RH were found to be significantly correlated (r = 0.96, P = 0.008); whereas, in Flocks 6 to 18, cake N and RH were not significantly correlated (r = 0.16, P = 0.609) (data not shown). Therefore, in this study RH had a greater influence on cake N retention than temperature in newer litter compared to older litter. However, RH and N loss were not significantly correlated in any of the analyses. The inverse relationship (negative correlation) between all litter N and N loss was also influenced by litter age. In Flocks 6 to 18, the correlation was significant with r = -0.97, but was not significant in Flocks 1 to 5 (r = -0.44).

The results of this experiment demonstrate that the factors of temperature and litter age can have significant impacts on N loss from broiler facilities. It can be concluded that temperature has more influence on N partitioning than moisture (humidity) since ambient RH levels did not vary by a seasonal pattern in this study and were not found to be correlated with N loss.

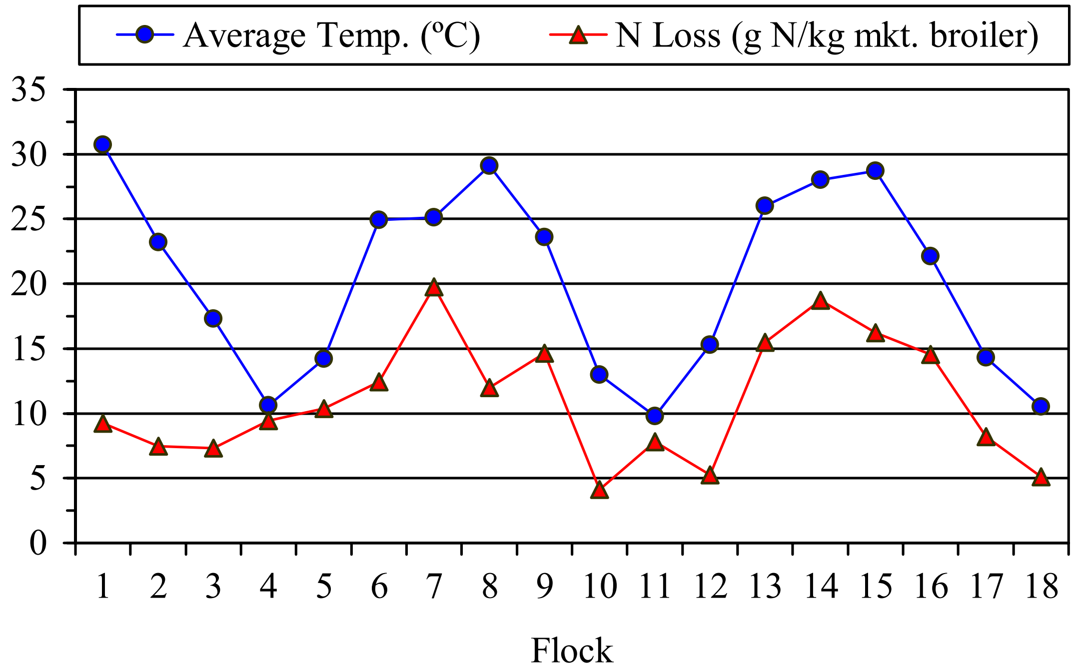

FIGURE 3.4. Average daily dry bulb temperature compared to N loss for Flocks 1 to 18.

CHAPTER IV

MEASUREMENT OF BROILER LITTER PRODUCTION RATES AND NUTRIENT CONTENT USING RECYCLED LITTER

Introduction

Manure management and disposal are two of the most important challenges that poultry producers face. Improper management of manure can lead to odor generation, fly breeding and excess nutrient loading of soil and water resources. For broiler producers, accurate prediction of litter production and nutrient content is important to properly plan for the disposal of litter materials from broiler housing. In commercial broiler production, litter is commonly recycled for several flocks before an entire clean-out is performed. Removal and replacement of all litter varies widely in the industry and can range from after two flocks to several years of production (Malone, 1992; Chamblee and Todd, 2002). Caked litter (cake) commonly found around drinkers or near evaporative cooling systems is typically greater than 35% moisture (Malone et al., 1992). It is commonly mechanically separated from the loose litter and removed from the house after each flock of broilers is marketed. The loose litter remains in the house and is recycled for the next flock of birds. This type of litter management leads to the production of two types of litter waste materials with potentially different characteristics and nutrient content. The removal of caked litter from broiler housing after each flock will also affect the rate of loose litter accumulation in broiler houses.

The rate of litter production and litter nutrient content can be affected by many factors, including the type and amount of bedding material used, number of flocks reared on the litter, feed formulation, litter management techniques, type of housing, ventilation rates and management, drinker management, bird health, performance parameters, and stocking density, and age at time of market (Malone, 1992). As a result, estimates of litter production and nutrient content in the published literature vary. Litter production data published in the peer-reviewed journal literature also provides little data regarding the amount of cake produced during broiler production. Litter production rates are most commonly reported as tons of litter on an “as is” or “wet” basis per 1,000 broilers. Calculating litter production rates on a wet basis can introduce error into litter production estimates due to variability in moisture content. In addition, litter production calculations based on numbers of birds can also contribute to variability in estimation due to variation in bird size. From commercial broiler houses in Pennsylvania, Patterson et al. (1998) reported considerably different rates of litter production from two companies growing birds to different ending body weights. Farms growing smaller birds produced litter at a rate of 1.07 ton per 1,000 broilers while the farms growing larger birds produced litter at a rate of 1.65 ton per 1,000 broilers. With regard to the factor of litter age, Chamblee and Todd (2002) estimated broiler litter production in Mississippi to be 1.6 ton per 1,000 broilers if the houses were cleaned out completely on an annual basis, and a rate of 1 ton per 1,000 broilers if houses were cleaned-out completely at the end of two years. Based on several sources, Malone (1992) estimated average broiler litter production rate to be 1.0 metric ton (dry matter basis) per 1,000 broilers per flock with a range of 0.7 to 2.0 metric tons. The Natural Resource, Agriculture, and Engineering Service (NRAES, 1999) reported whole litter production from broilers to be 1.25 ton per 1,000 birds with cake production at 0.4 ton per 1,000 birds. Thus, in NRAES (1999) cake represented 30 to 35% of the total litter. Depending on frequency of total house clean-out, Malone et al. (1992) reported that cake accounted for 35 to 40% of total litter production from broilers.

A great deal of variation exists between sources in the literature regarding litter nutrient content. On an "as is" or "wet" basis, Malone (1992) reported an average of 2.94, 3.22 and 2.03% for N, P_2O_5 and K_2O, respectively, from several sources in the United States. Patterson et al. (1998) reported broiler litter in Pennsylvania to have an average N, P_2O_5 and K_2O content of 3.73, 3.11, and 2.18%, respectively. Mississippi broiler litter was reported to contain 2.85, 1.45 and 2.95% N, P_2O_5 and K_2O, respectively (Chamblee and Todd, 2002). Bowers et al. (2002) reported pine shaving litter used for nine flocks in Alabama to be 3.11, 1.94 and 3.28% for N, P, and K, respectively. Previous research has also indicated that the number of flocks reared on the litter has a substantial influence on nutrient densities of broiler litter (Malone et al., 1992; Bowers et al., 2002; Chamblee and Todd, 2002). In addition, very little data were found in the literature regarding the nutrient content of cake. Malone et al. (1992) reported that cake was similar in N content but was 40 to 50% lower in P and K concentrations than loose litter on an as is basis. In contrast, Malone (1992) stated that cake nutrient density (litter used for 6 flocks) averaged 15% greater than loose litter on a dry-weight basis. Therefore, the basis (wet or dry) that nutrient densities are calculated in will affect the comparison of data. Research is needed to accurately determine the nutrient content of loose and caked broiler litter materials.

The objectives of the current research were: 1) accurately measure litter and cake production rates from broilers reared under simulated commercial conditions over several consecutive flocks using recycled rice hull litter, and 2) characterize the nutrient (N, P, and K) content, moisture, and pH of the two types of litter materials produced.

Materials and Methods

This experiment was conducted in conjunction with research described in Chapter II, and is part of a research project that was conducted in two phases. In the first phase, nine flocks of broilers (Flocks 1 through 9) were reared in four large pens under simulated commercial conditions without any litter treatments or amendments. Prior to Flock 10, two additional pens were added to the project for phase two (Flocks 10 through 18). Equal amounts of litter were removed from the original four pens and distributed evenly into the two new pens in the same building. No litter was moved between pens again after the second phase was started. Three of the six pens continued to be managed as in Flocks 1 to 9 (no litter added or litter amendments) for the continuation of this experiment. When the depth of the built-up litter became excessive (after Flocks 13 and 16), a portion of the litter from each pen was discarded during the weighing process between flocks. The mass of the discarded litter was recorded. Cake was removed from the pens at the end of each flock with a silage fork. Cake mass was recorded before disposal. Loose litter remaining after cake-out was collected, weighed, and returned to each pen and recycled for the next flock.

All materials (day-old chicks[9], feed and rice hull litter) used in this study were obtained directly from a commercial broiler integrator. Broilers were reared to 40 to 42 d of age, and feed and water were provided *ad libitum*. All broiler management practices (lighting, ventilation, supplemental heating, mortality collection, etc.) and stocking densities were followed as previously described in Chapter II.

Data and sample collection procedures were followed as previously described in Chapter II. The mass of all birds and litter materials entering and leaving the facility was recorded (±0.005 kg). Litter and cake pH were determined by mixing 3.0 g of litter material in 60 ml of deionized water and measuring with a pH meter[10]. Samples of all litter materials were acidified with aluminum sulfate (10 litter:1 $Al_2(SO_4)_3$ by wet weight), dried and analyzed for total N content on a dry matter basis by the procedures described in Coufal et al. (2005a). Nonacidified litter and cake samples were also dried for total phosphorus (P) and potassium (K) analysis. Duplicate samples (0.300 g ± 0.003 g) were digested in 8 ml of concentrated sulfuric acid at 350ºC in a heating block[11] for 45 min with one gram of a catalyst mixture (83.85% lithium sulfate[12], 13.86% cupric sulfate[13], and 2.29% selenium dioxide[4]) added to each sample before digestion. After digestion, samples were diluted to a final volume of 50 ml with deionized water. Total P and K content were determined by inductively coupled plasma (ICP) emission

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[9] Cobb-Vantress, Siloam Springs, AR
[10] Model 430, Corning Corporation, Corning, NY
[11] Model 23540, Labconco Corporation, Kansas City, MO
[12] Mallinckrodt Baker, Inc., Phillipsburg, NJ
[13] Sigma Chemical Co., St. Louis, MO

spectroscopy using a Spectroflame Modula S analyzer[14] at the Texas A&M University Soil, Forage and Water Testing Laboratory.

All statistical analyses were performed by one-way ANOVA using the GLM procedure of SAS[15]. Flock was the source of variation in the model statement. Data from individual pens were the replicates within flock. Means between flocks for the same parameters measured were separated using the PDIFF option of GLM procedure. Statistical significance between means was determined at $P<0.05$. All calculations for litter and cake production rates and nutrient content were performed on a dry matter basis.

Results and Discussion

Moisture and pH

New rice hull litter placed in the pens at the beginning of the experiment had an average moisture content of 9.4% and an average pH of 7.05. Moisture and pH data for litter and cake samples collected at the end of each flock are summarized in Table 4.1. Litter moisture was relatively consistent from flock to flock and ranged from 23.4 to 29.1% with an average of 26.4%. Cake moisture content was more variable than litter moisture with a range from 38.4 to 55.6% and an average of 46.9%. Cake moisture was approximately 1.5 to 2 times that of the litter. These values are similar to previously reported data by Malone et al. (1992). They reported average litter and cake moisture to be 27 and 42%, respectively, for commercial broiler houses using recycled litter and nipple drinkers. Although significant differences between flocks were observed, no

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[14] Spectro Analytical Instruments, Fitchburg, MA
[15] SAS for Windows, Version 8.01, SAS Institute, Cary NC

TABLE 4.1. Percent moisture and average pH for recycled rice hull broiler litter and cake at the end of each flock, Flocks 1 to 18[1]

Begin Date (m/y)	End Date (m/y)	Flock	litter moisture (%)	cake moisture (%)	litter pH[2]	cake pH[2]
7/01	8/01	1	26.1[cdef]	53.5[ab]	8.59[gh]	8.71[cd]
9/01	10/01	2	23.4[h]	53.3[ab]	8.78[def]	8.72[cd]
11/01	12/01	3	26.9[bcde]	55.6[a]	8.74[ef]	8.52[de]
1/02	2/02	4	26.2[cdef]	49.2[cd]	8.88[ab]	8.92[abc]
2/02	4/02	5	25.7[defg]	41.2[fg]	8.90[a]	8.88[bc]
4/02	5/02	6	26.6[bcde]	43.1[ef]	8.90[a]	9.14[a]
6/02	7/02	7	27.4[abcd]	45.1[ef]	8.85[abc]	8.94[abc]
7/02	9/02	8	26.0[defg]	38.4[g]	8.89[a]	9.03[ab]
9/02	10/02	9	27.2[bcd]	50.8[bc]	8.79[def]	8.38[e]
11/02	12/02	10	25.2[efg]	45.6[de]	8.57[h]	8.71[cd]
1/03	2/03	11	24.2[gh]	44.1[ef]	8.65[g]	8.79[bcd]
2/03	4/03	12	24.4[fgh]	44.8[ef]	8.72[f]	8.77[bcd]
4/03	6/03	13	26.9[bcde]	42.8[ef]	8.80[cde]	8.88[abc]
6/03	7/03	14	29.1[a]	46.4[de]	8.79[def]	8.82[bc]
8/03	9/03	15	28.4[ab]	44.8[ef]	8.82[bcd]	8.91[abc]
9/03	10/03	16	27.9[abc]	44.2[ef]	8.86[abc]	8.89[abc]
11/03	12/03	17	26.8[bcde]	46.2[de]	8.89[a]	8.87[bc]
1/04	2/04	18	28.3[ab]	52.7[abc]	8.90[a]	7.17[f]
Average			26.4	46.9	8.80	8.73
Pooled SEM			0.6	1.5	0.02	0.10

[1] Flocks 1 to 9, average of 4 pens; Flocks 10 to 18, average of 3 pens
[2] n=2 per pen
[a, b, … h] Means within a column lacking a common superscript differ ($P<0.05$).

consistent trends or seasonal effects were found for litter or cake moisture. Differences in litter and cake moisture on a flock by flock basis were likely influence by many factors such ambient temperature and humidity, bird health, drinker management and ventilation rate.

The addition of manure to the rice hulls increased litter pH from 7.05 to 8.59 after Flock 1. Litter pH increased significantly from Flock 1 to Flock 2, after which only small changes in pH were noted (Table 4.1). Average litter pH over all 18 flocks was 8.80. Cake pH was similar to litter pH with an average of 8.73. No consistent trends or seasonal effects were observed for cake pH. These values are similar to previously published data. Moore et al. (1996) reported that untreated rice hull litter that had been used for 4 flocks had a pH of 8.75. In contrast, Carey et al. (2000) and Singh et al. (2004) reported broiler litter to have an average pH of 8.4 to 8.5. These differences, although slight, could be due to the type of bedding material used in each study. The pH of new sawdust or wood shaving litter has been reported to be between pH 5 and 6.5 (Nahm, 2003), whereas the pH of new rice hulls used in this study was 7.05.

Nutrient Content

Nutrient content data for litter and cake are presented in Tables 4.2 and 4.3, respectively. All litter materials were analyzed on a dry matter basis. New rice hull litter at the beginning of Flock 1 contained 0.47, 0.03 and 0.27% total N, P and K, respectively. Nutrients accumulated more slowly in litter than cake. Litter N increased significantly for the first 7 flocks, whereas cake N increased much more rapidly with significant differences only through Flock 2. A similar trend was observed for P content. Cake nutrient content was also more variable than litter nutrient content. These findings are similar to those of Malone et al. (1992). They also observed large variations in cake nutrient content with litter age not being an important factor. In this study, cake N was greater than litter N in all flocks on a dry matter basis. However, if nutrient content was calculated on a wet-weight basis, litter and cake N were found to be very similar. Malone et al. (1992) reported similar results. In contrast to N content, litter P and K content were not always higher than cake P and K on a dry matter basis. Litter P was higher than cake P in 6 flocks, and litter K was higher than cake K in 3 flocks.

The variation in litter material nutrient levels observed in both this study and by previous authors is likely due to many of the factors previously discussed. However, one factor that seems to have been previously overlooked was that of season. The volatilization of N in the form of ammonia from poultry litter has been shown to be largely dependent on temperature and moisture (Elliott and Collins, 1982; Carr et al., 1990). Ambient weather conditions in Texas and other states in the southern United States are hot and humid in the summer. The use of evaporative cooling systems (such as the system used in this study) increases the humidity of air entering the facility. Therefore, warm and humid conditions are common in broiler houses in summer. Combined with high ventilation rates, such an environment is conducive to ammonia generation in the litter and subsequent N loss to the environment. These processes most likely account for the decreases in litter and cake N observed in summertime flocks (Flocks 7, 8, 14 and 15) compared to flocks grown during cooler periods of the year. In contrast, P and K are minerals that are not readily volatilized from the litter, although

TABLE 4.2. Nitrogen (N), phosphorus (P) and potassium (K) content of recycled rice hull broiler litter at the end of each flock on a dry matter basis, Flocks 1 to 18[1]

Begin Date (m/y)	End Date (m/y)	Flock	N	P	K
				(%)	
7/01	8/01	1	2.08[l]	0.85[k]	1.97[i]
9/01	10/01	2	2.87[k]	1.19[j]	2.50[h]
11/01	12/01	3	3.18[j]	1.38[i]	2.87[gh]
1/02	2/02	4	3.56[hi]	1.59[h]	3.12[defg]
2/02	4/02	5	3.73[fg]	1.57[h]	3.27[cdefg]
4/02	5/02	6	3.86[de]	1.81[g]	3.44[bcdef]
6/02	7/02	7	3.53[i]	1.92[fg]	3.55[bcde]
7/02	9/02	8	3.64[ghi]	2.35[ab]	3.89[b]
9/02	10/02	9	3.64[ghi]	2.30[abc]	3.81[b]
11/02	12/02	10	3.95[cd]	2.06[def]	2.97[fgh]
1/03	2/03	11	4.08[bc]	2.11[cdef]	3.03[efgh]
2/03	4/03	12	4.33[a]	2.11[cdef]	3.03[efgh]
4/03	6/03	13	3.97[bcd]	2.05[ef]	3.10[defg]
6/03	7/03	14	3.80[ef]	2.22[bcde]	3.63[bcde]
8/03	9/03	15	3.65[ghi]	2.26[abcde]	3.68[bcd]
9/03	10/03	16	3.69[fgh]	2.26[abcd]	3.76[bc]
11/03	12/03	17	4.02[bc]	2.46[a]	4.56[a]
1/04	2/04	18	4.10[b]	2.12[cde]	3.15[cdefg]
Pooled SEM			0.05	0.07	0.20

[1] Flocks 1 to 9, average of 4 pens; Flocks 10 to 18, average of 3 pens
[a, b, … l] Means within a column lacking a common superscript differ ($P<0.05$).

TABLE 4.3. Nitrogen (N), phosphorus (P) and potassium (K) content of caked rice hull broiler litter at the end of each flock on a dry matter basis, Flocks 1 to 18[1]

Begin Date (m/y)	End Date (m/y)	Flock	N	P (%)	K
7/01	8/01	1	3.40^{j}	1.74^{h}	3.64^{efghi}
9/01	10/01	2	4.76^{def}	1.83^{gh}	3.80^{efgh}
11/01	12/01	3	4.48^{fg}	1.94^{fg}	4.02^{defg}
1/02	2/02	4	4.54^{efg}	2.05^{def}	4.13^{cdef}
2/02	4/02	5	4.26^{ghi}	2.06^{def}	4.13^{cdef}
4/02	5/02	6	4.37^{gh}	1.97^{efg}	4.21^{cde}
6/02	7/02	7	4.07^{hi}	2.31^{c}	4.38^{cd}
7/02	9/02	8	4.00^{i}	2.60^{b}	4.60^{bc}
9/02	10/02	9	5.16^{bc}	2.16^{cd}	3.77^{efgh}
11/02	12/02	10	5.04^{cd}	2.19^{cd}	3.77^{efghi}
1/03	2/03	11	5.01^{cd}	2.09^{def}	3.37^{hi}
2/03	4/03	12	5.42^{ab}	2.05^{def}	3.20^{hi}
4/03	6/03	13	4.86^{cde}	2.05^{def}	3.46^{ghi}
6/03	7/03	14	4.53^{efg}	2.17^{de}	3.59^{fghi}
8/03	9/03	15	4.36^{gh}	3.00^{a}	6.89^{a}
9/03	10/03	16	4.96^{cd}	2.58^{b}	5.04^{b}
11/03	12/03	17	5.04^{cd}	2.45^{bc}	5.16^{b}
1/04	2/04	18	5.64^{a}	1.97^{efg}	3.13^{i}
Pooled SEM			0.12	0.06	0.22

[1] Flocks 1 to 9, average of 4 pens; Flocks 10 to 18, average of 3 pens

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

some small amounts may be lost as dust. For this reason, it would seem logical that litter and cake P and K would not vary seasonally to the extent of N. However, just the opposite was observed. From Tables 4.2 and 4.3, significant increases in litter and cake P and K levels can be observed for summer flocks. The increases are most evident in the cake for Flocks 8 and 15 which were reared during the hottest months of July, August and September. This increase in P and K content during summer months can be explained by increased P and K excretion by broilers during heat stress. Belay et al. (1992) demonstrated that heat stress in broilers significantly increased urinary excretion of minerals, including P and K. In the present study, when cooler weather conditions returned and subsequent flocks did not experience heat stress, litter and cake P and K content decreased. Therefore, it is evident that season of the year can greatly influence litter and cake nutrient content. These findings may help to explain some of the differences in litter nutrient content observed by previous researchers. Therefore, the time of year when litter sampling occurs could significantly affect the results of litter analysis. Combined with factors such as geographical region, diet formulation, bedding type and management practices, it is clear that litter and cake sampling and analysis is necessary on a routine basis for each producer to accurately know the nutrient content of the litter materials produced from their operation. Due to the many factors that can alter litter nutrient content, published nutrient values may not be representative of actual litter composition.

The nutrients of primary concern with regard to nutrient management planning are N and P. Litter N and P was approximately 4 and 2%, respectively, for Flocks 10 to

18 on a dry matter basis. This data is in agreement with the findings of Stephenson et al. (1990) and Chamblee and Todd (2002). Therefore, the ratio of N to P in the litter and cake was approximately 2:1.

Production Rates

The amount of litter and cake produced during each flock was carefully determined by weighing all the litter materials in each pen at the end of each flock. The dry matter content of all litter materials in each pen was determined, and the amount of litter accumulation for each flock was calculated by subtracting the litter dry matter mass from the previous flock from the ending litter dry matter mass of the flock in question. The rate of litter, cake and total litter (litter + cake) production for each flock and on a cumulative basis is presented in Table 4.4. All values are expressed as g of dry litter material per kg of live broiler marketed (g/kg). Litter and cake production per flock accounts only for the gain in mass from the beginning to the end of each flock, whereas cumulative calculations account for all litter materials that have accumulated since the start of Flock 1.

Litter, cake and total litter production averaged 153.3, 74.8 and 228.2 g/kg, respectively, for all 18 flocks. Significant flock to flock variation was observed for litter, cake and total litter production. Significantly more litter and cake were produced during cooler seasons (Flocks 4, 11, and 18) compared to summer (Flocks 7, 14, and 15). Flocks 1 and 8 did not follow this same trend and were not different from Flocks 4, 11, and 18. Increased composting within the litter and subsequent loss of mass during warm weather could explain these findings. Cooler temperatures in milder seasons could have

TABLE 4.4. Broiler litter, cake and total litter production per flock and cumulatively calculated as g of litter (dry matter basis) per kg of live marketed broiler (g/kg), Flocks 1 to 18[1]

Begin Date (m/y)	End Date (m/y)	Flock	Flock Litter	Cum. Litter	Flock Cake	Cum. Cake	Flock Total Litter	Cum. Total Litter
					(g/kg)			
7/01	8/01	1	228.7^{ab}	629.3^{a}	15.4^{i}	15.4^{i}	244.1^{bcd}	644.7^{a}
9/01	10/01	2	156.3^{cde}	385.0^{b}	80.0^{bcde}	48.9^{h}	236.3^{bcde}	433.9^{b}
11/01	12/01	3	144.4^{cde}	297.5^{c}	94.4^{b}	65.4^{bcdef}	238.8^{bcde}	362.8^{c}
1/02	2/02	4	191.2^{bcd}	269.3^{d}	78.8^{bcde}	68.9^{bc}	270.0^{bc}	338.2^{d}
2/02	4/02	5	226.3^{ab}	260.8^{d}	42.2^{gh}	63.6^{cdefg}	268.5^{bc}	324.4^{e}
4/02	5/02	6	122.2^{ef}	236.6^{e}	63.9^{defg}	63.7^{cdefg}	186.2^{ef}	300.2^{f}
6/02	7/02	7	106.0^{efg}	217.7^{f}	46.2^{fgh}	61.1^{defg}	152.2^{f}	278.8^{g}
7/02	9/02	8	197.7^{bc}	215.2^{f}	31.1^{hi}	57.4^{g}	228.8^{cde}	272.6^{gh}
9/02	10/02	9	76.6^{fg}	198.5^{gh}	68.6^{cdef}	58.7^{fg}	145.3^{f}	257.3^{ij}
11/02	12/02	10	279.0^{a}	207.0^{fg}	61.2^{defg}	59.0^{efg}	341.6^{a}	266.0^{hi}
1/03	2/03	11	225.8^{ab}	208.6^{fg}	68.0^{cdefg}	59.8^{defg}	293.7^{ab}	268.4^{ghi}
2/03	4/03	12	189.4^{bcd}	206.9^{fg}	90.7^{bcd}	62.6^{cdefg}	280.1^{abc}	269.5^{gh}
4/03	6/03	13	102.0^{efg}	198.8^{gh}	92.2^{bc}	64.8^{bcdef}	194.1^{def}	263.7^{hi}
6/03	7/03	14	62.8^{fg}	188.9^{hi}	99.8^{b}	67.4^{bcd}	162.6^{f}	256.3^{ij}
8/03	9/03	15	107.5^{efg}	183.6^{ij}	55.9^{efgh}	66.7^{bcde}	163.4^{f}	250.2^{j}
9/03	10/03	16	127.2^{def}	179.8^{ij}	102.6^{b}	69.1^{bc}	229.8^{bcde}	248.9^{j}
11/03	12/03	17	147.7^{cde}	177.9^{ij}	105.7^{b}	71.3^{ab}	253.4^{bcd}	249.2^{j}
1/04	2/04	18	45.4^{g}	170.3^{j}	200.7^{a}	78.7^{a}	246.1^{bcd}	249.0^{j}
Average			153.3		74.8		228.2	
Pooled SEM			22.4	4.4	9.7	2.5	21.1	4.1

[1] Flocks 1 to 9, average of 4 pens; Flocks 10 to 18, average of 3 pens
[a, b, … j] Means within a column lacking a common superscript differ ($P<0.05$).

resulted in a slowed rate of decomposition and a greater accumulation of litter mass. The rate of feed consumption and resulting manure production by the birds could also explain these results. When experiencing heat stress, birds will tend to consume less feed. Decreased feed consumption in such conditions would have resulted in less manure production and, therefore, less litter accumulation. Cake production was significantly lower in Flock 1 than all other flocks except Flock 8. This would be expected since the starting litter moisture in Flock 1 was less than 10%. Cake expressed as a percentage of all litter materials produced varied significantly from 6.3 (Flock 1) to 81.6% (Flock 18). Cake as a percentage of all litter produced per flock averaged over all 18 flocks was 32.8% on a dry matter basis and 39.8% on an as is basis. These average values are similar to the findings of the NRAES (1999) and Malone et al. (1992). In addition, litter accumulation is inversely related to the rate of cake production, as would be expected. This relationship is easily observed by comparing litter material production for Flocks 17 and 18. Total litter production for the two flocks was very similar. However, a significant increase in cake production from Flock 17 to 18 resulted in a significant decrease in litter production for the same flocks.

Cumulative production was calculated at the end of each flock by dividing the total litter and cake mass that had been generated since the start of the experiment by the total kg of live broilers that had been produced since the start of Flock 1. Therefore, the starting litter mass put into the facility at the beginning of the experiment is accounted for in the cumulative calculation, and represents the amount of litter material that would have to be disposed of if the facility were completely cleaned-out at that point in time.

Cumulative total litter production decreased significantly for the first seven flocks. Cumulative litter and total litter production rates decreased less with each subsequent flock produced. This is due to the fact that the rate of litter accumulation was less than the rate at which total kg of live broilers were being produced. Cumulative cake production rates increased with each flock since there was no starting cake mass at the beginning of the experiment. Cumulative litter, cake and total litter production were 170.3, 78.7 and 249.0 g/kg, respectively, at the end of 18 consecutive flocks. Calculated on a wet-weight basis, cumulative litter, cake and total litter production rates after 18 flocks were 236.5, 140.0 and 376.5 g of litter material per kg of live broiler weight. Litter material production can then be estimated simply by knowing the mass of broilers produced per flock and multiplying by the appropriate factor. For a 2.24 kg broiler (average broiler market weight in this study), litter, cake, and total litter production estimates would be 0.530, 0.314, and 0.843 kg per bird produced. This would equate to a total litter production rate of 1.86 lb/broiler or 0.93 US tons per 1,000 broilers on as is basis. This figure is much lower than the 2.5 lb per broiler or 1.25 US tons per 1,000 broilers specified by the NRAES (1999). However, these results are similar to litter production rates estimated by Chamblee and Todd (2002). They determined an as is litter production rate of 1 ton per 1,000 broilers after two years (10 flocks). Patterson et al. (1998) reported litter production on an as is basis to be 0.558 and 0.488 lb/lb of live broiler weight for litter that was used for two to three flocks and one to two flocks, respectively. In the present study, similar results were observed with wet-weight total litter production for Flocks 2 and 3 calculated to be 0.606 and 0.550 kg/kg of live broiler weight, respectively. Broiler ending live weight, starting litter depth and density, and litter material moisture content could account for any differences.

The data generated in this study can be used by broiler producers to estimate the amount of litter materials that will be generated over a range of flocks reared on the same litter. Coupled with nutrient analysis of litter materials, broiler producers can then estimate total nutrients available from litter materials.

CHAPTER V

EFFECTS OF TOP-DRESSING RECYCLED BROILER LITTER ON LITTER PRODUCTION, LITTER CHARACTERISTICS, AND NITROGEN MASS BALANCE

Introduction

Concerns regarding ammonia (NH_3) concentrations within poultry housing, ammonia emissions from poultry operations and subsequent negative environmental effects of excessive ammonia emissions have emphasized the need for research to find ways to reduce the volatilization of ammonia from poultry facilities. Typically in modern broiler production, the "caked" or "crusted" litter (cake) commonly found around drinkers or near evaporative cooling systems is mechanically separated from the loose litter and removed from the house between flocks. As more flocks are reared on the same litter, the absorptive capacity of the litter decreases and caking is increased (Malone et al., 1992). "Top-dressing" of recycled broiler litter is a method of litter management often used in commercial production to extend the useful life of litter and delay a complete house clean-out. The addition of the new, dry bedding material (typically 10% moisture content) increases the absorptive capacity of the litter and helps reduce caking of litter. This technique is widely used in broiler production and is commonly believed to reduce the caking of recycled litter. The use of top-dressing of recycled litter has been addressed very little in the scientific literature. This style of litter management has only been mentioned briefly as background information in other studies and reviews (Reece et al., 1979; Kunkle et al., 1981; Malone, 1992; Worley et al., 1999; National Research Council, 2003). In fact, no published data were found in the literature quantifying the effect of top-dressing litter on bird growth and performance, cake and total litter production rates, or retention of manure N in the litter.

The National Research Council (NRC) has stated that "the implementation of technically and economically feasible management practices … designed to decrease emissions should not be delayed" (NRC, 2003). Previous research discussed in Chapter II with 18 flocks of broilers reared consecutively on recycled litter indicated that N emissions from broilers in the summertime were lower with new litter compared to older litter. Therefore, this part of the research project investigates whether top-dressing of older litter would result in lower N emissions such as was observed with newer litter. If top-dressing was found to increase N retention in the litter, then this method could be a relatively simple and inexpensive means for broiler producers to reduce ammonia emissions from broiler facilities. In a recent review paper, Nahm (2003) suggested that the addition of high carbon-containing bedding materials such as rice hulls to animal manure could be beneficial in preventing the loss of N.

The goal of the present research was to determine if the management technique of top-dressing impacted N retention in recycled broiler litter and thereby N emissions from broiler rearing facilities. The effects of top-dressing recycled broiler litter on broiler performance, litter, cake, and total litter production rates, and litter composition were also evaluated.

Materials and Methods

Prior to the initiation of the top-dressing experiment, nine flocks of broilers (Flocks 1 through 9) were reared in four large pens under simulated commercial conditions without any litter treatments or amendments. After the ninth flock, equal amounts of litter were removed from the original four pens and distributed evenly into two additional pens in the same building. Three pens continued to be managed as before with no additional litter added and served as untreated controls. The other three pens were "top-dressed" with a thin layer (1 to 2 cm) of new rice hulls before the placement of each flock of broiler chicks in Flocks 10 to 18. When the depth of the built-up litter became excessive (after Flocks 13 and 16), a portion of the litter from each pen was discarded during the weighing process between flocks. The mass of the discarded litter was recorded. Cake was removed from the pens at the end of each flock with a silage fork. The mass of the cake was recorded before disposal. Loose litter remaining after cake-out was collected, weighed, and returned to each pen and recycled for the next flock.

All materials (day-old chicks[16], feed and rice hull litter) used in this study were obtained directly from a commercial broiler integrator. A total of 840 birds (420/treatment) were reared in 6 pens of approximately 3.2 m x 3.0 m (10.5 ft x 10 ft), yielding a stocking density of 697 cm^2/bird (0.75 ft^2/bird). Broilers were reared to 40 to 42 d of age with feed and water were provided *ad libitum*. All broiler management

[16] Cobb-Vantress, Siloam Springs, AR

practices (lighting, ventilation, supplemental heating, mortality collection, etc.) were followed as previously described in Chapter II.

Data and sample collection procedures were followed as previously described in Chapter II. The mass of all birds, feeds and litter materials entering and leaving the facility was recorded (±0.005 kg). Samples of litter materials, feeds and bird carcasses were analyzed for total N content on a dry matter basis as described in Chapter II. Loose litter samples collected after weighing the litter at the end of each flock were also analyzed for organic carbon (OC) content by combustion at 650ºC using an Elemantar vario Max CN analyzer[17] at the Texas A&M University Soil, Forage and Water Testing Laboratory.

Litter microbial populations were enumerated for Flocks 14 through 18 at 0, 14, 28, and 42 d. Five litter samples for each pen were collected and mixed in clean plastic bags. Samples were collected from similar points evenly distributed in each pen using a new, clean latex glove for each pen. Duplicate 10 g samples of litter from each pen were then mixed with 100 ml of sterile phosphate buffered saline (ph 7.2) in sterile Whirl-pak bags[18]. The mixture was allowed to sit for at least 15 min with occasional agitation. Ten ml of the rinse solution was pipetted from each bag and serially diluted using aseptic techniques. One ml of the serial dilutions was plated in duplicate on Plate Count Agar[19] and incubated for 48 h at 37ºC followed by 24 h at room temperature. Plates were allowed to incubate at room temperature to ensure that microorganisms with an optimal

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[17] Elementar Americas, Inc., Mt. Laurel, NJ
[18] Nasco, Fort Atkinson, WI
[19] Difco Laboratories, Becton, Dickinson, and Co., Sparks, MD

growth rate near room temperature (often the temperature of litter in a broiler house) had opportunity to develop visible colonies. Total colonies were counted after 72 h of incubation.

All statistical analyses were performed by one- way ANOVA using the GLM procedure of SAS[20] with flock, treatment, and flock by treatment interaction as sources of variation in the model. Pens for each treatment were the replicates within flock. Means for each parameter measured were separated using the PDIFF option of the GLM procedure. Statistical significance among means was determined at $P<0.05$. All N mass balance calculations were performed on a dry matter basis.

Results and Discussion

Broiler Performance

Broiler performance data for Flocks 10 to 18 are presented in Table 5.1. A significantly lower broiler body weight was observed for the top-dressed litter treatment group compared to the control group for Flock 14. No significant differences were observed in broiler body weights between control and top-dressed treatments for all other flocks. Broiler body weights averaged across all nine flocks were not significantly different between litter treatments. Feed conversion was not different between treatments with flocks. Mortality was significantly higher in wintertime flocks than summertime flocks. A significant difference between treatment groups was only observed in Flock 11 for mortality, and can most likely be attributed to natural variation.

[20] SAS for Windows, Version 8.01, SAS Institute, Cary NC

TABLE 5.1. Broiler performance data, Flocks 10 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Treatment[1]	Ending Body Wt. (kg)	Feed Conv.	Mortality (%)
11/02	12/02	10	C	2.28[efg]	1.64[a]	5.46[cdefg]
			T	2.30[fg]	1.68[ab]	5.58[bcd]
1/03	2/03	11	C	2.25[def]	1.68[ab]	13.37[a]
			T	2.24[de]	1.66[ab]	6.92[cde]
2/03	4/03	12	C	2.40[h]	1.74[bc]	6.44[cdef]
			T	2.42[hi]	1.74[bc]	9.27[bc]
4/03	6/03	13	C	2.21[cd]	1.64[a]	4.52[efgh]
			T	2.16[bc]	1.67[ab]	4.04[efgh]
6/03	7/03	14	C	2.16[bc]	1.66[ab]	1.20[h]
			T	2.07[a]	1.70[b]	2.15[gh]
8/03	9/03	15	C	2.13[ab]	1.67[ab]	3.57[efgh]
			T	2.09[a]	1.65[ab]	3.57[efgh]
9/03	10/03	16	C	2.31[g]	1.77[c]	1.90[gh]
			T	2.34[g]	1.75[bc]	2.62[fgh]
11/03	12/03	17	C	2.30[fg]	1.68[ab]	5.24[defg]
			T	2.32[g]	1.67[ab]	3.09[efgh]
1/04	2/04	18	C	2.47[i]	1.68[ab]	12.13[ab]
			T	2.43[hi]	1.67[ab]	9.05[bcd]
Average			C	2.28	1.68	5.98
			T	2.26	1.69	5.48
P-value[2]				0.097	0.580	0.440
Pooled SEM				0.02	0.02	1.38

[1] C = control pens, T = top-dressed pens (420 broilers/treatment)
[2] For comparison of treatment effect between nine-flock averages.
[a, b, … i] Means within a column lacking a common superscript differ (P<0.05).

Therefore, it can be concluded that top-dressing of litter had no beneficial effects on broiler performance compared to untreated control litter.

Litter Characteristics and Production Rates

At the start of the experiment (prior to Flock 10), litter moisture values were 26.2 and 26.4% for control and top-dressed pens, respectively. Litter pH was 8.82 for control pens and 8.79 for top-dressed pens (data not shown). Litter N was 3.61 and 3.62%for control and top-dressed pens, respectively (Table 5.2). These data verify that litter characteristics were equal across treatments at the beginning of the experiment. These litter characteristics are similar to other published data for broiler litter (Malone, 1992; Moore et al., 1996; Lacey et al., 2003; Singh et al., 2004).

Starting litter moisture values for Flocks 10 to 18 (not including top-dressing material) were different between treatments in Flock 17 (27.1 vs. 25.4% for control and top-dressed pens, respectively). Ending litter moistures were different in Flock 18 (28.3 and 26.3% for control and top-dressed, respectively). No significant differences in cake moisture existed between the treatments in any flock. For Flocks 10 to 18, average starting litter, ending litter, and cake moisture for control pens was 25.0, 26.8, and 45.7%, respectively. Average starting litter, ending litter and cake moisture for top-dressed pens was 24.3, 26.4, and 48.3%, respectively (data not shown). Thus, top-dressing of litter had no consistent effect on ending moisture. Average cake moisture was significantly higher for top-dressed pens. The moisture content of rice hulls used for top-dressing ranged from 7.9 to 11.5% (data not shown).

TABLE 5.2. Litter nitrogen (N) and organic carbon (OC) content[1], Flocks 10 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[2]	Starting Litter N	Ending Litter N	Cake N	Ending Litter OC	Ending Litter OC:N
				(%)				
11/02	12/02	10	C	3.61[d]	3.95[cd]	5.04[bcd]	34.97[g]	8.86[ef]
			T	3.62[d]	3.66[efg]	4.38[gh]	36.09[abcdef]	9.88[bc]
1/03	2/03	11	C	3.74[cd]	4.08[bc]	5.01[bcde]	36.69[ab]	8.98[ef]
			T	3.38[fg]	3.70[efg]	4.60[efg]	36.67[abc]	9.92[bc]
2/03	4/03	12	C	3.96[b]	4.33[a]	5.42[ab]	37.00[a]	8.56[f]
			T	3.71[d]	3.73[ef]	4.52[fg]	36.56[abcd]	9.80[bc]
4/03	6/03	13	C	4.12[a]	3.97[bc]	4.86[def]	36.42[abcde]	9.17[de]
			T	3.60[de]	3.57[g]	4.24[gh]	36.57[abcd]	10.24[a]
6/03	7/03	14	C	3.87[bc]	3.80[de]	4.53[fg]	36.24[abcdef]	9.54[cd]
			T	3.38[fg]	3.35[h]	4.18[gh]	36.25[abcdef]	10.81[a]
8/03	9/03	15	C	3.69[d]	3.65[fg]	4.36[gh]	35.62[cdefg]	9.76[c]
			T	3.26[g]	3.29[h]	4.06[h]	35.63[bcdefg]	10.82[a]
9/03	10/03	16	C	3.64[d]	3.69[efg]	4.96[cde]	35.49[efg]	9.63[cd]
			T	3.24[g]	3.27[h]	4.39[gh]	35.75[bcdefg]	10.95[a]
11/03	12/03	17	C	3.74[cd]	4.02[bc]	5.04[bcd]	35.36[gf]	8.79[ef]
			T	3.45[f]	3.58[g]	4.46[fgh]	35.61[defg]	9.96[bc]
1/04	2/04	18	C	3.88[bc]	4.10[b]	5.64[a]	35.81[bcdefg]	8.73[ef]
			T	3.45[ef]	3.66[efg]	5.36[abc]	36.01[abcdefg]	9.86[bc]
Average			C	3.81*	3.95*	4.98*	35.96	9.11*
			T	3.46*	3.53*	4.47*	36.18	10.25*
P-value[3]				<0.001	<0.001	<0.001	0.328	<0.001
Pooled SEM				0.05	0.05	0.15	0.37	0.16

[1] All analyses and calculations performed on dry matter basis.
[2] C = control group, T = top-dressed group (420 broilers/treatment)
[3] For comparison of treatment effect between nine-flock averages.
[a, b, … i] Means within a column lacking a common superscript differ (P<0.05).

Litter N and OC content data are presented in Table 5.2. After Flock 10, the top-dressed litter had significantly reduced N content compared to control litter. Cake N was significantly lower for top-dressed pens compared to the controls for five of the nine flocks, with the nine-flock average also significantly lower for top-dressed (4.47%) compared to the control pens (4.98%). This could be a combination of two processes, the first being a simple dilution effect. By adding clean litter that had a low N content, the percentage of N in the litter was simply diluted. Rice hulls used for top-dressing had a N content of 0.38 to 0.54% N on a dry matter basis. However, it does not seem rational that the addition of such a small amount of diluent to a large mass of litter could cause such a dramatic decrease in concentration since more manure was added to the litter during each flock. Lower N content in top-dressed litter could also be the result of increased N volatilization in top-dressed pens. The addition of new rice hulls to the old litter increased the OC:N ratio significantly in the top-dressed pens compared to the control pens in all nine flocks (Table 5.2). Thus, higher OC:N ratios in the litter stimulated microbial activity and increased the volatilization of N in the form of NH_3 due to increased microbial breakdown of proteins and uric acid in the manure. This reasoning is also supported by litter microbial counts performed for Flocks 14 to 18 (Figure 5.1). Average litter microbial counts for all five flocks were significantly higher for top-dressed litter pens compared to control pens at all four sampling times. These data suggest that increasing the OC:N ratio of the litter by top-dressing increased microbial proliferation per unit of litter mass. It is also important to note that the OC:N ratio was calculated on values based on samples of the entire litter mass at the end of the

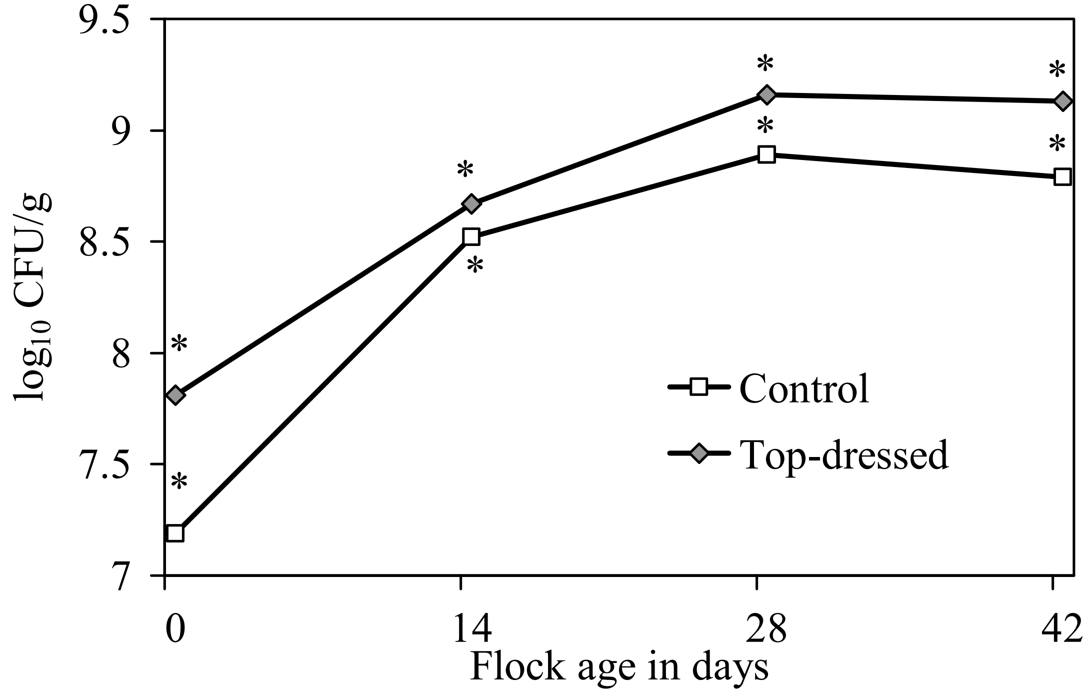

FIGURE 5.1. Average litter microbial counts (log_{10}CFU/g) on day 0, 14, 28, and 42 for control and top-dressed pens on Plate Count Agar for Flocks 14 to 18. * Indicates treatment means within day differ ($P<0.05$). For each mean value, n=30. Pooled SEM=0.031.

flock. It is probable that the OC:N ratio near the surface of the litter mass where the top-dressed litter material was applied was much higher than that at lower depths, and the area near the surface is where a majority of the aerobic microbial activity was most likely occurring. Thus, as fresh manure was added to the top of the litter, volatilization of N was occurring more rapidly in the top-dressed pen compared to the controls due to the increased OC:N ratio and microbial activity in the surface region of the litter mass.

Mean ending litter pH values were significantly higher for top-dressed pens compared to control pens in seven of the nine flocks (Figure 5.2). Cake pH was not different treatments for Flocks 10 to 17, but was significantly lower for control pens in Flock 18. However, pH values for starting litter, ending litter and cake averaged across all flocks were all significantly higher for the top-dressed pens compared to the controls (data not shown). While these values were different statistically, all pH values were greater than pH 8 with the exception of Flock 18 cake. Ammonia volatilization has been reported to be rapid at pH 8 and above (Reece et al., 1979; Carr et al., 1990; Derikx et al., 1994). Therefore, differences in N loss between the control and top-dressed litter was not likely due to differences in pH. Nevertheless, increased litter pH in top-dressed litter compared to control litter could also be an indicator of increased microbial enzymatic degradation of litter substrates. Kim and Patterson (2003) demonstrated that the inoculation of uric acid medium with uric acid-utilizing microorganisms from poultry manure increased the pH of the medium over eight days of incubation.

Litter, cake, and total litter material (litter + cake) production per flock was calculated as g of dry litter material per kg of marketed broiler (g/kg) and are presented

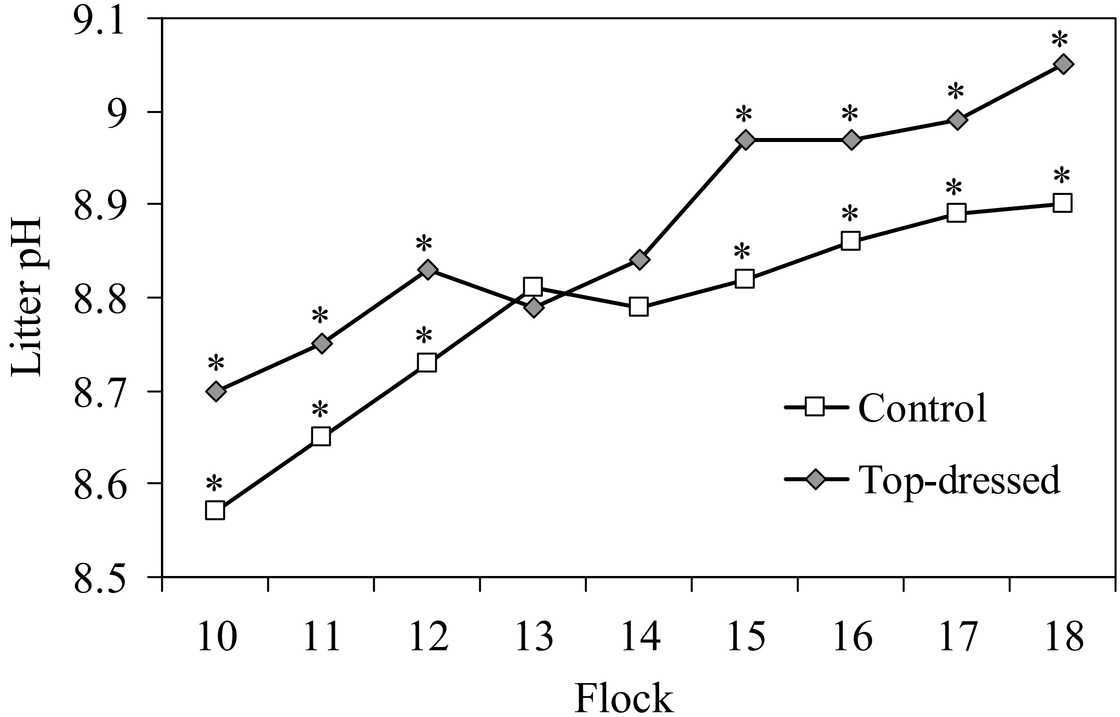

FIGURE 5.2. Average ending litter pH values for control and top-dressed pens for Flocks 10 to 18. * Indicates treatment means within flock differ (P<0.05). For each mean value, n=6. Pooled SEM=0.024.

in Table 5.3. Cake production averaged across all flocks was significantly greater for the control pens compared to the top-dressed pens. Top-dressing resulted in significant reductions in cake production in six of the nine flocks. These results were expected since use of this method by commercial producers is known to reduce litter caking problems in older, recycled litter. As a result of less caking in the top-dressed pens, more of the manure produced by the birds was retained in the pens as loose litter, and average litter production was significantly greater for top-dressed pens (176.4 g/kg) compared to the control pens (143.0 g/kg). However, total litter production was not different between treatments. Logically, the addition of extra litter material to the top-dressed pens in each flock would be presumed to increase the rate of litter production. However, this was not observed. This suggests that composting occurring within the litter mass was accelerated in the top-dressed pens. The greater rate of composting in the litter mass volatilized dry matter at a rate equal to what was added by the top-dressing. The increased OC:N ratios and increased microbial populations observed support such reasoning.

Nitrogen Mass Balance

Nitrogen balance data comparing top-dressed to control litter are presented in Table 5.4. Values are calculated as g N/kg of marketed broiler (g N/kg). Significant differences were observed for N retention in the litter for the first four flocks and Flock 18. However, these differences did not follow a consistent pattern. In Flocks 10 and 12, top-dressing of litter significantly reduced litter N retention compared to control pens; while in Flock 11, 13 and 18 top-dressing significantly increased N retention in the litter

TABLE 5.3. Broiler litter production rates[1], Flocks 10 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[2]	Litter	Cake	All Litter
				(g/kg)[3]		
11/02	12/02	10	C	279.0^{ab}	61.2^{efg}	341.6^{ab}
			T	217.7^{c}	35.6^{g}	251.7^{cd}
1/03	2/03	11	C	225.8^{bc}	68.0^{def}	293.7^{bc}
			T	309.6^{a}	51.8^{fg}	361.5^{a}
2/03	4/03	12	C	189.4^{cd}	90.1^{cde}	280.1^{cd}
			T	184.9^{cde}	51.7^{fg}	236.7^{de}
4/03	6/03	13	C	102.0^{ghi}	92.2^{cd}	194.1^{efg}
			T	175.6^{cdef}	58.9^{fg}	234.5^{de}
6/03	7/03	14	C	62.8^{hi}	99.8^{bc}	162.6^{g}
			T	120.3^{fgh}	53.6^{fg}	173.9^{fg}
8/03	9/03	15	C	107.5^{gh}	55.9^{fg}	163.4^{g}
			T	106.9^{gh}	47.1^{fg}	154.0^{g}
9/03	10/03	16	C	127.2^{efg}	102.6^{bc}	229.8^{de}
			T	173.3^{cdef}	53.9^{fg}	227.2^{def}
11/03	12/03	17	C	147.7^{defg}	105.7^{bc}	253.4^{cd}
			T	181.5^{cde}	62.9^{defg}	244.5^{cde}
1/04	2/04	18	C	45.4^{i}	200.7^{a}	246.1^{cde}
			T	118.2^{fgh}	128.2^{b}	246.4^{cde}
Average			C	143.0	97.4	240.5
			T	176.4	60.4	236.7
P-value[4]				0.001	<0.001	0.673
Pooled SEM				0.02	0.01	0.02

[1] All analyses and calculations performed on dry matter basis.
[2] C = control pens, T = top-dressed pens (420 broilers/treatment)
[3] Litter production calculated as grams of litter/kg of live marketed broiler.
[a, b, … i] Means within a column lacking a common superscript differ ($P<0.05$).
[4] For comparison of treatment effect between nine-flock averages.

compared to control pens. Significant reductions in cake production and cake N content in top-dressed pens resulted in significantly reduced N partitioned into cake of top-dressed pens compared to control pens for seven of the nine flocks. Over all nine flocks, N retained in total litter was significantly higher for the control pens (12.54 g N/kg) compared to the top-dressed pens (11.39 g N/kg). Since N partitioned into the marketed broiler and mortality carcasses was relatively constant, N volatilized to the environment is inversely related to the amount of N retained in the litter materials (previously discussed in Chapter II). Average N loss for all nine flocks was 10.61 and 11.92 g N/kg for control and top-dressed pens, respectively. As a percentage of N inputs, N loss was 20.14 and 22.51% for control and top-dressed pens, respectively. Therefore, top-dressing recycled litter did not reduce N loss on average over all nine flocks. It is important to note that when the control pens had less N loss in Flocks 10 and 12 than the top-dressed pens, the difference between the treatment groups was double the difference in Flock 11 when the top-dressed pens were lower in N losses. This suggests that large amounts of N in Flocks 10 and 12 were lost in the form of ammonia from the top-dressed pens due to a dramatic shift in some factor(s) regulating ammonia volatilization (pH, temperature, moisture, C:N, microbial activity, etc.). Based on this experiment, the practice of top-dressing recycled broiler litter would not be recommended as a strategy to reduce the volatilization of N from broiler rearing facilities.

TABLE 5.4. Nitrogen partitioning in broiler production[1], Flocks 10 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[2]	Litter	Cake	All Litter	Mortality	Marketed Broilers	Loss
				(g N/kg)[3]					
11/02	12/02	10	C	15.02^{b}	3.14^{ef}	18.16^{b}	0.66^{efgh}	28.55^{g}	4.13^{fg}
			T	7.78^{cdef}	1.56^{g}	9.34^{ef}	1.28^{bcde}	28.55^{g}	13.54^{bc}
1/03	2/03	11	C	14.62^{b}	3.43^{def}	18.05^{b}	1.43^{bc}	29.00^{c}	7.83^{def}
			T	19.92^{a}	2.37^{fg}	22.29^{a}	1.09^{bcdef}	29.00^{c}	3.35^{g}
2/03	4/03	12	C	13.95^{b}	4.91^{cd}	18.86^{b}	0.93^{bcdefg}	29.16^{b}	5.25^{efg}
			T	6.59^{cdefg}	2.40^{fg}	8.99^{f}	1.34^{bcd}	29.17^{b}	14.56^{b}
4/03	6/03	13	C	2.25^{hi}	4.48^{cd}	6.73^{g}	0.40^{gh}	28.90^{d}	15.48^{ab}
			T	8.39^{cde}	2.49^{fg}	10.88^{ef}	0.48^{fgh}	28.90^{d}	12.26^{bc}
6/03	7/03	14	C	-0.32^{i}	4.55^{cde}	4.23^{g}	0.17^{h}	28.86^{e}	18.71^{a}
			T	3.20^{ghi}	2.24^{fg}	5.44^{g}	0.31^{gh}	28.86^{e}	18.70^{a}
8/03	9/03	15	C	3.36^{gh}	2.44^{fg}	5.80^{g}	0.74^{defgh}	28.47^{h}	16.20^{ab}
			T	5.62^{defgh}	1.91^{fg}	7.53^{fg}	0.63^{fgh}	28.47^{hi}	14.06^{bc}
9/03	10/03	16	C	5.37^{efgh}	5.09^{c}	10.45^{ef}	0.36^{gh}	28.47^{i}	14.55^{b}
			T	7.50^{cdef}	2.37^{fg}	9.86^{ef}	0.48^{fgh}	28.46^{i}	14.40^{b}
11/03	12/03	17	C	9.15^{cd}	5.37^{bc}	14.51^{cd}	0.88^{cdefg}	28.79^{f}	8.21^{de}
			T	9.70^{c}	2.80^{fg}	12.49^{de}	0.55^{fgh}	28.80^{f}	10.31^{cd}
1/04	2/04	18	C	4.72^{fgh}	11.32^{a}	16.03^{bc}	2.53^{a}	30.57^{a}	5.13^{efg}
			T	8.90^{cde}	6.82^{b}	15.72^{bcd}	1.55^{b}	30.57^{a}	6.06^{efg}
Average			C	7.57	4.97	12.54	0.90	28.97	10.61
			T	8.62	2.77	11.39	0.88	28.98	11.92
P-value[4]				0.082	<0.001	0.049	0.681	0.511	0.052
Pooled SEM				1.25	0.54	1.19	0.22	0.01	1.38

[1] All analyses and calculations performed on dry matter basis.
[2] C = control group, T = top-dressed group (420 broilers/treatment)
[3] Values calculated as grams of N/kg of live marketed broiler.
[a, b, … i] Means within a column lacking a common superscript differ ($P<0.05$).
[4] For comparison of treatment effect between nine-flock averages.

CHAPTER VI

SUMMARY AND CONCLUSIONS

As discussed throughout this text, the main objectives of this research were to quantify broiler litter and cake production, characterize the litter materials produced, determine the fate of N inputs by mass balance, and evaluate the effects of top-dressing recycled litter on litter production and N volatilization. These objectives were accomplished in two phases. In the first phase, litter was allowed to "build-up" for nine consecutive flocks as is often done in commercial production. Litter and cake production were measured and the N mass balance performed. In the second phase, the litter mass generated in the first phase was evenly distributed into additional pens so that the method of top-dressing could be evaluated against the untreated litter for the same measurements. Nine additional flocks were reared in the second phase. Thus, litter production and N mass balance measurements were performed for 18 consecutive flocks on untreated, recycled broiler litter under simulated commercial conditions. Top-dressing of recycled litter was evaluated for the last nine flocks.

Nitrogen emission rates (g/kg) resulting from the current research were presented in Table 2.2. Total N loss was not converted to units of NH_3 to prevent any distortion to the data since NH_3 was not directly measured. 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, N_2). If N losses calculated in this research were assumed to be 100% in the form of NH_3, then the N emission rates calculated would represent the maximum amount of NH_3 emission possible. It is important to remember that the N emission rates must be adjusted by a factor of 17/14 when converting to NH_3 emission rates to account for the difference in molecular weight.

Accurate measurement and development of NH_3 emission rates has become an important issue in poultry research in the last several years. Much debate has focused on how to measure NH_3 production and in what units to report the results. From the data in this study, N losses could be calculated in many units. Some examples are: percentage of N inputs, g of N per kg of live marketed broiler (g N/kg), g of N per bird (g N/bird), g of N per day per bird (g N/d per bird), and as g of N per h per AU (g N/h per AU). The latter three units have commonly been reported by other researchers in the literature. Groot Koerkamp et al. (1998) suggested the most basic unit for emission rates should be "per animal". However, such a unit is not very precise and could vary greatly from one system of production to another. Different body weights of a "bird" between studies could seriously hinder accurate comparison of results. Additionally, the conversion of some units to others may require some assumptions or estimates, and this can also be detrimental to the accuracy of the data. We conclude that the unit of g N/kg would be easier to compare across studies that may utilize different broiler body weights and management systems. This is currently difficult to do with units that contain various time intervals and discrete variables such as "bird" or "animal unit". The NRC (2003) also suggested that animal units should be defined "in terms of animal live weight rather than an arbitrary definition of animal unit". This criteria is met with the commonly used emission rate unit of g N/h per AU. Therefore, the measurement taken at a precise time interval corresponds to the weight of the animals in the facility at that time. Estimation of total animal mass at any one given time can be difficult. Data from a mass balance method, such as the current study, measures all N losses over a period of time. Therefore, the calculation of g N/h per AU in this study would represent the "average" N loss per h over the entire grow-out period per AU of marketed broiler, and not the N emission for any given point in time. Values for this unit ranged from 2.10 to 10.3 g N/h per AU. Converted to units of NH_3 by correcting for molecular weight differences (assuming 100% of N loss was in the form of NH_3), the values would be 2.55 to 12.18 g NH_3/h per AU, with an average of 6.85g NH_3 per AU. The highest value of 12.18, corresponding to a summer flock, is similar to the value arrived at by Lacey et al. (2003) of 12.8 g NH_3/h per AU for a summer flock in Texas. Calculated in another unit, average N loss over all 18 flocks was 0.600 g N/d per bird (0.729 g NH_3/d per bird), which was similar to several of the data reviewed by Burns (2004). As a percent of N inputs, approximately 21% of all N inputs (chicks +feed) were lost to the environment.

This research has demonstrated that season is one of the most important factors affecting N loss from broiler facilities. The factor of ambient temperature, which is a reflection of weather conditions in each season of the year, was found to be significantly correlated to N loss. Relative humidity data did not exhibit seasonal variation and was not significantly correlated to N loss. The pH of litter also does not appear to be greatly affected by seasonality. Due to fluctuations in ambient weather conditions, broiler producers may not always be able to maintain optimal conditions within poultry housing. Therefore, litter pH may be the most important factor producers could manipulate on a continual basis to prevent the volatilization of N in the form of NH_3. This research indicates that seasonal variation will greatly influence N and NH_3 emission calculations and must be considered. For example, consider a hypothetical broiler farm of four houses with 25,000 broilers/house and grow-out conditions similar to those used in this study. Using data from Tables 2.1 and 2.2, a winter or spring flock such as Flock 12 would have estimated total N emissions averaging 66 lb N/d or 80 lb NH_3/d for all four houses (assuming 100% of N emitted was in the form of NH_3). In contrast, the same farm in a summer scenario (using Flock 14 data) would emit 217 lb N/d or 264 lb NH_3/d on average over the 41 day grow-out period. Therefore, season will greatly influence whether or not a producer will need to report NH_3 emissions under the requirements of CERCLA or EPCRA. Based on the average N emission rate of 11.07 g N/kg calculated in this study, a broiler farm housing 62,545 broilers (2.25 kg at market-age, 42 days) would produce on average 100 lb of NH_3 per day during a grow-out cycle.

The effects of top-dressing recycled broiler litter in this study were presented in Chapter IV. Top-dressing was found to significantly reduce litter caking as was expected. This method of litter management has been used widely for many years in the commercial broiler industry. However, this litter management strategy was not found to be effective at increasing litter N retention compared to the untreated litter. If top-dressing had been found to be effective at reducing N volatilization from recycled litter, this methodology could be readily used as a strategy to reduce NH_3 emissions from broiler housing. Replication of this study is needed to verify these findings. Based on this experiment, the already commonly used practice of top-dressing recycled broiler litter would not be recommended if the production of NH_3 was a concern to the producer (usually not a bird health concern in summer due to high ventilation rates). As shown in this experiment, top-dressing of recycled litter may actually increase N loss to the environment. There were also some indications that top-dressing reduced broiler ending body weights in summer flocks. A significant difference was observed in Flock 14 (Table 5.1). This result could be related to the increased microbial populations measured in the litter. Increased microbial activity would increase composting within the litter, and thus result in increased heat generation and liberation of NH_3. Top-dressing of recycled litter also significantly reduced litter and cake N content.

Season was found to significantly influence nutrient content of litter materials. Nitrogen content of litter materials was significantly reduced in summer flocks compared to winter flocks. This finding is most likely due to increased microbial enzymatic breakdown of uric acid and proteins in the litter and subsequent release of NH_3. Decreased feed consumption and manure production by the birds in hot weather could also be a factor affecting N content of litter. Conversely, litter and cake total P and K content was found to significantly increase during summer flocks compared to flocks reared in cooler weather. This was attributed to increased urinary and fecal mineral excretion by the birds due to heat stress. The increase in total P and K was more pronounced in the cake than the litter. This would stand to reason as birds were probably spending more time near the drinkers in hot weather, and therefore more manure was deposited in this area (cake was removed almost exclusively from under the drinker lines).

The data generated in this study can also be used by broiler producers to estimate the amount of litter materials that will be generated using different broiler house clean-out schedules. This is best illustrated by again considering a hypothetical broiler farm with four houses containing 25,000 broilers each and an average ending body weight of 2.25 kg. On a yearly basis, this farm would expect to produce approximately 1,575,000 kg of live broilers per year (7 flocks per year). Based on a yearly clean-out schedule and litter and cake cumulative production rates for Flock 7 from Table 4.4, this farm would produce an estimated 342,878 kg (378 US tons) of litter and 96,233 kg (106 US tons) of cake on a dry matter basis after 1 year. This would equate to a total litter material production rate of 0.69 US tons per 1,000 broilers on a dry matter basis. Corrected for moisture content (assuming 26 and 47% moisture for litter and cake, respectively), an estimated total of 711 US tons or 1.02 US ton per 1,000 broilers on an as is basis would be produced on this farm in one year. Based on a complete clean-out every two years (14 flocks produced), Flock 14 cumulative production rates from Table 4.4 would yield 595,035 kg (656 US tons) of litter and 212,310 kg (234 US tons) of cake after two years on a dry matter basis. This would equate to a total litter material production rate of 0.64 US tons per 1,000 broilers on a dry matter basis. Using the same moisture assumptions, an estimated total of 664 US tons per year or 0.95 US ton per 1,000 broilers on an as is basis would be produced on this farm. Therefore, performing a complete clean-out after 14 flocks (two years) rather than seven flocks (one year) would reduce litter production on this farm by 94 US tons on an as is basis every 2 years. This exercise demonstrates how this research could be utilized by broiler producers to estimate litter production.

The ability to predict litter production and nutrient content is important for proper nutrient utilization planning to mitigate negative impacts to soil and water resources.

REFERENCES

Anderson, N., R. Strader and C. Davidson, 2003. Airborne reduced nitrogen: ammonia emissions from agriculture and other sources. Environ. International 29:277-286.

Aneja, V. P., P. A. Roelle, G. C. Murray, J. Southerland, J. W. Erisman, D. Fowler, W. A. H. Asman, and N. Patni. 2001. Atmospheric nitrogen compounds II: emissions, transport, transformation, deposition and assessment. Atmos. Environ. 35:1903-1911.

Applegate, T. J., L. P. V. Potturi, and R. Angel. 2003. Model for estimating poultry manure nutrient excretion: a mass balance approach. Pages 296-302 in Proceedings of the Ninth International Animal, Agricultural and Food Processing Wastes Symposium, Research Triangle Park, NC.

Baek, B. H., V. P. Aneja and Q. Tong, 2004. Chemical coupling between ammonia, acid gases, and fine particles. Environ. Pollut. 129:89-98.

Belay, T., C. J. Wiernusz and R. G. Teeter. 1992. Mineral balance and urinary and fecal mineral excretion profile of broilers housed in thermoneutral and heat-distressed environments. Poult. Sci. 71:1043-1047.

Boles, J. C., Jr., K. Van Devender, J. Langston, and A. Rieck. 2004. Dry Poultry Manure Management. Publication MP-358, Arkansas Cooperative Extension Service, University of Arkansas, Fayetteville, AR.

Bowers, B. D., J. B. Hess, S. F. Bilgili, J. P. Blake, and M. K. Eckman. 2002. Nutrient level buildup in sand litter. Pages 289-293 in Proceedings of 2002 National Poultry Waste Management Symposium, Birmingham, AL.

Burgess, R. P., J. B. Carey and D. J. Shafer. 1998. The impact of pH on nitrogen retention in laboratory analysis of broiler litter. Poult. Sci. 77:1620-1622.

Burns, R. T. 2004. Poultry broiler ammonia emission factor comparisons. Pages 141-144 in Proceedings of 2004 National Poultry Waste Management Symposium, Memphis, TN.

Carey, J. B., R. P. Burgess, R. A. Russo, C. Chavez, T. P. Niemeyer and C. D. Coufal. 2000. Field evaluation of litter conditions in tunnel ventilated broiler houses at the end of the production cycle. Pages 340-343 in Proceedings of 2000 National Poultry Waste Management Symposium, Ocean City, MD.

Carlile, F. S. 1984. Ammonia in poultry houses: A literature review. World's Poult. Sci. J. 40:99-113.

Carr, L. E., F. W. Wheaton, and L. W. Douglass. 1990. Empirical models to determine ammonia concentrations from broiler chicken litter. Trans. ASAE 33:1337-1342.

Chamblee, T. N. and R. L. Todd. 2002. Mississippi broiler litter: fertilizer value and quantity produced. Research Report 23(5), Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Starksville, MS.

Draaijers, G. P. J., W. P. M. F. Ivens, M. M. Bos, and W. Bleuten. 1989. The contribution of ammonia emissions from agriculture to the deposition of acidifying and eutrophying compounds onto forests. Environ. Pollut. 60:55-66.

Derikx, P. J. L., H. C. Willers and P. J. W. ten Have. 1994. Effects of pH on the behavior of volatile compounds in organic manures during the dry-matter determination. Bioresource Tech. 49: 41-45.

Elliott, H. A. and N. E. Collins. 1982. Factors affecting ammonia release in broiler houses. Trans. ASAE 25(2):413-424.

Elwinger, K. and L. Svensson. 1996. Effect of dietary protein content, litter and drinker type on ammonia emission from broiler houses. J. Agric. Eng. Res. 64:197-208.

Erisman, J. W. and M. Schaap. 2004. The need for ammonia abatement with respect to secondary PM reductions in Europe. Environ. Pollut. 129:159-163.

Feagley, S., J. B. Carey, and B. Auvermann. 1998. Poultry waste management handbook. Texas Cooperative Extension Service, Texas A&M University System, College Station, TX.

Groot Koerkamp, P. W. G., J. H. M. Metz, G. H. Uenk, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, J. Hartung, J. Seedorf, M. Schroder, K. H. Linkert, S. Pederson, H. Takai, J. O. Johnsen, nd C. M. Wathes. 1998. Concentrations and emissions of ammonia in livestock buildings in northern Europe. J. Agric. Eng. Res. 70(1):79-95.

Hutchings, N. J., S. G. Sommer, J. M. Anderson, and W. A. H. Asman. 2001. A detailed ammonia emission inventory for Denmark. Atmos. Environ. 35:1959-1968.

Kim, W. K. and P. H. Patterson. 2003. Effect of minerals of activity of microbial uricase to reduce ammonia volatilization in poultry manure. Poult. Sci. 82:223-231.

Krupa, S. V. 2003. Effects of atmospheric ammonia (NH_3) on terrestrial vegetation: a review. Environ. Pollut. 124:179-221.

Kunkle, W. E., L. E. Carr, T. A. Carter and E. H. Bossard. 1981. Effect of flock and floor type on the levels of nutrients and heavy metals in broiler litter. Poult. Sci. 60:1160-1164.

Lacey, R. E., J. S. Redwine, and C. B. Parnell Jr. 2002. Emission factors for broiler production operations: a stochastic modeling approach. Pages 1-12 in Proceedings of 2002 ASAE Annual International Meeting/CIGR XVth World Congress, Chicago, IL.

Lacey, R. E., J. S. Redwine and C. B. Parnell, Jr. 2003. Particulate matter and ammonia emission factors for tunnel ventilated broiler production houses in the southern United States. Trans. ASAE 46(4):1203-1214.

Malone, G. W. 1992. Nutrient enrichment in integrated broiler production systems. Poult. Sci. 71:1117-1122.

Malone, G. W., T. Sims and N. Gedamu. 1992. Quantity and quality of poultry manure produced under current management programs. Final Report to the Delaware Department of Natural Resources and Environmental Control and Delmarva Poultry Industry, Inc., University of Delaware, Research and Education Center, Georgetown, DE.

Misselbrook, T. H., T. J. Van Der Weerden, B. F. Pain, S. C. Jarvis, B. J. Chambers, K. A. Smith, V. R. Phillips and T. G. M. Demmers. 2000. Ammonia emission factors for UK agriculture. Atmos. Environ. 34(6):871-880.

Mitchell, C. C. and J. O. Donald. 1995. The value and use of poultry manures as fertilizer. Publication ANR-244, Alabama Cooperative Extension System, Alabama A&M University, Huntsville, AL and Auburn University, Auburn, AL.

Moore, P. A., Jr., T. C. Daniel, D. R. Edwards, and D. M. Miller. 1996. Evaluation of chemical amendments to reduce ammonia volatilization from poultry litter. Poult. Sci. 75:315-320.

Nahm, K. H. 2003. Evaluation of the nitrogen content in poultry manure. World's Poult. Sci. J. 59:77-88.

National Climatic Data Center (NCDC). 2005. Meteorological data for College Station, TX. http://cdo.ncdc.noaa.gov/ulcd/ULCD. Accessed June 2005.

National Research Council. 2003. Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs. National Academy Press, Washington, D.C.

Natural Resource, Agriculture, and Engineering Service (NRAES). 1999. Poultry Waste Management Handbook. Cooperative Extension, Ithaca, NY.

Patterson, P. H., E. S. Lorenz, W. D. Weaver, Jr. and J. H. Schwartz. 1998. Litter production and nutrients from commercial broiler chickens. J. Appl. Poul. Res. 7:247-252.

Phillips, V. R., R. Scholtens, D. S. Lee, J. A. Garland, and R. W. Sneath. 2000. A review of methods for measuring emission rates of ammonia from livestock buildings and slurry or manure stores, part 1: assessment of basic approaches. J. Agric. Eng. Res. 77:355-364.

Rasnake, M., 1996. Broiler litter production in Kentucky and potential use as a nutrient source. Publication AGR-168, Kentucky Cooperative Extension Service, University of Kentucky, Lexington, KY and Kentucky State University, Frankfort, KY.

Redwine, J. S., R. E. Lacey, S. Mukhtar and J. B. Carey. 2002. Concentrations and emissions of ammonia and particulate matter in tunnel-ventilated broiler houses under summer and winter conditions in Texas. Trans. ASAE 45(4):1101-1109.

Reece, F. N., B. J. Bates and B. D. Lott. 1979. Ammonia control in broiler houses. Poult. Sci. 58:754-755.

Singh, A., J. R. Bicudo, A. L. Tinoco, I. F. Tinoco, R. S. Gates, K. D. Casey, and A. J. Pescatore. 2004. Characterization of nutrients in built-up broiler litter using trench and random walk sampling methods. J. Appl. Poult. Res. 13:426-432.

Sneath, R. W., M. R. Holden, V. R. Phillips, R. P. White and C. M. Wathes, 1996. An inventory of emissions of aerial pollutants from poultry buildings in the UK. Pages 207-211 in Proceedings of International Conference on Air Pollution from Agricultural Operations. Midwest Plan Service, Kansas City, MO.

Stephenson, A. H., T. A. McCaskey and B. G. Ruffin. 1990. A survey of broiler litter composition and potential value as a nutrient resource. Biol. Wastes 34:1-9.

Vest, L., B. Merka and W. I. Segars, 1994. Poultry waste: Georgia’s 50 million dollar forgotten crop. Publication 206, Georgia Cooperative Extension Service, University of Georgia, Athens, GA.

Wathes, C. M., M. R. Holden, R. W. Sneath, R. P. White, and V. R. Phillips. 1997. Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. Br. Poult. Sci. 38:14-28.

Wheeler, E. F., R. W. J. Weiss, and E. Weidenboerner. 2000. Evaluation of instrumentation for measuring aerial ammonia in poultry houses. J. Appl. Poul. Res. 9:443-452.

Wheeler, E. F., K. D. Casey, J. S. Zajaczkowski, P. A. Topper, R. S. Gates, H. Xin, Y. Liang, and A Tanaka. 2003. Ammonia emissions from U.S. poultry houses: part III – broiler houses. Pages 159-166 in Proceedings of Air Pollution from Agricultural Operations III Conference, Research Triangle Park, NC.

Worley, J. W., L. M. Risse, M. L. Cabrera, and M. P. Nolan, Jr. 1999. Bedding for broiler chickens: two alternative systems. Appl. Eng. Agric. 15:687-693.

Worley, J. W., M. Czarick and A. M. Cathey. 2002. Ammonia emissions from a commercial broiler house. Paper No. 024118 in Proceedings from 2002 ASAE Annual International Meeting/CIGR XVth World Congress, Chicago, IL.

APPENDIX

TABLE A-1. Nitrogen emissions for 18 consecutive flocks of broilers expressed in various units, Flocks 1 to 18

Begin Date (m/y)	End Date (m/y)	Flock	% of N inputs[1]	g N/kg[2]	g N/bd[3]	g N/d per bd[4]	g N/h per AU[5]
7/01	8/01	1	18.27[efg]	9.22[cdef]	19.96[defg]	0.487[efg]	4.69[fghi]
9/01	10/01	2	14.58[gh]	7.47[efg]	16.29[fgh]	0.407[fgh]	3.89[hij]
11/01	12/01	3	14.42[gh]	7.34[efg]	16.66[efgh]	0.417[fgh]	3.82[hij]
1/02	2/02	4	17.76[efg]	9.45[cde]	21.95[def]	0.535[ef]	4.80[fgh]
2/02	4/02	5	19.44[defg]	10.35[cde]	22.13[def]	0.540[ef]	5.26[efgh]
4/02	5/02	6	24.43[bcde]	12.45[c]	27.61[bcd]	0.690[cde]	6.49[cdef]
6/02	7/02	7	36.65[a]	19.74[a]	42.47[a]	1.036[a]	10.03[a]
7/02	9/02	8	22.65[cdef]	12.00[cd]	25.15[cde]	0.613[def]	6.09[defg]
9/02	10/02	9	27.80[bc]	14.66[bc]	34.03[ab]	0.830[abcd]	7.45[bcd]
11/02	12/02	10	7.91[h]	4.13[g]	9.41[h]	0.229[h]	2.10[j]
1/03	2/03	11	13.87[gh]	7.83[defg]	17.56[efgh]	0.428[fgh]	3.98[ghij]
2/03	4/03	12	9.67[h]	5.25[fg]	12.57[gh]	0.299[gh]	2.60[ij]
4/03	6/03	13	30.12[abc]	15.48[bc]	34.22[ab]	0.835[abcd]	7.87[bcd]
6/03	7/03	14	36.04[a]	18.71[ab]	40.41[a]	0.986[ab]	9.51[ab]
8/03	9/03	15	31.63[ab]	16.20[abc]	34.50[ab]	0.842[abc]	8.23[abc]
9/03	10/03	16	27.03[bcd]	14.55[bc]	33.68[abc]	0.802[bcd]	7.22[cde]
11/03	12/03	17	15.67[fgh]	8.21[defg]	18.82[defgh]	0.470[efgh]	4.28[ghij]
1/04	2/04	18	9.36[h]	5.13[fg]	12.62[gh]	0.300[gh]	2.54[j]
average			21.08	11.07	24.55	0.600	5.64
Pooled SEM			2.748	1.469	3.247	0.079	0.748

[1] N inputs = feed N + day-old chick N
[2] Values calculated as g N/kg of live marketed broiler.

[3] Values calculated as g N/marketed broiler.
[4] Values calculated as g N/d per marketed broiler.
[5] Values calculated as g N/h per AU, where 1 AU=500 kg of live animal wt. (marketed broiler)
[a, b, … j] Means within a column lacking a common superscript differ ($P<0.05$).

TABLE A-2. Litter pH, percent moisture, and percent nitrogen at the beginning of each flock, Flocks 1 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[1]	Starting Litter pH	Starting Litter Moisture (%)	Starting Litter N (%)
7/01	8/01	1	C	7.05	9.44	0.47
9/01	10/01	2	C	8.76	21.74	1.81
11/01	12/01	3	C	8.97	21.29	2.61
1/02	2/02	4	C	8.82	16.83	3.14
2/02	4/02	5	C	8.81	21.70	3.55
4/02	5/02	6	C	8.91	25.26	3.70
6/02	7/02	7	C	8.88	22.18	3.62
7/02	9/02	8	C	8.82	24.75	3.44
9/02	10/02	9	C	8.88	25.13	3.51
11/02	12/02	10	C	8.82	26.18	3.61
			T	8.79	26.37	3.62
1/03	2/03	11	C	8.78	24.27	3.74
			T	8.81	24.68	3.38
2/03	4/03	12	C	8.73	23.58	3.96
			T	8.78	23.73	3.71
4/03	6/03	13	C	8.72	21.43	4.12
			T	8.66	20.89	3.60
6/03	7/03	14	C	8.80	25.14	3.87
			T	8.77	23.85	3.38
8/03	9/03	15	C	8.91	27.04	3.69
			T	8.93	25.71	3.26

TABLE A-2. Continued

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[1]	Starting Litter pH	Starting Litter Moisture (%)	Starting Litter N (%)
9/03	10/03	16	C	8.95	26.30	3.64
			T	9.07	26.03	3.24
11/03	12/03	17	C	9.00	27.09	3.74
			T	9.06	25.47	3.45
1/04	2/04	18	C	9.04	23.79	3.88
			T	9.16	22.28	3.45

[1] C=control pens; T=top-dressed pens

TABLE A-3. Litter and cake pH, Flocks 10 to 18

Begin Date (m/y)	End Date (m/y)	Flock	Trt.[1]	Ending Litter pH	Cake pH
11/02	12/02	10	C	8.55	8.71
			T	8.70	8.75
1/03	2/03	11	C	8.65	8.79
			T	8.75	8.77
2/03	4/03	12	C	8.73	8.77
			T	8.83	8.79
4/03	6/03	13	C	8.81	8.88
			T	8.79	8.94
6/03	7/03	14	C	8.79	8.82
			T	8.84	8.81
8/03	9/03	15	C	8.82	8.91
			T	8.97	9.10
9/03	10/03	16	C	8.86	8.89
			T	8.97	8.96
11/03	12/03	17	C	8.89	8.87
			T	8.99	9.15
1/04	2/04	18	C	8.90	7.17
			T	9.05	8.28
Average			C	8.78	8.64
			T	8.88	8.84

[1] C = control group, T = top-dressed group

TABLE A-4. Day-old chick carcass moisture and nitrogen content on a dry matter basis[1]

Flock	Moisture	N
	(%)	
2	74.18	10.71
3	75.56	9.95
4	73.25	9.61
5	75.80	11.20
6	75.42	11.12
7	75.24	10.51
8	73.71	10.27
9	75.58	11.07
10	76.38	10.76
11	75.59	11.36
12	75.50	10.59
13	76.17	11.07
14	75.81	11.19
15	77.32	11.42
16	75.34	11.07
17	74.58	10.90
18	74.72	10.97

[1] Each flock sample contained 12 chick carcasses pooled for moisture and N analysis

TABLE A-5. Market-age broiler carcass moisture[1]

Flock	Moisture (%)
2	65.39
3	64.92
4	63.78
5	64.08
6	64.99
7	64.20
8	62.28
9	64.58
10	63.39
11	67.20
12	65.36
13	65.45
14	64.73
15	65.03
16	64.43
17	65.85
18	64.90

[1] Average of 12 broiler carcasses analyzed individually

TABLE A-6. Phosphorus (P) and potassium (K) content of top-dressed recycled rice hull broiler litter and cake on a dry matter basis at the end of Flocks 10 to 18[1]

	Litter		Cake	
	P	K	P	K
Flock	(%)		(%)	
10	1.99	2.73	2.01	2.94
11	1.92	2.59	1.84	2.50
12	1.94	2.55	1.96	2.82
13	1.79	2.36	1.89	2.88
14	1.95	2.95	2.02	3.15
15	1.89	2.61	2.66	5.33
16	1.98	2.96	2.22	3.77
17	2.01	3.12	1.97	3.48
18	1.76	2.28	1.68	2.51

[1] Average of 3 pens per mean

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SELECTED PUBLICATIONS

K. D. Knape, C. Chavez, R. P. Burgess, C. D. Coufal, and J. B. Carey. 2002. Comparison of eggshell surface microbial populations for in-line and off-line commercial egg processing facilities. Poult. Sci. 81: 695-698.

C. Chavez, K. D. Knape, C. D. Coufal, and J. B. Carey. 2002. Reduction of eggshell aerobic plate counts by ultraviolet irradiation. Poult. Sci. 81: 1132-1135

C. D. Coufal, C. Chavez, K. D. Knape, and J. B. Carey. 2003. Evaluation of a method of ultraviolet light sanitation of broiler hatching eggs. Poult. Sci. 82: 754-759.

C. Chavez, C. D. Coufal, R. E. Lacey, and J. B. Carey. 2004. The impact of methionine source on poultry fecal matter odor volatiles. Poult. Sci.83: 359-364.

C. Chavez, C. D. Coufal, J. B. Carey, R. E. Lacey, R. C. Beier, and J. A. Zahn. 2004. The impact of supplemental dietary methionine source on volatile compound concentrations in broiler excreta. Poult. Sci. 83: 901-910.