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308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

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Research Article
Mineral Composition of Litter in Commercial Broiler Houses

[1]Dana M. Miles, [1]John P. Brooks and [2]Philip A. Moore, Jr.

[1]USDA-ARS, Genetics and Sustainable Agriculture Research Unit, 810 Hwy 12 East, Mississippi State, 39762 MS, United States of America
[2]USDA-ARS, Poultry Production and Product Safety Research Unit, Fayetteville, 72701 AR, United States of America

Abstract
Objective: The overall aim was to assess mineral content of broiler litter originating from U.S. commercial broiler houses and to determine how mineral content varies with season, as well as location within houses. **Materials and Methods:** Over a period of 4 years, approximately 1100 litter samples were collected in a grid pattern within four U.S. commercial broiler houses. The sources of variation, on which analysis of variance was based, included season (winter vs. summer), bird age (placement, mid-flock, market) and location within the house (across, lengthwise). **Results:** The range of concentrations for the primary minerals was (g kg^{-1}): Ca 23.7$\pm$8.6, K 35.4$\pm$9.1, Mg 8.1$\pm$2.4, Na 10.9$\pm$3.3 and P 16.6$\pm$4.6. The secondary minerals were in the range of (mg kg^{-1}): Cu 730$\pm$360, Fe 1120$\pm$560, Mn 730$\pm$216 and Zn 550$\pm$150. Summer mineral content was greater at all sampling ages. At market age, mineral concentrations were greater in the cooling pad and brood areas but least near the fans. Litter minerals were greater near walls when compared to the center of houses. **Conclusion:** Half-house brooding explained the greater concentrations in the cooling pad and brood areas. Heavy cake in the fan area had distinct properties compared to litter elsewhere in the houses. Trends in mineral composition of broiler litter complemented known management practices related to brooding (half-house) and phase feeding (reduction in levels during growth period).

Key words: Broiler, litter, mineral contents, bird age, phase feeding

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Corresponding Author: Dana M. Miles, USDA-ARS, Genetics and Sustainable Agriculture Research Unit, 810 Hwy 12 East, Mississippi State, MS 39762, United States of America Tel: 662-320-7481 Fax: 662-320-7569

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 litter in the U.S. has historically been applied as fertilizer for pastures and for row crops. For this reason, much of the literature addressing the composition of litter reports N, P and K, without further analysis of minerals like Ca, Mg, Na, Cu, Fe, Mn and Zn. These minerals may be of importance to specialty crop production as more niche and organic farming operations emerge. Litter for fertilizer must be used properly. Locally, inappropriate litter management can lead to malodors and fly breeding habitat, whereas, regionally, the problems are nutrient loading of water and soil resources[1,2].

To prevent nutrient runoff, states regulate the application of litter as fertilizer since large broiler farm operations produce a significant amount of litter. For example, Georgia is the top broiler producing state with approximately 1.3 billon broilers grown per year. An estimate of litter production for the state of Georgia is 1.47 million metric t/year[3]. With this ample supply, litter-to-energy technologies are attractive and are being developed. Singh *et al.*[4] reviewed anaerobic digestion of litter and briefly discussed combustion, gasification, pyrolysis and cofiring. Whether for fertilizer or energy applications, end users need an accurate estimation of litter constituents to economically utilize the litter.

Litter mineral composition results directly from the bird diet, while optimizing broiler health and production is the primary aim of broiler nutritionists. Dietary energy, protein and amino acids are varied for meeting particular production criteria (i.e., growth rate, body composition)[5], but birds will regulate their intake to meet energy and protein needs. Thus, bird nutrition is very complex to meet their needs while combating environmental stressors. In the simple terms, the minerals Ca and P are essential for good bone formation and other minerals, such as Na, Cu, Fe, Mn and Zn, are added within a range of concentrations to prevent deficiencies or toxicities[5].

The purpose of the current study was to determine the mineral composition of broiler litter in U.S. commercial houses where the houses were subjected to intensive spatial sampling. Data for approximately 1100 litter samples were analyzed to understand seasonal influences and variation within houses on litter minerals. This study follows five previously published studies[6-10], four[6-8,10] of which used geostatistical contour plots to depict the spatial trends and variability of gaseous flux from litter (NH_3, N_2O and CO_2), litter temperature, moisture, pH, total N, total C and water soluble PO_4, NH_4 and NO_3. The final study[9] was the companion paper to the current report, Miles *et al.*[9] combined the four previous studies[6-8,10] to produce an overall assessment of seasonal and location within house influences on the above listed parameters. In addition to complementing the earlier data presentation[9], this is the first report of litter mineral variability for this large number of samples. The current study was successful in reporting the influence of season and in-house location on the mineral composition of broiler litter.

MATERIALS AND METHODS

Broiler facilities and litter sampling: Approximately 1100 litter samples were collected over a 4 years period within four U.S. commercial broiler houses. All houses were tunnel ventilated with automatic waterer and feeder lines down the length of each house. Two feeder lines with a waterer line on each side occupied each house. House dimensions were 12.8 m by 146.3 m for three houses and 12.8 m by 152.4 m for one house. To maintain the grid dimensions, 3.05 =m was omitted from each end of the longer house. A grid arrangement was used with 44 locations/house. Figure 1 shows 36 grid locations located 5 m apart (across the houses) and 12 m apart (down the length of the houses). Half way between the feeders and waterers, eight feeder/waterer (F/W) samples were collected at four locations through the length of the house. The F/W locations are indicated with an "X" on Fig. 1.

Litter was sampled three times during each flock, at chick placement, mid-flock (21 days) and market age (43-45 days). Litter samples were collected using a hand trowel removing the top 5 cm of litter and placing it in a plastic bag. Bags were sealed and then chilled for transport to the laboratory. At the lab, samples were frozen until analyses could be performed. The initial bedding material was pine shavings. There were two winter flock measurements, litter had been recycled through flocks 8 and 15 for the winter studies. There were four summer flock measurements where litter had been reused for 12, 17, 29 and 30 flocks.

Litter characterization: The litter minerals investigated were Ca, K, Mg, Na, P, Cu, Fe, Mn and Zn. For each sampling location and time during the studies, 1 g fine-ground sample of broiler litter was dry ashed in a ceramic crucible at 500°C for 4 h. This was followed by dissolution of the ash for 1 h in 1.0 mL of 6 M HCl. A second dissolution followed in 40 mL of a double acid solution (0.125 M H_2SO_4 and 0.05 M HCl), lasting another hour. The crucible contents were then filtered through Whatman No. 2 paper[11]. Inductively coupled plasma (ICP) was used to analyze the filtrate for mineral content.

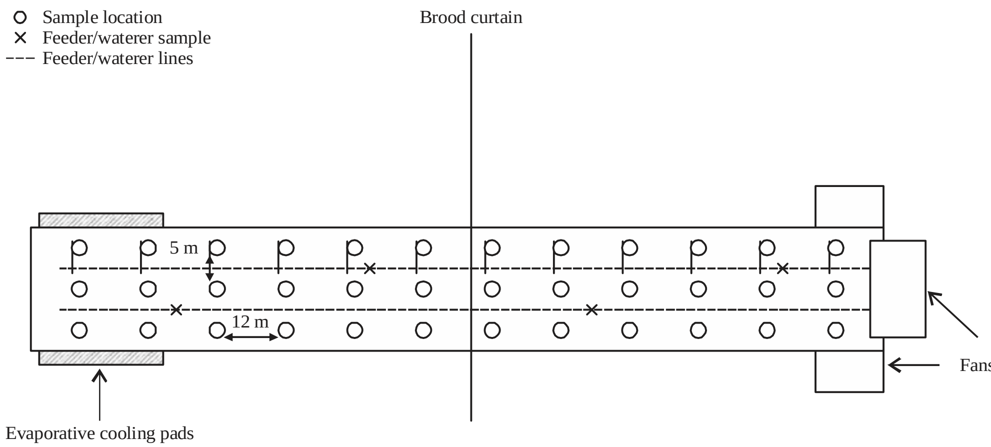

Fig. 1: Grid sampling plan of commercial broiler houses for litter sampling
Adapted from Miles *et al.*[9]

Statistical analyses: The procedures of SAS[12] (PROC GLM) were used to perform analysis of variance among the measurements. The sources of variation were bird age, season and in-house location. Because of interaction among the sources (bird age $\times$ season $\times$ location), a second analysis was performed at each bird age. For some parameters, the remaining interaction of season $\times$ location was still significant ($\alpha = 0.05$).

RESULTS

Results for litter mineral composition at each bird age (chick placement, mid-flock and market age) are presented in Tables 1-3. Seasonal variation is given in Table 1. Locations across the houses (designated as cooling pad (CP), brood (B), non-brood (NB), fan (F) and feeder/waterer (F/W) are shown in Fig. 2 and results are in Table 2. Figure 3 depicts the lengthwise sample locations (walls, center and F/W) and Table 3 provides the results of mineral content.

The range of concentrations for the primary minerals was (g kg^{-1}): Ca = 23.7$\pm$8.6, K = 35.4$\pm$9.1, Mg = 8.1$\pm$2.4, Na = 10.9$\pm$3.3 and P = 16.6$\pm$4.6. Overall, the secondary minerals averaged (mg kg^{-1}): Cu = 730$\pm$360, Fe = 1120$\pm$560, Mn = 730$\pm$216 and Zn = 550$\pm$150.

Winter vs. summer variation: The results for the seasonal influences on the mineral composition of broiler litter are shown in Table 1. For all but two elements, summer values exceeded winter values at all bird ages. One exception was for Fe at placement and mid-flock, at both these times Fe was greater in winter, rather than summer. The other exception was for Cu at market age, where winter concentration in litter was 685 mg kg^{-1} vs. the summer concentration of 616 mg kg^{-1}.

Variation across broiler houses: The results for litter mineral composition at locations across the houses (Table 2) were not as straightforward as the seasonal influences were. At chick placement, the brood area had the greatest concentrations of Ca, K, Na, Cu, Mn and Zn, but least for Fe. The greater concentrations in that area would be consistent with the half-house brooding practice. Magnesium and P showed no differences across the houses at chick placement. During mid-flock, both CP and B generally had the highest mineral content for Ca, K, Na, Cu, Mn and Zn and again the least amount of Fe. Similar to the placement date, Mg and P showed no differences across the houses at mid-flock.

By market age, the results are more varied such that almost each mineral had distinct results for the zones across the houses. Calcium had the greatest concentration (25.1 g kg^{-1}) in the CP area, followed by B, then NB and F/W and finally, the F area exhibited the least Ca at 16 g kg^{-1}. At this time, there was no statistical difference for K concentration across the house, which ranged from 33.8-35.3 g kg^{-1}. Magnesium was greatest in the NB area, least in the F area, but the CP, B and F/W samples did not appear different than the NB or F locations. Sodium was more distinctly separated by zone in that the greatest concentrations were in the CP and B, followed by NB and F/W, with the least concentration in the F area. Phosphorus was greatest in the NB and least at the F/W and F, but the CP and B did not appear different than any of these areas. Copper was similar to Na (i.e., greatest at CP and B, followed by NB and least at F) except that the F/W samples also had the greatest Cu concentrations. Iron was an anomaly similar to the earlier measurements during the flock. The least concentrations of Fe were at CP, B and F, with the greatest level at the F/W locations. Mid-range Fe concentrations existed in the NB area.

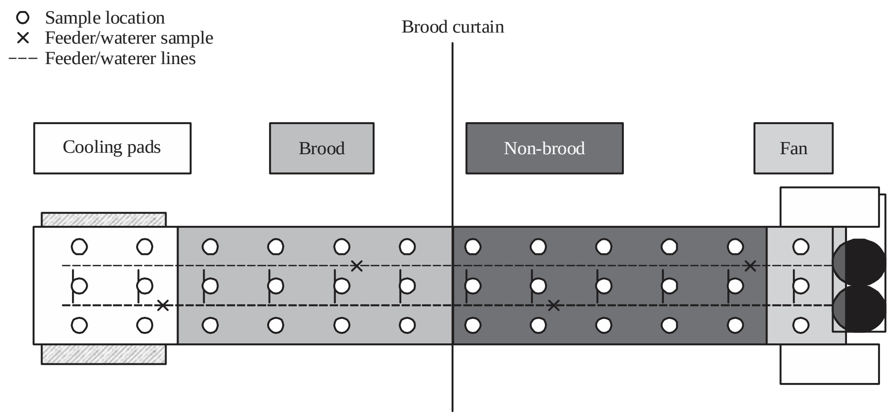

Fig. 2: Sampling zones across commercial broiler houses: Cooling pad, brood, non-brood, fan and feeder/waterer
Adapted from Miles *et al.*[9]

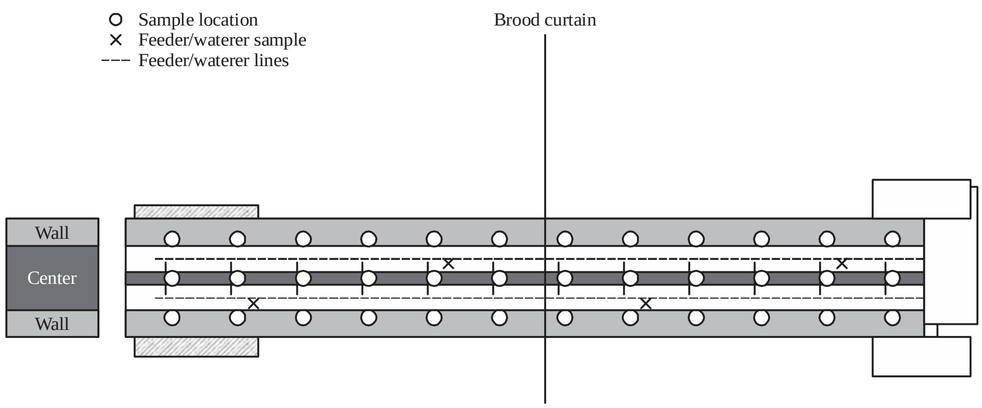

Fig. 3: Lengthwise sampling zones in commercial broiler houses
Adapted from Miles *et al.*[9]

Table 1: Seasonal mineral composition of broiler litter in US commercial broiler houses

	Broiler age								
	Placement			Mid-flock			Market		
	Season			Season			Season		
	Winter	Summer	LSD	Winter	Summer	LSD	Winter	Summer	LSD
Litter properties									
Ca ($g\ kg^{-1}$)	20.5[b]	30.7[a]	2.36	20.2[b]	30.1[a]	1.45	19.20[b]	25.60[a]	0.81
K ($g\ kg^{-1}$)	31.7[b]	42.1[a]	3.04	33.3[b]	38.6[a]	1.16	33.30[b]	37.70[a]	1.12
Mg ($g\ kg^{-1}$)	7.0[b]	10.5[a]	0.67	7.5[b]	9.3[a]	0.41	7.00[b]	8.20[a]	0.23
Na ($g\ kg^{-1}$)	9.7[b]	13.3[a]	0.99	10.0[b]	12.6[a]	0.56	9.50[b]	12.20[a]	0.38
P ($g\ kg^{-1}$)	15.0[b]	20.8[a]	1.38	15.2[b]	19.0[a]	0.80	14.70[b]	16.90[a]	0.42
Cu ($mg\ kg^{-1}$)	690.0[b]	946.0[a]	95.00	753.0[b]	939.0[a]	78.00	685.00[a]	616.00[b]	45.00
Fe ($mg\ kg^{-1}$)	1273.0[a]	1153.0[b]	114.00	1359.0[a]	1058.0[b]	146.00	920.00[b]	1196.00[a]	80.00
Mn ($mg\ kg^{-1}$)	638.0[b]	919.0[a]	59.00	681.0[b]	909.0[a]	31.00	597.00[b]	800.00[a]	25.00
Zn ($mg\ kg^{-1}$)	478.0[b]	680.0[a]	43.00	520.0[b]	674.0[a]	23.00	455.00[b]	593.00[a]	17.00

The final two minerals, Mn and Zn, shared the same relative ranks among the zones: Greatest concentrations were in CP, B, NB and at F/W with the least concentration at F.

Variation lengthwise within broiler houses: When comparing the primary mineral concentrations near the walls, in the center of houses or at the F/W locations (Table 3), the

Table 2: Mineral composition of broiler litter for zones across the width of U.S. commercial broiler houses

	Broiler age																	
	Placement						Mid-flock						Market					
	Location inside house (across)						Location inside house (across)						Location inside house (across)					
	CP	B	NB	F	F/W	LSD	CP	B	NB	F	F/W	LSD	CP	B	NB	F	F/W	LSD
Litter minerals																		
Ca (g kg^{-1})	26.6^{ab}	27.5^{a}	23.9^{abc}	21.0^{c}	22.6^{bc}	4.39	26.2^{a}	26.1^{ab}	23.6^{abc}	21.0^{c}	23.4^{bc}	2.70	25.1^{a}	22.9^{b}	19.7c	16.00^{d}	21.1^{c}	1.41
K (g kg^{-1})	36.2^{ab}	38.3^{a}	36.6^{ab}	34.1^{ab}	31.1^{b}	5.66	35.3^{ab}	36.5^{a}	35.6^{ab}	33.5^{b}	35.0^{ab}	2.17	33.8	34.6	35.3	34.60	34.8	1.95
Mg (g kg^{-1})	8.3	9.0	8.7	7.9	7.8	1.26	8.2	8.4	8.4	8.1	7.8	0.76	7.3^{ab}	7.4^{ab}	7.6^{a}	7.01^{b}	7.2^{ab}	0.41
Na (g kg^{-1})	12.0^{ab}	12.8^{a}	10.4^{cb}	9.6^{c}	10.1^{c}	1.83	12.0^{ab}	12.4^{a}	10.2^{c}	9.4^{c}	11.3^{b}	1.04	11.2^{a}	11.1^{a}	9.8^{b}	9.20^{c}	10.3^{b}	0.65
P (g kg^{-1})	17.0	18.1	17.9	16.2	16.2	2.57	16.5	16.9	17.3	16.5	16.0	1.48	15.3^{ab}	15.3^{ab}	15.9^{a}	14.80^{b}	15.0^{b}	0.74
Cu (mg kg^{-1})	851.0^{ab}	901.0^{a}	781.0^{abc}	674.0^{bc}	628.0^{c}	177.00	881.0^{a}	923.0^{a}	806.0^{ab}	702.0^{b}	718.0^{b}	146.00	737.0^{a}	715.0^{a}	607.0^{b}	491.00^{c}	693.0^{a}	79.00
Fe (mg kg^{-1})	1006.0^{c}	913.0^{c}	1337.0^{b}	1734.0^{a}	1590.0^{a}	212.00	995.0^{c}	908.0^{c}	1402.0^{b}	1879.0^{a}	1371.0^{b}	272.00	933.0^{c}	850.0^{c}	1118.0^{b}	1391.00^{a}	974.0^{c}	140.00
Mn (mg kg^{-1})	772.0^{ab}	811.0^{a}	743.0^{ab}	669.0^{b}	730.0^{ab}	110.00	804.0^{a}	799.0^{a}	763.0^{ab}	714.0^{b}	802.0^{a}	58.00	678.0^{a}	673.0^{a}	654.0^{a}	600.00^{b}	686.0^{a}	43.00
Zn (mg kg^{-1})	570.0^{ab}	603.0^{a}	558.0^{ab}	508.0^{b}	530.0^{ab}	80.00	599.0^{a}	601.0^{a}	578.0^{ab}	549.0^{b}	589.0^{ab}	43.00	508.0^{a}	506.0^{a}	497.0^{a}	456.00^{b}	513.0^{a}	29.00

CP: Cooling pad, B: Brood, NB: Non-brood, F: Fan, F/W: Feeder/waterer

overall trend showed that wall concentrations were greatest and center levels were least, with F/W samples usually also least. There were a few exceptions. First, for Ca and Na, the F/W location did not appear different than either the wall or the center at market age nor did it at mid-flock for K. Second, at market age, K was greatest at F/W along with the wall locations. Third and the final exception, Na did not appear different down the length of the house during mid-flock.

Trends for the secondary minerals for the length of the houses were usually greatest near the walls and least in the center at placement. At mid-flock, wall concentrations were greatest, but F/W levels were also greatest for Fe, Mn and Zn. By market age, Cu appeared greatest at the F/W and least in the center. The Cu wall concentrations did not appear different than either the F/W or center locations. The concentration of Fe did not appear different at any location for the market age samples. The final samples for Mn and Zn were similar down the length of the houses, as they were across the houses. The greatest concentrations were near the walls and at the F/W and concentrations were least in the center of houses.

DISCUSSION

The study presents the mineral concentrations found in built up broiler litter in U.S. commercial broiler houses at chick placement, mid-flock and market age. The values were determined for winter vs. summer, for locations across the houses (CP, B, NB, F and F/W) and down the houses lengthwise (walls, center and F/W). Thus, the disparity of the mineral composition of broiler litter was quantified in this research with respect to season and in-house location.

Broiler diets are formulated to meet bird requirements. Phase feeding provides different formulations for broiler growth stages: Starter, grower and finisher. As expected, mineral composition of broiler litter decreased as bird age increased. Providing optimal broiler nutrition is a highly technical science in balancing bird needs, ingredients, interaction of various factors and, importantly, the ultimate cost of the feed. One study noted that Ca requirements for grower feed could be reduced to optimize body weight gain, feed conversion ratio and tibia ash[13].

It is also expected that summer mineral content of litter is greater than winter. Birds are more likely to experience heat stress in summer. Studies show that broilers excrete increased amounts of K, P, S, Mg, Cu, Mo and Zn when experiencing heat stress[14]. Additionally, the problems of increased litter moisture and ammonia in winter flocks, while trying to conserve heated air, require dietary modifications. In winter, routine reductions in dietary minerals reduces water intake and produces less fecal and litter moisture.

Table 3: Lengthwise mineral composition of broiler litter in US commercial broiler houses

	Broiler age											
	Placement				Mid-flock				Market			
	Location inside house (lengthwise)				Location inside house (lengthwise)				Location inside house (lengthwise)			
	Wall	Center	F/W	LSD	Wall	Center	F/W	LSD	Wall	Center	F/W	LSD
Litter minerals												
Ca (g kg^{-1})	26.9^{a}	22.0^{b}	22.6^{b}	3.57	25.6^{a}	22.6^{b}	23.4^{b}	2.19	21.9^{a}	20.4^{b}	21.1^{ab}	1.03
K (g kg^{-1})	38.9^{a}	33.0^{b}	31.1^{b}	4.59	36.5^{a}	34.0^{b}	35.0^{ab}	1.76	35.5^{a}	33.3^{b}	34.8^{a}	1.43
Mg (g kg^{-1})	9.2^{a}	7.6^{b}	7.8^{b}	1.02	8.7^{a}	7.7^{b}	7.8^{b}	0.62	7.6^{a}	7.1^{b}	7.2^{b}	0.30
Na (g kg^{-1})	11.8^{a}	10.6^{ab}	10.1^{b}	1.49	11.4	10.7	11.3	0.85	10.6^{a}	10.0^{b}	10.3^{ab}	0.48
P (g kg^{-1})	18.8^{a}	15.5^{b}	16.2^{b}	2.09	17.6^{a}	15.6^{b}	16.0^{b}	1.20	15.9^{a}	14.8^{b}	15.0^{b}	0.54
Cu (mg kg^{-1})	878.0^{a}	716.0^{b}	628.0^{b}	144.00	888.0^{a}	771.0^{ab}	718.0^{b}	119.00	668.0^{ab}	629.0^{b}	693.0^{a}	58.00
Fe (mg kg^{-1})	1224.0^{b}	1074.0^{b}	1590.0^{a}	172.00	1241.0^{ab}	1146.0^{b}	1371.0^{a}	221.00	1044.0	974.0	974.0	102.00
Mn (mg kg^{-1})	812.0^{a}	670.0^{b}	730.0^{ab}	90.00	803.0^{a}	726.0^{b}	802.0^{a}	47.00	676.0^{a}	628.0^{b}	686.0^{a}	31.00
Zn (mg kg^{-1})	606.0^{a}	502.0^{b}	530.0^{b}	65.00	607.0^{a}	547.0^{b}	589.0^{a}	35.00	510.0^{a}	475.0^{b}	513.0^{a}	22.00

F/W: Feeder/waterer

For locations across the house at market age, generally greater mineral concentrations were found in the CP and B areas. Since half-house brooding was reported in the earlier studies[6-8,10], greater concentrations throughout the flock in those areas are expected. In addition, one consistent observation was that the least mineral concentrations were assessed in the F area. The F area phenomena deserve detailed analyses. The F area was a place of light infiltration into the houses, for congregation of the birds and for heavy cake[15] formation. In the previous study[9], least litter pH, greatest litter moisture, greatest litter N and least litter gas flux were observed for market age samples in the F area. From these observations it appears, heavy cake in the F area has distinct properties compared to litter elsewhere in the house.

This study offers a different type of conclusion than previous study. With gases emitted from litter, the objective is to reduce them, during and after the flock, to protect bird health, productivity and the environment. Controlling excess litter moisture through bird diet, as well as waterer and cooling pad maintenance is also desirable. With moisture control, ammonia emissions are less and paw quality is better. However, the diet is prescribed and the mineral content is a result of the broiler diet. Mitigation of mineral concentrations is not the goal (assuming that bird health has been good), but the aim is to present the data for comprehensive litter management.

As noted in the companion paper[9], the user's objectives determine the significance of the data. The strategic nature of the sampling offers a resource for contributing to a whole farm production model. Or, for the mineral contents presented here, the dataset offers actual averages and range of concentrations that are important to fertilizer users as well as litter-to-energy technologies. The data is of value to the poultry industry, providing inferences for improving house structure, feed and water delivery systems and looking at bird migration patterns during the flock. A public database to maintain this and other animal research is needed so that the individual interests of integrators/researchers can be studied and modeled for process improvements. Because litter properties vary spatially throughout broiler houses, extension personnel endorse various methods for sampling litter to get a "representative" sample. These methods should be compared to the dataset to find the best representative sampling locations for producers trying to estimate litter nutrient content.

CONCLUSION

Trends in mineral composition of broiler litter complemented known management practices related to brooding and phase feeding. This is the first report of litter mineral variability for this vast quantity of samples. The range of actual values of litter mineral content was presented for the poultry industry, fertilizer clients and litter-to-energy end users.

SIGNIFICANCE STATEMENT

- Season and location within commercial broiler houses affect concentrations of Ca, K, Mg, Na, P, Cu, Fe, Mn and Zn in broiler litter
- Mineral composition of poultry litter, besides reports for P and K, are scarcely found in the literature
- Range of actual values of litter mineral content was presented for the poultry industry, fertilizer clients and litter-to-energy end users

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