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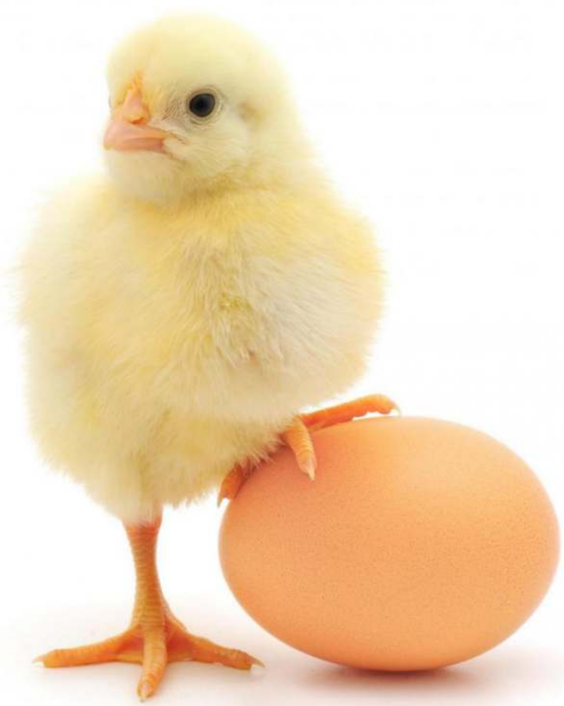

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Mid-Flock and Post-Harvest Spatial Characterization of Broiler Litter Gas Flux and Nutrients

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Abstract: The purpose of this work was to quantify the spatial variability of litter surface gas flux of NH_3, N_2O and CO_2 while making concurrent measurements of litter temperature and assessing litter moisture content, pH, total N and total C from laboratory analyses. Two U.S. commercial broiler houses were intensively sampled along a grid for litter properties and gas flux on a farm in Mississippi (humid subtropical climate) where the original bedding material was pine wood shavings. Before chicks were placed, the average gas flux from both houses was: 156 mg $NH_3/m^2/h$, 4.4 mg $N_2O/m^2/h$ and 6440 mg $CO_2/m^2/h$. At mid-flock and after birds were harvested, pooled values from 44 locations resulted in: 260 mg $NH_3/m^2/h$, 13.1 mg $N_2O/m^2/h$ and 13100 mg $CO_2/m^2/h$ and 351 mg $NH_3/m^2/h$, 15.1 mg $N_2O/m^2/h$ and 18400 mg $CO_2/m^2/h$, respectively. A greater degree of data variability resulted from measurements over time rather than between the houses. A good example is greater litter moisture near sidewalls during the post harvest measurement. All parameters were depicted as color contour plots; upper extremes for gas flux occurred between feeders and waterers. Tabular values cannot convey the complexity of litter surface characteristics and relationships. The efficacy of the data will be best derived by the user's goal for improving bird productivity and management.

Key words: Ammonia, broiler, emissions, litter

INTRODUCTION

As a consequence of rising agricultural commodity prices, the world re-entered a period of 'agflation' that Rabobank projected would bring record high food prices in late 2013; they expected the most severe ramifications to be felt by meat and dairy industries using feed intensive crops (Nunes, 2012). Beyond economical pressures, concentrated animal agriculture is challenged to reduce its ecological footprint (National Research Council, 2003). Relative to large scale animal production facilities, soil and water pollution have been researched since the 1960's in the United States (U.S.). However, a significant number of air quality research projects have only emerged in approximately the last 15 years. Mitigating emissions to increase bird productivity and reduce environmental concerns necessitate a better understanding of the complex interrelationships among house structure and management, bird growth cycle and litter characteristics.

Ammonia has long been recognized as an irritant gas in broiler houses and the associated problems are well known: respiratory and ocular diseases (Bullis *et al*., 1950; Valentine, 1964; Charles and Payne, 1966) which are usually accompanied by diminished body weight gain and inefficient feed conversion (Anderson *et al*., 1964; Charles and Payne, 1966; Reece *et al*., 1981; Miles *et al*., 2004). Outside broiler houses, NH_3 can compromise the environment by decreasing biodiversity on land, causing nutrient enrichment of water bodies and contributing to aerosol formation. In addition to NH_3, climate change encourages measurement of greenhouse gas (GHG) emissions from concentrated animal feeding operations (Greenhouse Gas Working Group, 2010). American agriculture contributes approximately 6.3% of all U.S. GHG emissions (U.S. Environmental Protection Agency, 2012). The primary GHG emissions from agriculture are CH_4 and N_2O with approximately 67.9% of N_2O originating from agricultural soil management. Although broiler litter has not been considered a significant source of N_2O, CH_4, or CO_2 (Wathes *et al*., 1997), emission estimates and models should be refined so that new management strategies do not present the solution to one problem while creating another.

During multiple broiler flocks, earlier intensive spatial studies revealed: the unique view of spatial flux and litter properties within commercial houses using color contour plots; that birds may insulate the litter to negate seasonal effects; emergence of samples between feeders and waterers as different from surrounding litter from the middle to end of the growout; that compacted litter (i.e. caked litter or cake) can create a seal to limit

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gas evolution from litter; tabular (average) values do not adequately represent litter surface characteristics and litter gas flux for NH_3, N_2O and CO_2 increases with bird age (Miles *et al*., 2006, 2008, 2011).

In contrast to those studies conducted with birds in the houses, the objective of this research was to assess selected litter compounds, chemical and physical properties prior to chick placement, during mid-growout and after birds were harvested. As the final in the series of rigorous spatial litter research, the report of litter NH_3, N_2O and CO_2 gas flux, total N and total C content, moisture content, pH and temperature can be used by industry and researchers to improve bird growth and litter management. The data set lends itself to inclusion in developing predictive models of litter emissions.

MATERIALS AND METHODS

Farm description and litter sampling: Two U.S. commercial broiler houses were intensively sampled for litter (combination of manure, bedding material, feathers, spilled feed and water) and gas flux on a farm in Mississippi (humid subtropical climate) where the original bedding material was pine wood shavings. The farm originally had 4 tunnel ventilated houses built in 2003; then 4 additional houses were built in 2005. The older houses are oriented lengthwise west to east (main entry to fan end) while the newer houses are in north to south direction on a separate part of the property. All houses had essentially the same construction details except that the newer houses were approximately 6.1 m longer. The older houses measure 12.8 m by 146.3 m and the new houses measure 12.8 m by 152.4 m. For the grid sampling imposed in the houses (Fig. 1), 3.05 m was excluded from each end of the newer houses. All houses feature solid sidewalls, insulated drop ceilings; box inlets (0.15 m by 1.52 m) near the ceiling, along each sidewall located approximately 6.1 m apart; infrared brooders (propane heaters) down the entire length of the center of the house; no space heaters; two automatic feeder lines down the length of the house; two automatic, nipple waterer lines located on either side of each feeder line; evaporative cooling pads on the sidewalls in the front or brood half of the house; two 0.91 m fans in the brood half (one in the end, one near the center in the sidewall) used for minimum ventilation; ten 1.2 m fans and one 0.91 m fan at the opposite end or non-brood half of the house; placement of approximately 28,000 broilers; migration fencing (lengthwise division of the house into quarters) and operate in all in/all out mode.

Litter reuse is common in U.S. broiler houses with decaking between flocks (Sistani *et al*., 2003). Decaking is the removal of the encrusted upper layer of litter (compacted litter or cake); the cake is removed mechanically by a machine pulled through the house behind a tractor. Cake has been characterized as 5-10 cm thick (Sistani *et al*., 2003) and friable litter is loose particles of dried feces and bedding (Miles *et al*., 2011). The extent to which cake is removed is determined by the farmer's assessment of litter quality, quantity of cake build up during a flock and occurrence of disease during the previous flock. Total clean out is determined by the integrator and by the availability of new bedding materials in the region. All houses in the current study were decaked prior to sampling. Sampling was conducted prior to chick placement (pre-flock), on day 23 of the flock (mid-flock) and after birds were sold (post harvest). One house was sampled from each set of houses. Sampling was performed in House 1 (H1), one of the older houses, before/during/after flock 30 and in House 2 (H2), one of the newer houses, before/during/ after flock 12. With the growout and layout periods approximately 42-45 and 14-21 days, respectively, this farm grows approximately 5.5 flocks annually.

A grid pattern was imposed across the litter surface that included sampling locations (n = 36) separated by 5 m across the house and 12 m down the length of the houses (Fig. 1). Eight additional samples were taken equidistance between feeders and waterers (FW) in a zigzag pattern lengthwise. For each location, litter from approximately the upper 5 cm was collected via hand trowel and placed in a plastic bag. All bags were sealed just after collection, chilled and transported back to the laboratory.

Litter physical and chemical properties: Litter surface temperature was measured using an infrared device (Raynger ST, Raytek Corp., Santa Cruz, CA, U.S.) just before gas flux was estimated at each location. Litter conditions were qualitatively noted as well, such as "extreme cake" or "friable litter". Qualitative descriptions of the litter conditions indicated very little cake in either house during the middle of the flocks. After birds were harvested, both houses again had similar litter conditions: the outer grid samples were mostly caked; the center had very loose, disturbed litter from the forklift used during harvest.

At the laboratory, litter samples were frozen until analysis for moisture content, pH, total N and total C. Thawed litter was oven dried (65 C for 48 h) to determine moisture content by loss in weight and pH was determined using a deionized H_2O-to-litter ratio of 5:1. Analysis of total N and total C was accomplished via combustion (Max CN analyzer, Elementar Americas, Inc., Mt. Laurel, NJ, U.S).

Litter gas flux: Gas flux of NH_3, N_2O and CO_2 was estimated using a static chamber method in conjunction with a photoacoustic multigas analyzer (Innova 1412; California Analytical, Orange, CA, U.S). The analyzer pumps in a gas sample, seals it in the analysis cell and sequentially rotates optical filters specific to each gas while infrared light passes through a chopper. The pulsing light produces a pressure change in the gas that is measured as an acoustic signal by dual microphones; the signal is proportional to the gas concentration in the analysis cell. The analyzer uses algorithms to compensate for cross interference of other gas species and it measures water vapor to account for possible interference with the configured gases (e.g., with NH_3). The initial gas concentrations (at time 0) were recorded as a vented, cylindrical chamber (35 cm height, 14.3 cm radius) was inverted over and screwed into the litter, as has been done in previous work (Miles *et al*., 2006, 2008, 2011). The concentration difference (after approximately 70s when the analyzer draws in a second sample) is used to estimate gas flux using the ideal gas law, deployment time and the area covered by the chamber.

Gas flux in the entirety of H1 and H2 was estimated for mid-flock and post harvest measurement dates. A limited time frame for the farmer to get the houses ready for bird placement precluded the entire grid sampling at the pre-flock measurement. Only the length of the houses in the center of the grid was sampled for gas flux at the pre-flock date. Those flux estimates are presented in Table 1 as pooled values.

Data analyses: Color contour plots (variograms) were produced using geostatistical software (Golden Surfer 8.0; Golden, CO) for the litter total N, total C, temperature, moisture content and pH at pre-flock, mid-flock and post harvest (Fig. 2) and for NH_3, N_2O and CO_2 at mid-flock and post harvest (Fig. 3). The variograms were used to illustrate spatial variability among the parameters. The software uses weighted linear combinations of sample values while minimizing error variance between locations, a statistical method known as kriging, to produce a surface representation of the entire area of the house floor. Traditional statistics were not assessed for the litter properties, compounds and gas flux because the grid sampling regime imposes bias (samples are not random). Pooled values for all parameters and measurement dates are given in Table 1. Circles were added to the spatial plots (Fig. 2 and 3) to depict the FW litter parameters that appeared different (higher or lower in magnitude) than surrounding samples.

RESULTS

Litter total N (Fig. 2) primarily ranged from 20 to 34 mg/g in H1 at the pre-flock date, except for a segment near the brood half left sidewall and a small center region in the non-brood half (both approximately 40 mg/g). In H2, the range of total N was similar, but more of the litter was <26 mg/g. At mid-flock the H1 brood sidewall area remained elevated and another area in front of the fans in the non-brood half was evident (both approximately 40 mg total N/g). In H2, at mid-flock, the center of the house

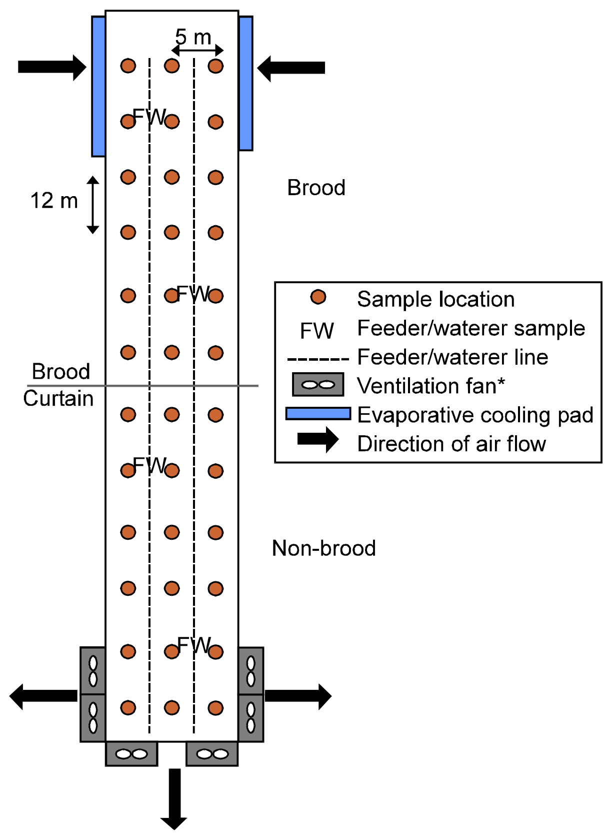

Fig. 1: Plan view of commercial broiler house measurement sites for litter gaseous surface flux, concurrent temperature and litter sampling to determine moisture content, pH, total N and total C. *Non-brood end contains 11 fans; 10 have 1.2 m diameter and one has 0.91 m diameter

was near 40 mg total N/g in an area between the evaporative cooling pads. At the post harvest sampling, total N in H1 again ranged from 20 to 34 mg/g over most of the floor area with two elevated (40 mg/g) regions in front of the evaporative cooling pads and one sidewall area in the middle of the non-brood half of the house. In contrast, most of the H2 litter total N was around 40 mg/g with two areas near the evaporative cooling pads showing the highest total N at 52 to 62 mg/g. Regarding the FW samples, 5 of 8 at pre-placement had higher total N than nearby samples. At mid-flock, the two FW samples in near the cooling pads (one in each house), had lower total N; at this time one FW location near the fan end had greater total N in H2. After harvesting, only two FW locations were different, both had higher total N and were in H1.

Litter total C (Fig. 2) was approximately 190 to 270 mg/g in over most of the floor area in both houses at the pre-flock and mid-flock measurements. Elevated regions of litter total C in the brood half of the houses exhibited

Table 1: Pooled litter values (n = 44 locations) measured in U.S. commercial broiler houses during summer conditions

	House 1[1]			House 2[1]		
	Time relative to bird age					
	Pre-flock	Mid-flock	Post harvest	Pre-flock	Mid-flock	Post harvest
Litter components (mg/g)						
Total N	30.5±3.2	30.6±3.0	30.7±3.9	25.8±3.4	28.3±3.5	40.9±5.8
Total C	266±22	270±19	360±12	258±25	271±27	376±21
Air temperature (°C)	26.6±0.8	29.9±0.7	21.9±0.8	29.6±0.9	28.2±0.6	21.0±0.3
Litter properties						
Temperature (°C)	27.7±0.5	30.4±1.6	23.5±1.1	29.5±0.4	29.6±1.5	23.6±0.9
Moisture (%)	18.9±1.8	26.1±3.7	37.1±8.3	18.3±1.8	24.4±4.3	36.2±9.9
pH	8.3±0.2	8.0±0.2	8.5±0.3	8.3±0.2	8.1±0.3	8.3±0.7
Gas flux (mg/m^2/h)						
NH_3	195±74[2]	293±240	359±353	117±51[2]	226±177	343±171
N_2O	5.7±4.9[2]	17.2±13.0	21.5±18.0	3.0±2.2[2]	8.9±7.0	8.7±6.2
CO_2	6110±970[2]	14900±6930	22300±14200	6760±2020[2]	11300±5930	14500±7230

[1]Originally pine wood shavings bedding material was reused for 30 flocks in house 1 and 12 flocks in house 2

[2]Gas flux estimates at the pre-flock date were derived only from 12 locations down the center of each house

approximately 330 mg/g; this level persisted down the center of H2 in the non-brood half and was evident in front of the right sidewall fans. At post-harvest, total C was greater than the two previous measurement dates, ranging from 330 to 370 mg/g in H1 and 330 to 460 mg/g in H2. The highest measured litter total C (430-460 mg/g) was in front of the right sidewall fans in H2. During the three measurement dates, seven FW locations appeared different and only one of those (near the cooling pad at mid-flock) appeared lower than surrounding total C.

Pre-flock litter temperatures in H1 ranged from 25.9-28.6 C with little noted spatial variability; in H2, these temperatures ranged from 28.6-30.8 C (Fig. 2) and were spatially irregular. Outside temperatures likely explain the higher temperatures in H2 since this house was sampled later in the morning. Outside temperatures during the corresponding measurements were 23-26 C for H1 and 28-30 C for H2. At mid-growout litter temperatures appeared greater than either the pre-flock or post-harvest measurements, with the highest measured values near 34 C in throughout most of H1 from left sidewall across the center, but near the sidewalls in H2, ranging from approximately 30 to 33.5 C. Post harvest litter temperature was much cooler than the mid-flock assessment ranging from 21 to 25 C in both houses with little spatial variability.

Litter moisture content increased with the progression of measurement dates. At pre-flock, no trends based on location were noted and litter moisture was approximately 15 to 21% in both houses. These low litter moisture levels persisted down the center of both houses at mid-flock, but more so in H2. Litter moisture increased at several sidewall regions, ranging from 23 to 27%. Also, at mid-flock the moisture increased further in H2 in front of the evaporative cooling pads and in H1 near the right sidewall at the house center as well as in front of the fans in the non-brood half of the house (approximately 35%). At the post harvest measurement, litter moisture down the center of H2 and in the brood center of H1 remained low (23 to 25%). Greater portions of both houses had litter moisture from 29 to 39%, with the highest litter moisture content near sidewalls (43 to 55%). Moisture content at FW locations appeared different than nearby samples in a mere four measurements, half of which were greater.

Litter pH overall appeared lowest during mid-flock (7.2 to 8.4), with higher values near the sidewalls in both houses. Before the flocks, litter pH ranged approximately 7.4 to 8.6, again with higher values near house sidewalls. One exception was noted in H2, in front of the right evaporative cooling pads at 6.6. Most of the litter pH increased in both houses at post-harvest to approximately 8.4. However, opposing values appeared in H1 in front of the evaporative cooling pads where the left side had low pH (6.8) compared to the highest measured pH on the right side (9.6). In H2, the lowest pH was evident in front of the evaporative cooling pads (6.0 to 7.4). Differences in pH at FW appeared mainly during the post harvest measurement and all were greater than surrounding litter pH.

Pooled values for all parameters appear in Table 1 as averages with the standard deviation of measurements from 44 locations for each measurement date. Because the full grid measurements were not possible prior to bird placement for gas flux, the pre-flock gas flux estimates for the center of the houses (12 locations) are reported as collective values without the corresponding variograms. Generally, gas flux and its variability appeared to increase with the progressive dates. These parameters offer a prime example to show how pooled measurements do not convey the dynamic nature of the litter surface gas flux like the data presented in the contour plots. Similarly, the other litter properties and parameters are not adequately described by average values; the contour plots indicate localized areas of extremes that would otherwise be masked.

Mid-flock and post harvest gas flux estimates indicated low flux values over most of the litter surface in both houses. All gas fluxes tended to be lower down the

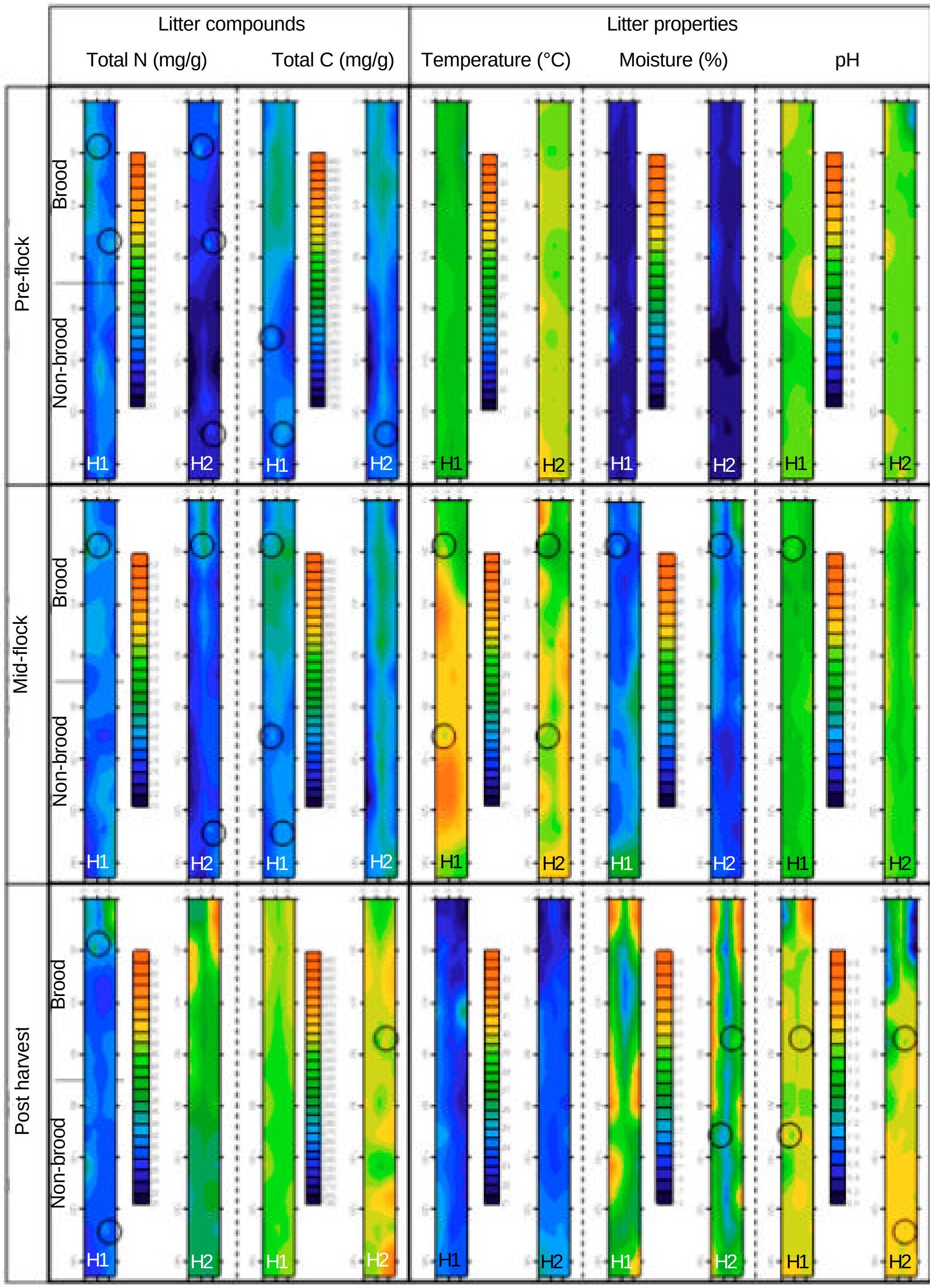

Fig. 2: Variograms of litter total N and C, surface temperature, moisture content and pH in two U.S. commercial broiler houses after reusing litter for 30 flocks (H1) and 12 flocks (H2) during summer. Circles denote extreme values measured between feeders and waterers

center of the houses during the mid-flock measurement: 0-200 mg $NH_3/m^2/h$, 0-8 mg $N_2O/m^2/h$ and 0-10000 mg $CO_2/m^2/h$. During mid-flock NH_3 was elevated near portions of the sidewalls in both houses (500-800 $mg/m^2/h$) and was distinguished (as higher than surrounding samples) at 7 of 8 FW locations (denoted

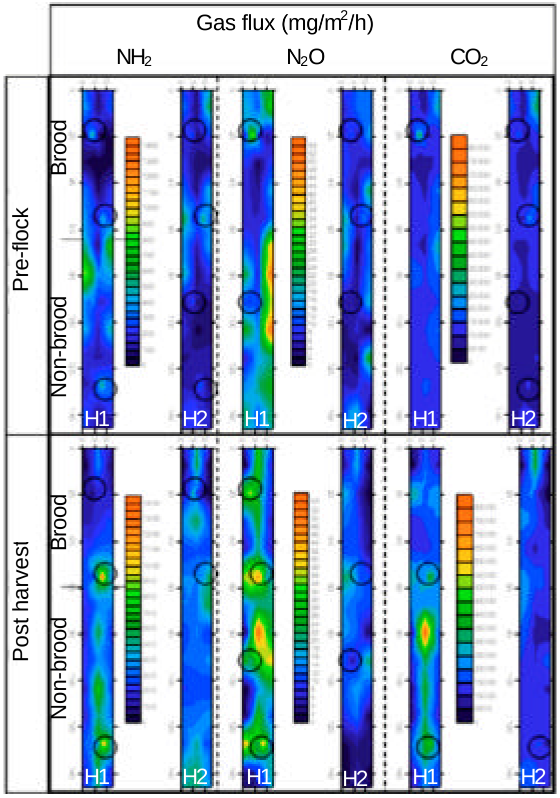

Fig. 3: Variograms of litter NH_3, N_2O and CO_2 gas flux estimated in two U.S. commercial broiler houses after reusing litter for 30 flocks (H1) and 12 flocks (H2) during summer. Circles denote extreme values measured between feeders and waterers

by circles on Fig. 3). At the post harvest measurement date, NH_3 flux increased down the center of H1 primarily in the non-brood end of the house. The greatest flux (1000-1400 mg $NH_3/m^2/h$) was measured at the two FW locations near the right sidewall in H1. In H2, elevated NH_3 flux was apparent in the center of the brood half of the house, one sidewall area approximately mid-house and in the region near the tunnel fans. Nitrous oxide flux tended to be greater in the non-brood half of H1 during mid-flock with the highest levels near the right sidewall (approximately 54 mg $N_2O/m^2/h$). At post harvest, more of the entire litter area indicated an increase in N_2O flux, with the most elevated estimates appearing in the center of the house and at FW locations. The magnitude of N_2O flux in H2 was much lower than H1 and did not differ appreciably between the measurement dates. Carbon dioxide litter flux was similar in both houses at mid-flock and did not differ greatly from that time in H2. However, in H1, at the post harvest measurement, CO_2 flux down the center of the house in the non-brood half increased and registered the highest flux of the experiment (80000 mg CO_2 m^2/h).

DISCUSSION

Concentration of litter total N in both houses was similar to previously reported values in a summer growout of approximately 20-30 mg/g (Miles *et al.*, 2011), with one exception. At the post harvest measurement, H2 total N was greater, averaging 40.9 mg/g. The increase in this house does not correspond to any known differences in management between the two houses. However, the lack of strong spatial trends among the measurement dates corresponds well to the previous summer flock measurements. Litter total N appeared to change little from day 1 to 43 (Miles *et al.*, 2011), as in the current study from pre-flock to post harvest. The tabular values also support these observations.

Litter total C appeared similar at the pre-flock and mid-flock measurements in both houses, but was elevated during post harvest. The trend for elevated C down the center of H2 is novel compared to no discernible spatial trend in the previous work (Miles *et al.*, 2011). Also a new trend, total C appeared to increase with time in the current study, which is unexpected. Without addition of new bedding and with increased fecal deposition later in the flock, litter total C would not be expected to increase. A plausible explanation for the greater total C at the post harvest measurement is that, during the broiler harvest, the forklift (used to carry crated birds) mixed more bedding into the upper layers of litter that were sampled. For in-house composting, a between flock management practice, the ratio of C to N is important. Calculating C:N ratio from Table 1, those values ranged from 8.7:1 to 11.7:1. This compares to the overall C:N ratio of 11:1 for earlier winter and summer flocks combined (Miles *et al.*, 2011) and 15:1 for broiler litter containing 4.7% N at 25% moisture content (Manure Composting Manual, 2005). The U. S. Environmental Protection Agency recommends 30:1 as an ideal ratio for composting.

Unlike previous spatial measurements (Miles *et al.*, 2008, 2011) performed just after chick placement (when brooder heaters were operating), the pre-flock measurements do not show elevated litter temperature in the brood half of the houses, as would be expected. The highest measured litter temperatures occurred at mid-flock. It would be reasonable to assume that the birds insulated the litter during this measurement period and that the irregularity of most intense heat resulted from bird migration during researcher intrusion. The assumption is supported by end of flock temperatures in the previous works (Miles *et al.*, 2008, 2011) where winter and summer litter temperatures exceeded the post harvest temperatures reported here.

Litter moisture content increased over time with the highest litter moisture adjacent to the evaporative cooling pads. Pad operation during the summer growouts would expectedly contribute to increased litter moisture content in this area.

Litter pH was lower at mid-flock than either pre-flock or post harvest measurements. Extremes in pH values were evident during the post harvest measurement. Very high moisture content has been associated with lower pH in previous studies (Miles *et al*., 2008, 2011), making the extremely high pH near the right cooling pad in H1 during the post harvest measurement an unexplained anomaly.

Gas flux of NH_3, N_2O and CO_2 from broiler litter tended to increase over time, a trend that agrees earlier research during the growout (Miles *et al*., 2008, 2011). When differentiated from the surrounding litter flux, gas flux of all species was generally greater at FW locations. This is opposite to earlier observations where FW litter was heavily caked and gas flux was low. It is likely that the disturbed litter surface at the post harvest measurement caused the trend toward higher litter flux at FW, whereas in previous end of flock measurements, caked surfaces created a seal limiting gas flux.

Spatial variability of litter total N, total C, temperature, moisture content, pH, gas fluxes of NH_3, N_2O and CO_2 in two U.S. commercial broiler houses was represented in color contour plots. The plots demonstrate that tabular, average values do not adequately characterize the surface distribution of litter properties and gas flux. Overall trends were more influenced by the measurement time rather than variability between the houses. Localized upper extremes of most parameters appeared near sidewalls and were predominantly associated with proximity to the evaporative cooling pads. Emissions between feeders and waterers largely depend on the degree of litter compaction. User defined interests will drive the value to be gained from the spatial research of litter compounds, properties and gas flux. Ultimately, the data should be used to better bird productivity, improve management strategies and reduce broiler house emissions.

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