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Research Article

Implications of Intensive Spatial Sampling of Broiler Litter: Characteristics and Gaseous Emissions

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Abstract

Objective: The purpose of the study was to gain an overall assessment of seasonal influences and location within houses on litter physical and chemical properties as well as litter gas flux in U.S. commercial broiler houses. **Materials and Methods:** More than 1000 litter samples as well as *in situ* gas flux of NH_3, N_2O and CO_2 were collected spatially within four U.S. commercial broiler houses over a period of 4 years. Analysis of variance among the measurements was performed with season, bird age and location within the house as the sources of variation. **Results:** Total litter cleanout (where fertilizer is the end use) is recommended during winter where litter moisture is lower and litter total N is higher than at the end of summer flocks. At chick placement and during mid-flock, the highest NH_3 losses were in the fan areas. At market age, fan area samples were extremely caked and gas volatilization was lowest. **Conclusion:** During the growout, NH_3 gas flux could be minimized by zone litter treatments which could potentially enhance broiler productivity. The areas to treat near the end of the flock are in front of the cooling pads and in the brood and non-brood areas, where NH_3 gas flux magnitude had tripled since chick placement.

Key words: Ammonia, broiler, emissions, litter, gas flux

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Broiler house structure, litter dynamics and bird age exhibit intricate interrelationships. A better understanding could diminish gaseous emissions while increasing bird productivity. In the U.S. broiler industry, chickens are grown for meat and are usually housed in large (13/150 m or larger), solid-sidewall barns. An organic bedding material, either pine wood shavings or rice hulls, covers the floor and becomes known as litter when the birds defecate on it. Other components of litter are feathers, dander and spilled feed and water. Where birds congregate (i.e., high traffic areas), litter can compact and form a dense, moisture rich layer known as "Cake[1]". Between flocks, cake and some litter are usually removed with a machine pulled by a tractor.

Another important aspect of the U.S. industry is the practice of half-house brooding where chicks are confined to half of the house and the air is heated during the first 7-12 days of the flock. The temperature profile during brooding has been shown[2]. In that winter study, the litter temperature in the brood half of the house exceeded the non-brood litter temperature by approximately 15°C. The presence of cake and the half-house brood practice are pertinent to the present study in that the major findings are closely related to these.

Mitigation of emissions from litter is important to maintain bird and farm worker health as well as avoid negative environmental consequences. High concentrations of NH_3 in broiler houses has been shown to cause ocular and respiratory disease in birds as well as lower body weights and impair production[3-7]. In the environment, NH_3 can cause eutrophication of water bodies, decrease ecosystem biodiversity on land and contribute to aerosols forming in the atmosphere. Other gases such as N_2O and CO_2 are greenhouse gases and can contribute to climate change. It is estimated that approximately 6.3% of all U.S. greenhouse gases come from American agriculture[8]. Broiler emission models should include these gases although broiler litter is not a major source[9] of N_2O or CO_2.

The overall aim of the current study was to combine 4 previously published, intense spatial studies[10-12,2] to gain an overall assessment of seasonal influences and location within houses on litter physical and chemical properties and well as litter gas flux in U.S. commercial broiler houses. The assessment was successful in showing significant effects of season and zones for recommending practices to improve litter utilization and bird productivity. This is the first report to include this vast number of samples (~1100) of concurrent house measurements during growout as well as litter sampling.

MATERIALS AND METHODS

Summary of measurements: In U.S. commercial broiler houses, *in situ* estimation of gaseous flux from litter (NH_3, N_2O and CO_2) and litter temperature were determined as well as the following for approximately 1100 litter samples: Moisture, pH, total N, total C and water soluble PO_4, NH_4 and NO_3. Details for each published study can be found in Miles *et al.*[2,10-12].

Broiler facilities and litter sampling: Over a period of 4 years, litter samples were collected in four U.S. commercial broiler houses via a grid pattern having 44 locations per house at three bird ages during each flock: Chick placement, mid-flock (21 days) and market age (43-45 days). Figure 1 depicts the sampling layout with 36 grid locations located 5 m apart across the houses and 12 m apart down the length of the houses. Three tunnel ventilated houses measured 12.8/146.3 m and one measured 12.8/152.4 m. For the longer house, 3.05 m was excluded from each end. The broiler houses were located in Mississippi (humid subtropical climate) and had pine shavings as the original bedding material. Measurements were made in winter on reused litter (8 and 15 flocks) and in summer (flocks 12, 17, 29 and 30). Automated feeder and water lines ran the length of each house, there were two feeder lines in each house with a waterer line on each side of the feeders. Eight Feeder/Waterer (F/W) samples were taken halfway between the feeders and waterers at four locations down the house (marked with an "X" on Fig. 1).

The upper 5 cm of litter was collected with a hand trowel and sealed in a plastic bag prior to transport back to the laboratory. Samples were chilled for transport to the laboratory and were then frozen until analyses were performed.

Litter characterization: Prior to gas flux determination and litter collection, litter surface temperature was measured at each location using an infrared thermometer (Rayngerl ST, Raytek Corp., Santa Cruz, CA, U.S.). Qualitative notes were made for litter condition (i.e., friable or extreme cake). On thawed samples, moisture content was determined by loss in weight after oven drying litter (65°C for 48 h) and pH was found using a deionized H_2O to litter ratio of 5:1. Total N and C were ascertained by combustion (Max CN analyzer, Elementar Americas, Inc., Mt. Laurel, NJ, U.S.). After the litter was water extracted, PO_4, NH_4 and NO_3 were determined using flow injection analysis (QuikChem 8000, Lachat Instruments, Milwaukee, WI, U.S.).

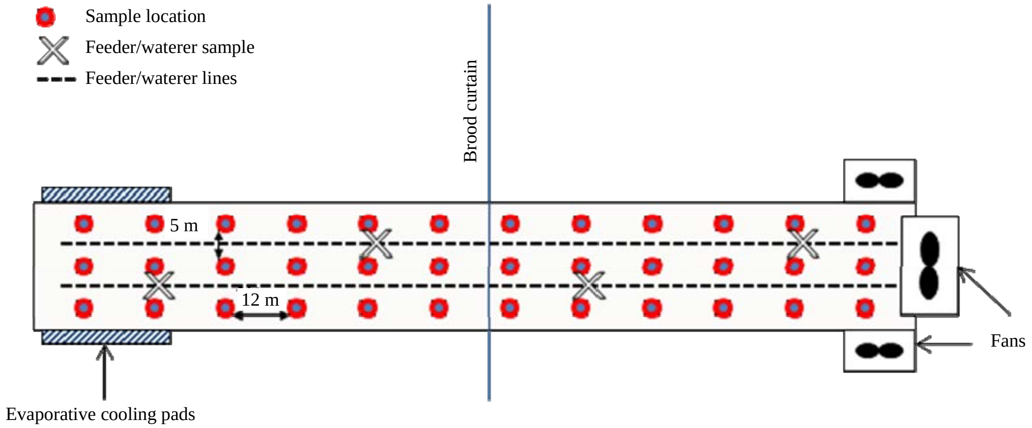

Fig. 1: Overall sampling plan of commercial broiler houses for litter surface gas flux, temperature and litter sampling

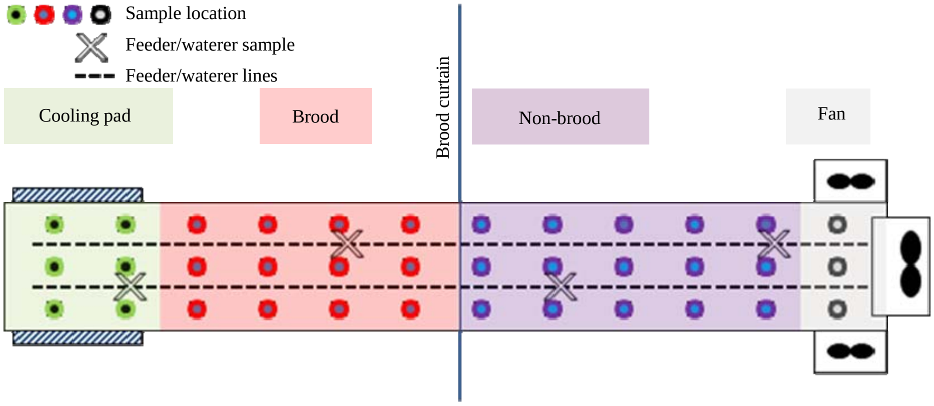

Fig. 2: Sampling zones across commercial broiler houses: Cooling pad, brood, non-brood, fan and feeder/waterer

Litter gas emissions: A static chamber in conjunction with a photoacoustic multigas analyzer (Innova 1412, California Analytical, Orange, CA, U.S.) was used to estimate gas flux of NH_3, N_2O and CO_2. The operation has been described in the study of Miles *et al.*[12]. Briefly, a vented, cylindrical container (14.3 cm radius and 35 cm height) was inverted over the litter just before the analyzer pumped in a sample (time 0). After 70 sec the analyzer drew in a second sample and the change in gas concentration was used to estimate the gas flux when combined with the chamber area and deployment time.

Data analyses: Analysis of variance among the measurements was performed using the procedures of SAS (PROC GLM)[13]. Season, bird age and location within the house [either across the house (Fig. 2) or lengthwise (Fig. 3)] were the sources of variation. Interaction among these sources (season×bird age×location) made it appropriate to perform another analysis of variance at each bird age. Occasionally, the season×location interaction remained significant. Significant effects were declared at $\alpha = 0.05$. Regardless of the interaction, the main effects of season and/or location were usually significant and are reported. In the previous studies[2,10-12], color contour plots (variograms) were produced using geostatistical software (Golden Surfer 8.0; Golden, CO) to visualize trends for the litter properties and gas flux.

RESULTS

The results are presented in Table 1-3 for each bird age: Chick placement, mid-flock and market age. Table 1 lists each parameter during winter and summer. Table 2 shows the data for location across the houses that were classified as Cooling Pad (CP), Brood (B), Non Brood (NB), Fan (F) and Feeder/Waterer (F/W). The samples associated with each area across the houses are depicted in Fig. 2. Table 3 classifies samples lengthwise within houses as near the walls, in the center or F/W. These locations are shown in Fig. 3.

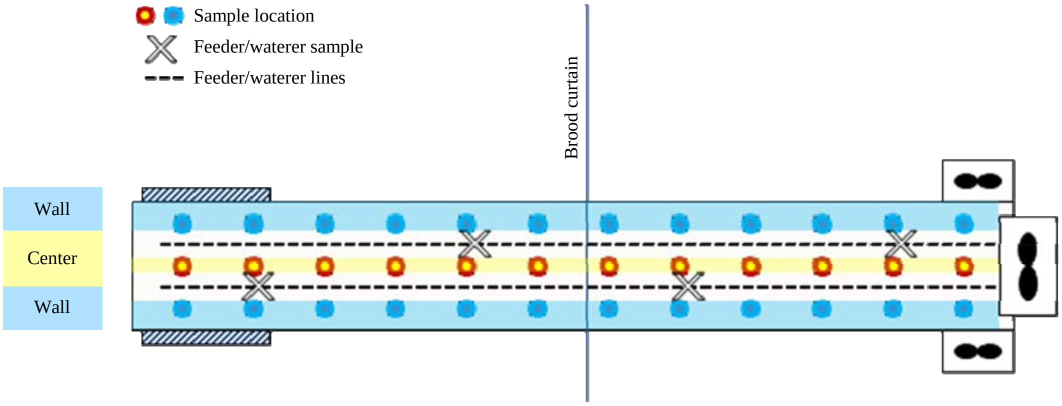

Fig. 3: Lengthwise sampling zones in commercial broiler houses

Table 1: Seasonal characteristics of litter and air properties, gas flux and litter chemical components in U.S. commercial broiler

	Broiler age								
	Placement			Mid-flock			Market		
	Season			Season			Season		
Litter properties	Winter	Summer	LSD	Winter	Summer	LSD	Winter	Summer	LSD
Temperature (°C)	24.20^b	30.70^a	0.92	28.00^b	29.40^a	0.37	27.90^b	32.90^a	0.51
Moisture (%)	25.00^a	22.00^b	0.74	25.50	25.60	0.84	33.80^b	39.30^a	1.77
pH	8.50^a	8.38^b	0.08	8.24^a	8.09^b	0.05	8.28^b	8.44^a	0.09
Air properties									
Temperature (°C)	23.90^b	31.40^a	1.11	25.30^b	28.30^a	0.28	22.80^b	28.20^a	0.52
Relative humidity (%)	58.30^b	72.10^a	2.09	70.10^b	72.60^a	1.17	56.10^b	88.10^a	2.51
Gases flux (mg m^{-2} h^{-1})									
NH_3	287.00^b	419.00^a	50.00	312.00^b	363.00^a	47.00	857.00	842.00	125.00
N_2O	8.70	7.90	1.90	2.25^a	12.70^b	2.25	22.40^a	18.10^b	4.04
CO_2	5091.00	4657.00	576.00	11542.00	12379.00	1058.00	23201.00^b	27213.00^a	2425.00
Litter chemical components									
Total N (%)	2.44^b	2.74^a	0.09	2.67^b	2.83^a	0.09	2.57^a	2.35^b	0.08
Total C (%)	26.77^b	28.44^a	0.70	27.49	27.73	0.62	26.09^a	24.70^b	0.63
PO_4 (mg kg^{-1})	10294.00^a	4320.00^b	1154.00	4896.00^a	4676.00^b	214.00	4412.00^a	3397.00^b	247.00
NH_4 (mg kg^{-1})	9212.00^a	2981.00^b	807.00	4464.00^a	3426.00^b	292.00	7140.00^a	3782.00^b	871.00
NO_3 (mg kg^{-1})	9519.00^a	3004.00^b	1704.00	2414.00	2759.00	732.00	474.00^b	1091.00^a	254.00

LSD: Least significant difference

Litter physical properties: Litter temperature upon bird placement showed highly significant ($p<0.0001$) interaction among season and locations within the house, both across and lengthwise. This is an understandable effect since the birds were brooded in the cooling pad and brood areas of the houses (Fig. 2). Thus, the overall means for winter vs summer brood temperatures at placement are not reflective of the half-house brooding management practice. The mean temperature of 24.2°C in winter (Table 1) is low (due to including the other, non-heated half of the houses) and was not what the chicks experienced. Half-house brooding was clearly depicted in the variograms reported earlier[2,11,12]. In the current study for litter temperature across the houses at chick placement (Table 2), the CP and B areas had the greatest temperature (31.7 and 32.2°C, respectively) with the F/W temperature mid-range at 27°C and the lowest litter temperatures overall in the NB and F areas (22.1 and 21.4°C, respectively). The means and standard deviations were actually CP = 31.9±5.33, B = 32.4±3.83, NB = 16.6±4.63, F = 15.9±4.35, F/W = 22.4±10.8 in winter and CP = 31.5±1.24, B = 32±1.03, NB = 29.4±1.54, F = 28.7±2.05 and F/W = 31.6±1.4 in summer. Note the greater variation in winter and especially the standard deviation of the F/W in winter at 10.8. Since the F/W samples ran the length of the houses, the greater variation is expected with half of the house heated and the other half not heated. Overall at chick placement, the center of the houses were hotter (Table 3) than the samples closer to the sidewalls, which again is logical given the placement of the brood heaters down the center of the houses.

Table 2: Characteristics of zones across the houses for litter and air properties, gas flux and litter chemical components in U.S. commercial broiler

	Broiler age																	
	Placement						Mid-flock						Market					
	Location within house (across)						Location within house (across)						Location within house (across)					
Litter properties	CP	B	NB	F	F/W	LSD	CP	B	NB	F	F/W	LSD	CP	B	NB	F	F/W	LSD
Temperature (°C)	31.70^{a}	32.20^{a}	22.100^{c}	21.40^{c}	27.00^{b}	1.72	26.90^{d}	28.60^{c}	29.70^{a}	29.30^{ab}	28.70^{bc}	0.69	27.60^{c}	29.60^{b}	30.30^{ab}	30.70^{a}	29.90^{ab}	0.91
Moisture (%)	21.70^{c}	22.20^{bc}	25.500^{a}	25.90^{a}	23.10^{b}	1.38	24.40^{b}	24.30^{b}	25.70^{b}	28.30^{a}	27.90^{a}	1.54	33.60^{c}	32.90^{c}	36.80^{b}	44.10^{a}	35.80^{bc}	3.08
pH	8.30^{b}	8.23^{b}	8.670^{a}	8.68^{a}	8.34^{b}	0.15	8.02^{c}	8.01^{c}	8.25^{ab}	8.33^{a}	8.22^{b}	0.10	8.39^{a}	8.41^{a}	8.43^{a}	7.74^{c}	8.22^{b}	0.16
Air properties																		
Temperature (°C)	31.2^{a}	31.20^{a}	22.00^{c}	21.80^{c}	26.50^{b}	1.98	26.00^{d}	26.70^{c}	27.40^{ab}	27.80^{a}	27.10^{bc}	0.52	23.60^{c}	24.10^{c}	25.0^{b}	25.6^{ab}	26.20^{a}	0.94
Relative Humidity (%)	56.9^{b}	59.60^{b}	66.70^{a}	67.00^{a}	66.10^{a}	3.73	70.20	71.80	71.70	71.80	71.90	2.17	67.50^{ab}	66.40^{b}	67.2^{ab}	67.8^{ab}	71.00^{a}	4.50
Gas flux (mg m^{-2} h^{-1})																		
NH_3	380.00^{b}	330.00^{b}	308.00^{b}	543.00^{a}	328.00^{b}	94.00	227.00^{c}	285.00^{c}	376.00^{b}	489.00^{a}	413.00^{ab}	87.00	918.00^{a}	1082.00^{a}	959.00^{a}	246.00^{c}	483.00^{b}	217.00
N_2O	11.30^{a}	7.30^{b}	7.90^{ab}	9.20^{ab}	7.70^{ab}	3.57	15.70^{b}	11.30^{c}	17.20^{b}	26.00^{a}	13.50^{bc}	4.17	26.10^{a}	21.00^{a}	27.4^{a}	3.90^{c}	11.10^{b}	7.01
CO_2	6056.00^{a}	5387.00^{ab}	3918.00^{c}	6435.00^{a}	4348.00^{bc}	1080.00	10011.00^{b}	10266.00^{b}	11753.00^{b}	16189.00^{a}	16774.00^{a}	1971.00	26918.00^{a}	26531.00^{a}	28358.00^{a}	14720.00^{c}	17036.00^{b}	4222.00
Litter chemical components																		
Total N (%)	2.77^{a}	2.83^{a}	2.35^{b}	2.17^{c}	2..71^{a}	0.17	3.08^{a}	2.91^{b}	2.63^{cd}	2.48^{d}	2.74^{bc}	0.16	2.54^{ab}	2.52^{ab}	2.35^{c}	2.62^{a}	2.46^{bc}	0.14
Total C (%)	28.87^{a}	29.38^{a}	26.63^{b}	23.00^{c}	27.53^{b}	1.30	29.47^{a}	29.08^{a}	26.68^{b}	24.55^{c}	27.12^{b}	1.07	26.58^{a}	27.19^{a}	24.90^{b}	21.23^{c}	24.30^{b}	1.17
PO_4 (mg kg^{-1})	6736.00^{b}	7340.00^{b}	7510.00^{b}	7724.00^{b}	10387.00^{a}	2148.00	4439.00^{bc}	4548.00^{b}	5262.00^{a}	5250.00^{a}	4125.00^{c}	398.00	3363.00^{d}	3491.00^{cd}	4523.00^{b}	6218.00^{a}	3836.00^{c}	429.00
NH_4 (mg kg^{-1})	6901.00^{b}	6785.00^{b}	5563.00^{b}	5806.00^{b}	8678.00^{a}	1502.00	4379.00^{ab}	4219.00^{b}	3446.00^{c}	4017.00^{b}	4829.00^{a}	544.00	4683.00^{c}	4774.00^{c}	6011.00^{bc}	12571.00^{a}	6455.00^{b}	1517.00
NO_3 (mg kg^{-1})	4269.00^{bc}	7378.00^{ab}	6433.00^{bc}	4140.00^{c}	10440.00^{a}	3174.00	1982.00^{ab}	3338.00^{a}	2564.00^{ab}	1378.00^{b}	2882.00^{ab}	1364.00	633.00	799.00	616.00	797.00	611.00	443.00

CP: Cooling pad, B: Brood, NB: Non brood, F: Fan, F/W: Feeder/waterer, LSD: Least significant difference

Table 3: Lengthwise characteristics of litter and air properties, gas flux and litter chemical components in U.S. commercial broiler houses

	Broiler age											
	Placement				Mid-flock				Market			
	Location within house (lengthwise)				Location within house (lengthwise)				Location within house (lengthwise)			
Litter properties	Wall	Center	F/W	LSD	Wall	Center	F/W	LSD	Wall	Center	F/W	LSD
Temperature (°C)	26.10^{b}	28.80^{a}	27.00^{b}	1.42	28.90	28.70	28.70	0.56	29.70	29.50	29.90	0.73
Moisture (%)	24.70^{a}	21.90^{c}	23.10^{b}	1.12	25.90^{b}	23.80^{c}	27.90^{a}	1.22	36.40^{a}	33.80^{b}	35.80^{ab}	2.26
pH	8.53^{a}	8.33^{b}	8.34^{b}	0.12	8.20^{a}	8.04^{b}	8.22^{a}	0.08	8.31^{a}	8.39^{a}	8.22^{b}	0.11
Air properties												
Temperature (°C)	26.20	27.20	26.50	1.58	27.00	26.80	27.10	0.42	24.50^{b}	24.50^{b}	26.20^{a}	0.75
Relative humidity (%)	63.80^{a}	60.60^{b}	66.10^{a}	2.97	72.10^{a}	70.30^{b}	71.90^{ab}	1.75	67.40^{b}	66.30^{b}	71.00^{a}	3.62
Gas flux (mg m^{-2} h^{-1})												
NH_3	370.00	301.00	328.00	77.00	363.00^{a}	265.00^{b}	413.00^{a}	69.00	782.00^{b}	1237.00^{a}	483.00^{c}	159.00
N_2O	7.70	9.80	7.70	2.89	17.60^{a}	11.90^{b}	13.50^{b}	3.27	26.80^{a}	15.60^{b}	11.10^{b}	5.16
CO_2	4844.00^{ab}	5225.00^{a}	4348.00^{b}	875.00	12207.00^{b}	9531.00^{c}	16774.00^{a}	1531.00	25522.00^{a}	27572.00^{a}	17036.00^{b}	3096.00
Litter chemical components												
Total N (%)	2.61^{a}	2.47^{b}	2.71^{a}	0.12	2.77	2.81	2.74	0.12	2.47	2.45	2.46	0.10
Total C (%)	27.02^{b}	28.81^{a}	27.53^{b}	0.95	27.11^{b}	29.09^{a}	27.12^{b}	0.79	24.99^{b}	26.93^{a}	24.30^{b}	0.86
PO_4 (mg kg^{-1})	7318.00^{b}	7392.00^{b}	10388.00^{a}	1745.00	4835.00^{a}	4987.00^{a}	4125.00^{b}	323.00	4111.00^{ab}	4158.00^{a}	3836.00^{b}	315.00
NH_4 (mg kg^{-1})	6257.00^{b}	6126.00^{b}	8678.00^{a}	1220.00	3796.00^{b}	4128.00^{b}	4829.00^{a}	442.00	6132.00	5507.00	6455.00	1112.00
NO_3 (mg kg^{-1})	7282.00^{b}	4025.00^{c}	10440.00^{a}	2578.00	3309.00^{a}	1260.00^{b}	2082.00^{b}	1108.00	813.00^{a}	459.00^{b}	611.00^{ab}	325.00

F/W: Feeder/waterer, LSD: Least significant difference

At the mid-flock and market ages, the discussion of significant effects is greatly simplified for litter temperature. No interactions were significant for season and location, but the main effects of season and locations across the houses were highly significant ($p<0.0001$). Mean summer temperatures exceeded winter by 1.4°C at mid-flock and 5°C at market age. Across the houses, CP was coolest and the warmest litter temperatures were in the NB and F areas. Down the length of the houses, temperatures did not appear different among the walls, center and F/W measurements for mid-flock and market ages.

Litter moisture content at chick placement indicated no significant interaction between season and the lengthwise measurements ($p = 0.58$), but there was interaction between season and area across the houses ($p = 0.0004$). This is again expected because of half-house brooding. All main effects (season, across house and lengthwise) were highly significant. Winter litter moisture content was greater than summer (25 vs 22%) at placement. Across the houses, litter moisture was greatest in the F and NB areas, lesser at the F/W and B locations and least at the CP. Down the houses, litter moisture at the walls was greatest, followed by the F/W and least in the center.

At mid-flock, there were no interactions between season and location for litter moisture content. As a main effect, season was not significant ($p = 0.95$), with winter and summer moisture contents at 25.5 and 25.6%, respectively. However, classifications of both locations were highly significant with the greatest moisture at F and F/W and the least at CP, B and NB across houses. Down the houses, F/W had the highest litter moisture (27.9%), followed by the walls (25.9%) and least again in the center (23.8%). Once the birds reached market age, the reverse was evident where walls had the highest litter moisture (36.4%), the least was in the center (33.8%), but neither of these appeared different than the F/W locations (35.8%). Also at market age, litter moisture content was greatest at F area, followed by NB and least at CP and B. Again the F/W samples did not appear different than the NB and CP/B locations. Summer litter moisture content at the end of the growouts was greater than in winter (39.3 vs 33.8%). For the remaining variables, only the discussion of main effects will be included in order to focus on the tabular data and to simplify the report.

Litter pH was greater in winter at chick placement and mid-flock, but was greater in summer at market age. This is similar to the trend in litter moisture content (Table 1). Across the houses at placement, litter pH was greatest at the NB and F locations and least at the CP, B and F/W. By mid-flock, the F area had the highest litter pH, followed by F/W, but the NB did not appear different than either of these. Again the least litter pH was in the CP and B areas (8.02 and 8.01, respectively). At market age, the highest litter pH was at the CP, B and NB locations (8.39-8.43), followed by F/W and the least at the F area. Near the fans, litter becomes extremely caked (has the highest moisture content) and exhibited the lowest pH. These conditions limit gas flux as discussed. Lengthwise at placement, the wall samples had greater pH than center and F/W samples. At mid-flock, wall and F/W samples were greater than the center of houses. But at market age, litter pH was similar for wall and center locations and less for F/W.

Air temperature: Air temperatures within houses behaved statistically similar to litter temperatures, as would be expected. Winter temperatures were lower than summer air temperatures at each bird age. Across the houses at chick placement, the greatest air temperatures were in the CP and B areas (31.2°C) and were least at the NB and F (22 and 21.8°C, respectively). At mid-flock the lowest temperature was at the CP (26°C), where air entered the houses during tunnel ventilation. The temperature increased in the B area (26.7°C), followed by the NB (27.4°C) and was highest at F locations (27.8°C). This same trend was evident at the end of the growout with most temperatures approximately 2.5°C lower than at mid-flock. Down the length of the houses, air temperatures did not appear different among the walls, center and F/W. A possible anomaly that may deserve further scrutiny occurred at the end of the flocks: Air temperature was highest at the F/W locations both in the across and lengthwise classifications.

Litter gaseous flux: Gas flux of NH_3 from litter was greater in summer at chick placement and during mid-flock. By market age, however, winter and summer gas fluxes did not appear different (857 and 842 mg m^2 h^{-1}, respectively). Across the houses at placement, NH_3 flux was highest at F and lower as well as similar among CP, B, NB and F/W locations. In the middle of the growout, F again had the greatest NH_3 flux. The F/W locations were next highest and were similar to F and NB locations. The NB had the third highest NH_3 flux, with the least at CP and B. At market age, the F area had the least NH_3 flux, 246 mg m^2 h^{-1} (as noted above due to the highest litter moisture content and extremely caked litter). The greatest NH_3 flux at the end of the flock occurred at CP, B and NB, approximately 1000 mg m^2 h^{-1}, with about half as much evident at the F/W. Ammonia flux was similar at placement among the walls, center of the houses and F/W. At mid-flock, wall and F/W NH_3 flux exceeded the center flux estimates. However, at market age, the center of the houses had the greatest NH_3 flux followed by the walls and then the F/W.

Gas flux of N_2O was not seasonally dependent at the beginning of the growout, but was greater in winter at both mid-flock and at the end. Across the houses at placement, the greatest N_2O flux occurred at the CP and was least at the adjacent B area. The other locations (NB, F and F/W) were mid-range and did not appear different that the CP or B areas. By mid-flock the B area still had the least N_2O flux from the litter, followed by CP and NB, with the highest at F. At this time, F/W was mid-range and appeared no different than CP, B or NB. At the end of the flock, F had the lowest N_2O flux 3.9 mg m^2 h^{-1} (as was noted for NH_3). The F/W N_2O flux was approximately 3 times greater than at F. The greatest N_2O flux was at CP, B and NB which was about 6 times higher than at F (~25 mg m^2 h^{-1}). Lengthwise, no N_2O flux estimates appeared statistically different at placement. At mid-flock and market age, wall flux was greater than the center of houses and the F/W areas.

Gas flux of CO_2 was not seasonally dependent at either placement or mid-flock. By market age, summer CO_2 flux exceeded winter flux (27,213 vs 23,201 mg m^2 h^{-1}, respectively). Across the houses when chicks were placed, CO_2 flux was greatest at CP, B and F. However, the B area did not appear different than F/W. The NB area had the lowest CO_2 flux at placement. By mid-flock, the distinctions were more clear with the greatest CO_2 flux at the F and F/W and least at CP, B and NB. Like the other gases at market age, the F exhibited the least CO_2 flux, followed by F/W and the highest fluxes at CP, B and NB. Down the length of the houses at placement, the highest CO_2 flux was in the center with the lowest at F/W. The walls were mid-range and did not appear different than either the center or F/W. At mid-flock, F/W indicated the highest flux, with the walls next and the least flux down the center of the houses. By market age, down the center of the houses and the walls, samples appeared no different and were greater than the F/W CO_2 flux.

Litter chemical components: Total N in litter was greater in summer vs winter at chick placement and at mid-flock. At market age, however, total N was greater in winter vs summer (2.57 and 2.35% N, respectively). At placement across the houses CP, B and the F/W areas had the highest total N, followed by NB and then F. At mid-flock CP was greatest followed by B and F again had the least amount of litter total N. The F/W samples did not appear different than B or NB and NB was similar to both F/W and F. At the end of the flocks, F had the greatest litter total N concentrations and shared this distinction with CP and B. However, CP and B did not appear different than F/W. The F/W samples were also similar to NB litter total N which exhibited the least concentration. Down the length of the houses at placement, wall and F/W samples were greatest with the least concentration in the center. However, at mid-flock and at market age no areas appeared different.

Total C in litter followed trends similar to total N at placement and market age in winter vs summer, where summer litter C was greater at placement, but winter litter C was greater at market age. Winter and summer did not appear different at mid-flock. For litter total C, areas across the house were more distinct in differences than those for total litter N. Upon chick placement, at mid-flock and at market, CP and B>NB and F/W>F. The trend was the same lengthwise for each broiler age; litter total C content was greater in the center of houses (~27%) than near the walls or at the F/W (~24.6%).

Water soluble litter compound concentrations of PO_4, NH_4 and NO_3 at chick placement were greater in winter than summer. The same was true at mid-flock for PO_4 and NH_4, but NO_3 showed no seasonal influence. At market age, again PO_4 and NH_4 were greater in winter, but NO_3 was greater in summer.

DISCUSSION

At chick placement, mid-flock and market age, the report detailed expected results for litter physical and chemical characteristics as well as gas flux during winter vs summer, across the houses for zones selected as CP, B, NB, F and F/W and lengthwise down the houses near walls, in the center or at F/W. Extension websites recommend various methods for sampling broiler houses because it is known that litter properties vary with location. This study quantifies the expected variation between locations as well as season.

House temperatures are controlled for bird comfort and litter temperatures are a direct result. Although, it is well known that increases in temperature, moisture and pH increase emissions[14] of NH_3, controlling house temperature to decrease emissions, without negatively affecting bird growth, would be difficult. In addition, other research has shown that house ambient temperature and relative humidity were not significant influences on broiler emissions[15]. Litter moisture increased during growouts (with greater deposition from the birds) by at least 10% and was dependent on location. Controlling litter moisture may be difficult as well other than ensuring that waterers and cooling pads are operating properly. Chemical litter treatments (e.g., aluminum sulfate, sodium bisulfate and sulfuric acidified clay) decrease litter pH and reduce NH_3 losses from litter[16]. Efficacy and persistence of litter treatments are usually a function of the application rate, but generally the NH_3 abatement is limited to three weeks or less[17]. Historically, litter treatments have been applied just prior to chick placement. Zone litter treatments are likely the best option for managing litter NH_3 emissions within the flock.

With total clean out of litter for fertilizer use, growers could benefit from greater total N and lower litter moisture in performing a winter cleanout. More total N in litter would benefit crops, while lower litter moisture reduces transport costs. Although there were no seasonal differences in NH_3 flux at market age, N_2O flux was higher in winter with CO_2 flux higher in summer, indicating that mitigation of these gases will need separate strategies. However, at the end of flocks, extremely caked samples in the fan area limited all three gases and produced the least gas flux during that time. This suggests that the gases were physically sealed within the litter and the anaerobic conditions of the caked litter limited gas flux. This is an important finding for discussion with integrators and comparison to possible negative health effects on the birds when reared over caked litter. High litter moisture is undesirable because of increases in respiratory disease, virus survival, dermatitis and breast burns[18] in addition to increasing NH_3 emissions and removal costs. The best solution would be to develop a litter additive, one that does not rely on high moisture, to seal in the gases.

The value of these results lies in the user's goals. Other studies found in the literature had not sampled in a strategic manner, but this method lends itself to finding an actual average and to inclusion in an emission model. Further studies could breakout analyses according to management practices, such as brood vs non-brood at placement if further scrutiny was desired at chick placement. There is a need for a database to house the raw data from this and other animal studies and there are discussions among U.S. scientists to form such a resource.

CONCLUSION

The primary recommendation from this study involves zone litter treatment for NH_3 control during the flock. At chick placement and during mid-flock, the highest NH_3 losses were in the fan areas. Since no chicks are present in the fan area at placement, NH_3 control would likely not be cost effective at that time. However, mid-flock treatment of the fan area should be considered. The fan area is the smallest area studied and would take little material to cover it. By the end of the growout at market age, fan area samples were extremely caked and gas volatilization was lowest. The areas to treat near the end of the flock are in front of the cooling pads, in the brood and non-brood areas, more than 90% of the floor area. Because the NH_3 flux in these areas had tripled in magnitude since chick placement, the last 2-3 weeks of the flock should be the target for zone litter treatment, especially in the center of the houses.

SIGNIFICANCE STATEMENTS

- The broiler litter composition and gas flux data presented are ideal for inclusion in an emission model
- The primary recommendation is to control NH_3 gas flux during the final 2-3 weeks of a growout using zone litter treatments in the cooling pad, brood and non-brood areas of houses
- In addition to better growout conditions for the birds and farm workers, NH_3 control is environmentally beneficial, reducing the potential for aerosol formation in the atmosphere as well as nutrient enrichment of water and land

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