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Research Article
FGD Gypsum Litter Effects on Gaseous Losses from a Broiler House

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Abstract
Background and Objectives: Greenhouse gas (GHG) emissions are increasing at an unprecedented rate and are expected to double pre-industrial revolution levels within this century. The effects of broiler house management on these emissions are unknown. A study was conducted to examine the effect of FGD gypsum bedding on efflux of NH_3, CO_2, CH_4 and N_2O. **Materials and Methods:** FGD gypsum bedding was compared with pine shavings and pine shaving+FGD gypsum (50:50 mix) and each litter type was either decaked or rotovated after each flock. Flux measurements (CO_2, CH_4 and N_2O) and NH_3 concentrations were taken during flocks 4 and 5. **Results:** Litter treatment had little effect on GHG gas emissions during flocks 4 and 5 but NH_3 concentrations tended to be lower with FGD gypsum. Decaking tended to lower NH_3 concentration and GHG emissions due to removal of some of the manure material. **Conclusion:** This first examination of the effects of different litter materials on GHG emissions from broiler houses showed that FGD gypsum can reduce NH_3 concentrations without impacting climate change; however, more research is needed to verify these results.

Key words: Ammonia, carbon dioxide, climate change, FGD gypsum, global warming potential, greenhouse gases, litter management, methane, nitrous oxide

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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

Greenhouse gas (GHG) emissions have increased at an unprecedented rate and are expected to double pre-industrial revolution levels within this century[1,2]. This rise in emissions is widely believed to be the primary impetus driving global climate change and, if no action is taken to reduce these emissions, global temperature is likely to rise 2°C above pre-industrial levels[3]. Given that shifts in climate change could have huge implications for agricultural production and the environment, scientists worldwide have undertaken research to identify abatement strategies for minimizing GHG emissions. Much of this mitigation work to reduce anthropogenic sources of GHG emissions from agriculture has been conducted in row crop production systems fertilized with both inorganic and manure fertility sources or from manure storage while minimal research has focused on GHG contributions from the broiler industry.

While air quality inside broiler production facilities has been a major concern for many years, potential contributions of GHGs (CO_2, CH_4 and N_2O) exhausted from housing have more recently emerged as an environmental issue. Ammonia (NH_3) has traditionally been the atmospheric contaminant of greatest concern with regard to animal health and welfare; elevated NH_3 concentrations in broiler houses have been linked to decreased bird health resulting in lower body weight and impaired production[4-9]. Once in the environment, NH_3 has been linked to acidification of soil and water, increased eutrophication of water bodies, decreased ecosystem biodiversity on land and to aerosol formation in the atmosphere[10]. Carbon dioxide, CH_4 and N_2O are heat trapping gases and are believed to contribute to climate change. The greenhouse effect from CH_4 and N_2O is particularly of concern because they have a global warming potential 25 times and 298 times that of CO_2, respectively[11]. Ammonia and GHG emissions emerging from broiler production facilities are primarily a result of litter management and house conditions.

Broiler production systems are diverse with respect to litter management and environmental conditions. This diversity has been shown to influence gaseous flux. For example, NH_3, CO_2, CH_4 and N_2O losses from a commercial broiler production facility have been shown to increase with bird age[12,13]. Calvet *et al.*[14] also reported that GHG emissions increased with bird age and litter temperature. Miles *et al.*[15] reported that gas losses were influenced by litter density, with fluxes diminishing in areas of heavy caking.

Traditionally, pine shavings have been the bedding of choice for broiler production. However, availability of pine shavings has become increasingly limited and costly due to competition with expanding markets for wood byproducts and use as a biofuel. Flue gas desulfurization (FGD) gypsum can be used as an alternative bedding material for broiler production and can decrease NH_3 volatilization[16]. What's more, there are strong indications that FGD gypsum litter can reduce P loss from runoff following broiler litter applications to agricultural fields[17-19]. Traditionally, carbonaceous materials have been used as bedding for broiler production; how FGD gypsum use might affect NH_3 and GHG emissions is unknown. Therefore, we conducted a study to determine the influence of FGD gypsum bedding, compared with pine shavings, on the flux of NH_3, CO_2, CH_4 and N_2O from a broiler house.

MATERIALS AND METHODS

Treatment and husbandry: A study was conducted at the USDA-ARS Poultry Research Unit located at Mississippi State, MS, USA to evaluate the influence of using FGD gypsum as a bedding material for broiler production. Litter treatments consisted of pine shaving (PS; as a control), FGD gypsum and FGD gypsum+PS (50:50 v/v). For this 50:50 mixture, FGD gypsum was top dressed on the PS. Pine shavings were obtained from a local sawmill and FGD gypsum from a local fossil-fuel power plant. Treatments were implemented by placing approximately 8 cm of bedding into its respective pens. In addition, this study incorporated a management treatment in which each litter type was either decaked or rotovated after each flock. Only the rotovated treatments were mixed. The study was implemented as a 3×2 factorial design in a single poultry house with 8 replicate pens.

A total of 576 one-day-old (Ross×Ross 708) male birds were obtained from a commercial hatchery for each flock, weighed, randomly allotted to the six treatment groups and placed in the eight replicate pens per treatment located within a tunnel-ventilated research facility. Birds were housed in 1×1.5 m pens until 56 d of age, achieving a stocking density of 11 birds m^{-2}. Birds were provided a commercial type corn-soy diet, with the feed and water being provided *ad libitum*. Ventilation was managed according to typical poultry housing guidelines. All procedures for live birds were conducted under the approval and guidelines of the USDA-ARS, Mississippi State location Institutional Animal Care and Use Committee.

Gas emission measurements: Gas measurements were conducted on the litter of flocks 4 and 5. Treatments were held constant in pens over the 5 flocks to evaluate the influence that multiple flock cycles will have on FGD gypsum litter. No amendments were added to control ammonia volatilization of the litter. Static chambers were deployed in each pen to elucidated differences in gas flux among treatments using procedures similar to that described by Watts *et al.*[20] according to the USDA-ARS GRACEnet Protocol[21]. Briefly, cylindrical chambers with a radius of 12.7 cm and a height of 20 cm were placed in the pen litter; placement depth was measured to determine total head space at each sampling. The top of each chamber had a septum to enable sampling with a syringe. Due to constraints of there being live birds in the pens, the entire chamber was placed into the pens at the time of flux measurements and removed after. One chamber was deployed per pen. On sampling days, gas samples were extracted from the head space at 0, 20 and 40 min time intervals using gas-tight polypropylene syringes and injected into evacuated glass vials (6 mL) fitted with butyl rubber stoppers. Samples were stored at 25°C until analyzed. Gas samples were analyzed by a Shimadzu (GC-2014) gas chromatograph. Estimates of cumulative efflux of each trace gas were calculated from gas efflux at each sampling date integrated over time using the trapezoidal rule[22]. Flux measurements (CO_2, CH_4 and N_2O) were taken during flocks 4 and 5 (before bird placement and at 14, 28, 35 and 48 days after placement).

Ammonia concentrations from the litter were determined using a stainless-steel dynamic flux chamber connected to a photoacoustic gas analyzer. The stainless-steel flux chamber, constructed similarly to that described by Woodbury *et al.*[23], was equipped with an internal stir fan to keep air within the chamber uniform. Chambers were deployed for 10 min to determined ammonia concentrations, which previous research has shown to be an appropriate duration[24]. Ammonia was determined on the same dates as GHG measurements.

Temperature of the litter was determined on each sampling day by arbitrarily taking 3 measurements within the center of each pen between drinking lines and feeders using an infrared thermometer. Litter was also collected on each sampling day on a per pen basis to determine gravimetric moisture content. Litter moisture was determined by taking 5 grab samples from the 4 corners and center of each pen to make a composite sample. The samples were then dried in a forced-air drying oven at 55°C until weight became constant.

Data analysis: The experiment was conducted as a 3×2 factorial design (3 litter treatments×2 management treatments) with eight blocks arranged in a randomized complete block design. Data analysis was conducted using the Mixed Models Procedure (Proc Mixed) of the Statistical Analysis System[25]. Correlations of litter temperature and moisture with GHG emissions and NH_3 concentration were conducted using the correlation procedure in SAS (Proc Corr)[26]. Error terms appropriate to the factorial design were used to test the significance of main effects and their interactions. A significance level of $p \leq 0.10$ was established *a priori*; values which differed at $0.10 < p \leq 0.15$ were considered trends.

RESULTS AND DISCUSSION

Temperature: Temperature of the broiler litter was unaffected by litter treatment, management, or the interaction of these two throughout most of the study. On 23 July, gypsum alone had a lower litter temperature than the control pens and the pens containing gypsum and shavings, while the latter two treatments had similar temperatures (Table 1). On 11 June and 13 September, there were trends for decaking to have lower litter temperatures than rotovating; an opposite trend was noted on 11 October. A significant litter by management interaction on 29 August showed that decaked gypsum with shavings had the lowest litter temperature, which was lower than all other treatment combinations except rotovated gypsum. Further, rotovating had a higher temperature than decaking only in pens containing gypsum plus shavings.

Bowers *et al.*[27] observed lower surface temperatures with new and used sand litter during fall months when compared to new or used pine shavings. When comparing the two sand to the two pine shavings treatments during summer months, temperatures were almost equal. Watts *et al.*[16] observed no differences in bedding temperature when FGD gypsum was compared to pine shavings and pine bark over the span of three consecutive flocks. Given that temperature was controlled in the research facility with the use of fans, it was not unexpected to see few differences in litter temperature. Further, the few differences in litter temperature noted in our study, while statistically significant, were not likely biologically important (<1°C).

Moisture: Moisture content of litter showed a more frequent influence of litter treatment with the control being significantly higher than gypsum alone on six dates and higher than gypsum plus shavings on four of those dates (Table 2). Management had virtually no effect on litter moisture, with the exception that decaking had higher litter moisture than rotovating on 29 August. A trend for a litter by management interaction on 25 June showed that the rotovated control had higher moisture than all other treatments. Another trend observed on 9 August was similar in that the rotovated control had higher moisture than most of the other treatments.

Table 1: Litter temperature (°C) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	23.06^{NS}	28.36^{NS}	26.17^{NS}	31.12$^{a\ 1}$	24.30^{NS}	23.83^{NS}	24.50^{NS}	24.19^{NS}	22.40^{NS}	16.75^{NS}
Gypsum	23.16	28.44	26.25	29.21^{b}	23.89	23.82	24.64	24.11	22.66	16.30
G+shavings	22.95	28.41	26.33	29.82^{a}	24.05	23.78	24.45	24.18	22.54	16.29
p-value	0.197	0.817	0.720	0.011	0.218	0.676	0.379	0.942	0.765	0.154
Management										
Decake	22.99^{b}	28.44^{NS}	26.32^{NS}	29.67^{NS}	24.03^{NS}	23.78^{NS}	24.45^{b}	24.09^{NS}	22.75^{a}	16.44^{NS}
Rotovate	23.12^{a}	28.36	26.18	29.77	24.13	23.84	24.61^{a}	24.23	22.32^{b}	16.46
p-value	0.141	0.417	0.364	0.687	0.603	0.264	0.146	0.542	0.147	0.923
L*M²										
C-D	23.04^{NS}	28.44^{NS}	26.39^{NS}	30.32^{NS}	24.19^{NS}	23.85^{a}	24.44^{NS}	24.35^{NS}	22.66^{NS}	16.65^{NS}
C-R	23.09	28.29	25.95	29.92	24.41	23.81^{a}	24.56	24.04	22.14	16.85
G-D	23.11	28.45	26.18	28.86	23.91	23.84^{a}	24.58	23.89	22.75	16.40
G-R	23.20	28.42	26.32	29.56	23.86	23.80^{ab}	24.70	24.32	22.58	16.20
GS-D	22.81	28.44	26.41	29.82	23.99	23.66^{b}	24.32	24.04	22.84	16.26
GS-R	23.09	28.38	26.25	29.81	24.11	23.90^{a}	24.58	24.32	22.24	16.32
p-value	0.565	0.863	0.349	0.171	0.837	0.035	0.872	0.360	0.819	0.744

[1]Withing a column, values followed by the same letter are not significantly different (p>0.15). Values which differed at 0.10, <p≤0.15 were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

Table 2: Litter moisture (%) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	3.88^{NS}	17.22$^{a\ 1}$	12.91^{NS}	21.96^{NS}	28.85^{a}	10.56^{a}	21.43^{a}	37.34^{a}	36.89^{a}	39.74^{NS}
Gypsum	2.91	13.82^{b}	11.13	18.88	26.09^{b}	8.81^{b}	18.86^{b}	32.50^{b}	32.09^{b}	34.68
G+Shavings	3.20	15.11^{b}	11.44	19.66	27.80^{ab}	9.32^{b}	19.36^{b}	31.21^{b}	33.55^{ab}	36.61
p-value	0.257	0.004	0.433	0.231	0.095	0.008	0.379	0.015	0.072	0.331
Management										
Decake	3.60^{NS}	14.84^{NS}	11.80^{NS}	20.73^{NS}	27.44^{NS}	10.02^{a}	19.76^{NS}	34.20^{NS}	33.91^{NS}	36.45^{NS}
Rotovate	3.06	15.92	11.86	19.59	27.72	9.10^{b}	20.00	33.16	34.45	37.57
p-value	0.277	0.177	0.961	0.450	0.784	0.042	0.790	0.548	0.752	0.687
L*M²										
C-D	3.66^{NS}	15.76^{b}	12.56^{NS}	21.25^{NS}	27.20^{b}	10.79^{NS}	21.26^{NS}	37.59^{NS}	35.82^{NS}	35.95^{NS}
C-R	4.10	18.68^{a}	13.26	22.66	30.50^{a}	10.32	21.60	37.09	37.96	43.52
G-D	3.58	14.30^{bc}	12.26	20.99	26.45^{b}	9.54	19.17	34.15	33.59	36.79
G-R	2.25	13.35^{c}	10.00	16.76	25.74^{b}	8.08	18.54	30.85	30.59	32.58
GS-D	3.57	14.46^{bc}	10.58	19.96	28.68^{ab}	9.74	18.85	30.88	32.31	36.61
GS-R	2.84	15.75^{b}	12.31	19.35	26.92^{b}	8.90	19.88	31.54	34.79	36.61
p-value	0.328	0.147	0.370	0.309	0.114	0.644	0.757	0.638	0.343	0.223

[1]Withing a column, values followed by the same letter are not significantly different (p>0.15). Values which differed at 0.10, <p≤0.15 were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

Moisture increased with flock age for both flocks and decreased during the inter-flock period. Gravimetric moisture content for the FGD gypsum and FGD gypsum+PS were generally lower than the control. Similar results have been observed with both refined wallboard gypsum[28] and FGD gypsum[16]. These results reinforce the findings that FGD gypsum may exhibit a higher affinity for absorbing moisture than PS[16] which is one of the qualities of FGD gypsum that may promote flock health[16].

Ammonia (NH_3): Effects of litter treatment on NH_3 concentration were observed (Table 3). On 25 June, the control had a significantly higher NH_3concentration than FGD gypsum and FGD gypsum+PS; there was a similar trend on 11 October. On 13 September, FGD gypsum+PS had a lower NH_3 concentration than the control or gypsum alone. Decaking resulted in lower NH_3 concentrations than rotovating on six days across the duration of the study (Table 3). The only significant litter by management

Table 3: Ammonia concentration (ppm) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	67.18[NS]	50.41[a 1]	54.73[NS]	62.08[NS]	59.25[NS]	43.10[NS]	57.38[a]	81.75[NS]	85.25[a]	108.50[NS]
Gypsum	61.04	43.54[b]	56.26	58.74	55.66	40.99	55.50[a]	84.38	74.31[b]	106.69
G+Shavings	60.95	43.68[b]	54.14	58.51	50.84	40.83	48.00[b]	82.75	73.38[b]	106.56
p-value	0.182	0.032	0.864	0.519	0.214	0.390	0.093	0.821	0.118	0.953
Management										
Decake	59.88[b]	43.15[b]	51.06[b]	59.71[NS]	55.40[NS]	38.31[b]	49.17[b]	78.46[b]	78.75[NS]	104.92[NS]
Rotovate	66.23[a]	48.60[a]	59.03[a]	59.84	55.10	44.98[a]	58.08[a]	87.46[a]	76.54	109.58
p-value	0.047	0.047	0.020	0.962	0.939	<0.001	0.018	0.013	0.665	0.418
L*M[2]										
C-D	70.90[a]	49.15[NS]	53.01[NS]	64.51[NS]	60.81[NS]	40.99[NS]	51.50[NS]	77.62[NS]	88.25[NS]	106.50[NS]
C-R	63.46[ab]	51.66	56.45	59.64	57.69	45.21	63.25	85.88	82.25	110.50
G-D	55.15[bc]	42.02	51.98	57.71	53.62	37.14	51.00	79.75	73.62	98.00
G-R	66.92[a]	45.06	60.54	59.78	57.70	44.85	60.00	89.00	75.00	115.37
GS-D	53.59[c]	38.29	48.19	56.90	51.79	36.80	45.00	78.00	74.38	110.25
GS-R	68.31[a]	49.08	60.10	60.11	49.92	44.86	51.00	87.50	72.38	102.87
p-value	0.012	0.295	0.574	0.456	0.718	0.514	0.809	0.988	0.838	0.221

[1]Withing a column, values followed by the same letter are not significantly different ($p>0.15$). Values which differed at 0.10, $<p\leq 0.15$ were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

interaction occurred early in the study on 11 June. Decaking reduced NH_3 concentration compared to rotovating in both gypsum treatments but not in the control. Further, the decaked control had a higher NH_3 concentration than either decaked-gypsum treatment while there were no differences among the three litter treatments under rotovating.

Gypsum treatments generally lowered the NH_3 concentration but were significant only on three dates. The decrease can be attributed to conversion of ammonium carbonate to less volatile ammonium sulfate by gypsum[29]. In addition, the effects of gypsum on lowering moisture content can also reduce ammonia volatilization[16]. This reduction was evidenced by a strong positive correlation between bedding moisture and NH_3 concentration (Pearson's Correlation Coefficient = 0.489; $p<0.001$). Interestingly, a significant negative correlation was observed between temperature and NH_3 concentration (Pearson's Correlation Coefficient = -0.494; $p<0.001$). This was likely due to the fact that when temperature increased, fans turned on and removed NH_3 from the house.

Decaking likely lowered NH_3 due to removal of some of the manure compared with rotovating, which simply mixed the manure in with the bedding material. Interestingly, decaking lowered NH_3 concentration on the first three dates following flock placement. It is possible that NH_3concentration is lowered by decaking when litter moisture is relatively low (early after flock placement) and the effect becomes less pronounced when moisture is high and reaching a plateau/maximum later in the flock cycle.

Carbon dioxide (CO_2): To the best of our knowledge this study represents the first examination of the effects of different litter materials on GHG emissions from broiler houses. Carbon dioxide emissions from broiler litter was not greatly affected by treatments. Gypsum alone had greater CO_2 efflux than either the control or gypsum with shavings on 13 September (Table 4). On 9 July, there was a trend for gypsum with shavings to have higher CO_2 efflux than gypsum alone, with the control not being different from either gypsum treatment. Decaking had significantly lower CO_2 efflux compared to rotovating on 11 June and 29 August only. A significant litter by management interaction occurred on 25 June where rotovating had higher CO_2 efflux than decaking only in the gypsum alone litter treatment. Cumulative CO_2 emitted throughout the study was not affected by litter, management, nor the interaction of these two treatments (Table 7). Carbon dioxide emissions were not significantly correlated with litter temperature (Pearson's Correlation Coefficient = 0.002; p = 0.960) but were positively correlated with litter moisture (Pearson's Correlation Coefficient = 0.517; $p<0.001$). It is presumed that the higher levels of litter moisture allowed a larger and/or more active population of microorganisms that generate CO_2 emissions.

Differences observed for CO_2 efflux can be related to the organic matter (carbon source) of the litter. In the present study, litter treatments could not be visually differentiated after the 3rd flock of heavy broilers. This would suggest that organic matter in the litter reached equilibrium after the third flock so that the primary source of CO_2 efflux was manure

Table 4: Carbon dioxide efflux (g m^{-2} day^{-1}) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	10.98[NS]	17.70[NS]	37.99[ab 1]	43.85[NS]	20.48[NS]	6.82[NS]	11.50[b]	49.64[NS]	49.16[NS]	33.61[NS]
Gypsum	10.55	16.92	32.24[b]	37.77	24.13	6.68	13.75[a]	52.91	46.37	31.66
G+Shavings	11.49	16.93	39.92[a]	45.50	23.55	7.30	11.32[b]	46.97	44.13	30.62
p-value	0.662	0.814	0.144	0.237	0.519	0.677	0.086	0.377	0.639	0.873
Management										
Decake	9.11[b]	16.68[NS]	37.74[NS]	42.84[NS]	22.04[NS]	4.96[b]	11.97[b]	49.37[NS]	45.17[NS]	32.17[NS]
Rotovate	12.90[a]	17.69	35.70	41.90	23.40	8.90[a]	12.41	50.31	47.94	31.75
p-value	<0.001	0.378	0.531	0.810	0.627	<0.001	0.681	0.785	0.526	0.929
L*M[2]										
C-D	9.05[NS]	19.10[a]	37.09[NS]	44.32[NS]	16.22[NS]	5.26[NS]	10.73[NS]	49.89[NS]	45.31[NS]	33.10[NS]
C-R	12.92	16.30[ab]	38.89	43.38	24.74	8.38	12.27	49.39	53.00	34.11
G-D	8.61	14.72[b]	33.44	37.49	25.08	4.95	13.12	50.74	43.39	34.36
G-R	12.49	19.11[a]	31.05	38.06	23.18	8.41	14.37	55.08	49.36	28.96
GS-D	9.68	16.20[ab]	42.69	46.72	24.82	4.69	12.06	47.48	46.81	29.06
GS-R	13.29	17.66[ab]	37.16	44.27	22.28	9.92	10.59	46.47	41.45	32.17
p-value	0.989	0.046	0.652	0.950	0.203	0.316	0.383	0.782	0.416	0.750

[1]Withing a column, values followed by the same letter are not significantly different (p>0.15). Values which differed at 0.10, <p≤0.15 were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

rather than bedding material. Bowers *et al.*[27] reported that organic matter buildup consistently decreased after each flock with only marginal nutrient increases beyond the 4th flock. It is interesting to note that the two dates in which management significantly affected CO_2 emissions were the two dates immediately following placement of a flock in the poultry house. It is likely that the reduced quantity of manure from decaking resulted in the lower CO_2 efflux on these two dates, after which the management treatment had no significant effect since new manure was being added to the litter. Barker[30] suggested that the levels of gases in poultry housing are closely associated with manure management. The reason that gypsum alone had higher CO_2 efflux than the other litter treatments on one date is unknown but was likely due to placement of the sampling chambers on fresh chicken manure.

Nitrous oxide (N_2O): The production of N_2O from the litter depends on feces composition, microbes and enzymes involved and environmental conditions of the litter including interactions between available C and N. The fact that N_2O emissions from broiler litter were unaffected by litter treatments throughout the study suggests that few differences in these controlling factors occurred during the later flocks. However, decaking lowered N_2O emissions compared with rotovating on three days with a similar trend on a fourth date (Table 5). This is likely due to some of the manure being removed during the decaking process. A trend for a litter by management interaction was observed on 13 September where decaking had higher N_2O efflux compared with rotovating in the gypsum with shavings treatment only. As with CO_2, cumulative N_2O emissions across the entire study were unaffected by either treatment or their interaction (Table 7). Nitrous oxide emissions were positively correlated with both litter temperature (Pearson's Correlation Coefficient = 0.187; p<0.001) and litter moisture (Pearson's Correlation Coefficient = 0.167; p<0.001).

Methane (CH_4): Control plots had higher methane emissions than either gypsum treatment on 9 August (Table 6). On 29 August, methane was also significantly affected by litter treatments with gypsum>gypsum with shavings>control. Decaking lowered CH_4 emissions compared with rotovating on 9 July, with a similar trend on 23 July. Conversely, decaking had higher CH_4 emissions than rotovating on 27 September. A trend for a litter by management interaction was observed on 9 July where decaking had lower CH_4 efflux compared with rotovating in the gypsum alone treatment only; in fact, the gypsum alone-rotovated treatment had higher CH_4 emissions than all other treatment combinations except rotovating in the control treatment (Table 6). Decaking significantly reduced cumulative CH_4 efflux across the study compared with rotovating (Table 7), likely due to this treatment removing some of the manure, a potential source of methane production. Methane emissions were not significantly

Table 5: Nitrous oxide efflux (mg m^{-2} day^{-1}) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	0.62^{NS}	3.51^{NS}	12.29^{NS}	14.82^{NS}	7.77^{NS}	2.28^{NS}	4.15^{NS}	17.87^{NS}	4.88^{NS}	2.70^{NS}
Gypsum	1.53	5.63	9.77	12.47	5.39	2.16	4.28	16.63	6.78	3.06
G+Shavings	1.09	4.24	10.08	14.19	5.10	3.02	5.16	12.01	4.37	3.57
p-value	0.180	0.582	0.637	0.871	0.658	0.988	0.873	0.670	0.459	0.936
Management										
Decake	0.44^{b} [1]	3.856^{NS}	8.41^{b}	10.25^{b}	5.65^{NS}	1.06^{b}	4.61^{NS}	15.01^{NS}	5.73^{NS}	4.10^{NS}
Rotovate	1.72^{a}	5.67	13.09^{a}	17.41^{a}	6.53	3.25^{a}	4.45	16.00	4.96	2.11
p-value	0.003	0.471	0.057	0.066	0.736	0.111	0.926	0.862	0.642	0.318
L*M [2]										
C-D	0.35^{NS}	4.66^{NS}	8.94^{NS}	11.59^{NS}	4.21^{NS}	0.68^{NS}	2.53^{b}	13.10^{NS}	3.83^{NS}	2.16^{NS}
C-R	0.89	2.35	15.64	18.06	11.34	3.88	5.78^{ab}	22.63	5.93	3.23
G-D	0.47	5.34	10.23	11.88	6.46	0.74	3.52^{ab}	22.38	7.63	4.83
G-R	2.60	5.91	9.31	13.07	4.32	3.58	5.04^{ab}	10.89	5.93	1.28
GS-D	0.50	1.54	6.08	7.25	6.27	1.74	7.79^{a}	9.55	5.72	5.30
GS-R	1.67	0.93	14.08	21.10	3.94	2.30	2.54^{b}	14.47	3.02	1.83
p-value	0.262	0.180	0.258	0.390	0.249	0.690	0.116	0.285	0.462	0.550

[1]Withing a column, values followed by the same letter are not significantly different ($p>0.15$). Values which differed at $0.10, <p\leq 0.15$ were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

Table 6: Methane efflux (mg m^{-2} d^{-1}) as affected by litter treatment, management and their interaction

	Date									
Litter	11-Jun	25-Jun	9-Jul	23-Jul	9-Aug	29-Aug	13-Sep	27-Sep	11-Oct	26-Oct
Treatments										
Control	-0.020^{NS}	0.264^{NS}	0.051^{NS}	-0.046^{NS}	0.452^{a} [1]	-0.224^{c}	-0.086^{NS}	0.105^{NS}	0.160^{NS}	0.223^{NS}
Gypsum	-0.003	0.301	0.442	0.056	-0.171^{b}	0.409^{a}	-0.118	0.148	0.204	0.026
G+shavings	-0.046	0.183	-0.051	-0.027	0.020^{b}	0.104^{b}	0.158	-0.027	0.273	0.121
p-value	0.966	0.914	0.401	0.864	0.034	0.003	0.199	0.171	0.646	0.346
Management										
Decake	-0.008^{NS}	0.144^{NS}	-0.337^{b}	-0.134^{b}	0.182^{NS}	0.088^{NS}	-0.103^{NS}	0.144^{a}	0.209^{NS}	0.138^{NS}
Rotovate	-0.038	0.354	0.631^{a}	0.122^{a}	0.018	0.105	0.073	0.006^{b}	0.216	0.108
p-value	0.827	0.371	0.003	0.130	0.399	0.908	0.198	0.082	0.947	0.794
L*M [2]										
C-D	0.044^{NS}	0.027^{NS}	-0.344^{b}	-0.279^{NS}	0.458^{NS}	-0.269^{NS}	-0.268^{NS}	0.223^{NS}	0.146^{NS}	0.282^{NS}
C-R	-0.085	0.501	0.446^{ab}	0.187	0.447	-0.179	0.096	-0.013	0.174	0.164
G-D	0.058	0.387	-0.458^{b}	-0.039	0.001	0.460	-0.182	0.242	0.194	-0.078
G-R	-0.065	0.215	1.341^{a}	0.152	-0.342	0.359	-0.054	0.053	0.214	0.129
GS-D	-0.128	0.019	-0.209^{b}	-0.083	0.089	0.075	0.140	-0.032	0.287	0.210
GS-R	0.036	0.348	0.106^{b}	0.028	-0.049	0.134	0.176	-0.022	0.260	0.031
p-value	0.593	0.498	0.150	0.663	0.778	0.837	0.594	0.393	0.971	0.310

[1]Withing a column, values followed by the same letter are not significantly different ($P>0.15$). Values which differed at $0.10, <p\leq 0.15$ were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

correlated with litter temperature (Pearson's Correlation Coefficient = -0.010; p = 0.824) nor litter moisture (Pearson's Correlation Coefficient = 0.021; p = 653).

Global warming potential (GWP): Each greenhouse gas (CO_2, N_2O and CH_4) has an established global warming potential (GWP) based on the relative radiative forcing of 1 kg of the trace gas compared with 1 kg of CO_2 over a specific interval of time ($CO_2 = 1$, $N_2O = 298$, $CH_4 = 25$)[11]. In this study, GWP was calculated from the cumulative emissions of each trace gas. Global warming potential was not affected by litter, management, nor their interaction (Table 8). However, the relative percent contribution of methane to GWP was significantly higher for the rotovating treatment compared with decaking. Again, this was likely due to the decaking treatment removing some of the manure as a potential source of methane production. The fact that GWP was unaffected shows that gypsum can be used in poultry houses without any significant negative impact on climate change.

Table 7: Cumulative trace gas efflux as affected by litter treatment, management and their interaction

	Trace gas		
Litter	CO_2 (kg m^{-1} day^{-1})	N_2O (g m^{-1} day^{-1})	CH_4 (mg m^{-1} day^{-1})
Treatments			
Control	3.84^{NS}	1.06^{NS}	13.48^{NS}
Gypsum	3.76	0.97	18.45
G+Shavings	3.83	0.89	10.13
p-value	0.924	0.849	0.707
Management			
Decake	3.74^{NS}	0.85^{NS}	4.95$^{b\ 1}$
Rotovate	3.88	1.10	23.09^{a}
p-value	0.452	0.304	0.032
L*M²			
C-D	3.68^{NS}	0.75^{NS}	-0.83^{NS}
C-R	4.01	1.37	27.79
G-D	3.65	1.05	10.08
G-R	3.86	0.90	26.82
GS-D	3.88	0.74	5.59
GS-R	3.77	1.04	14.66
p-value	0.615	0.443	0.620

[1]Withing a column, values followed by the same letter are not significantly different (p>0.15). Values which differed at 0.10<p≤0.15 were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

Table 8: Global warming potential (GWP) and the contribution (%) of each trace gas to GWP as affected by litter treatment, management and their interaction

	Trace gas			
Litter	GWP	CO_2 (%)	N_2O (%)	CH_4 (%)
Treatments				
Control	4.16^{NS}	92.75^{NS}	7.25^{NS}	0.0077^{NS}
Gypsum	4.05	93.59	6.40	0.0110
G+shavings	4.09	93.66	6.33	0.0059
p-value	0.923	0.834	0.834	0.7010
Management				
Decake	3.99^{NS}	94.10^{NS}	5.90^{NS}	.0033$^{b\ 1}$
Rotovate	4.21	92.46	7.42	.0130^{a}
p-value	0.346	0.271	0.274	0.0580
L*M2				
C-D	3.90^{NS}	94.45^{NS}	5.55^{NS}	0.0003^{NS}
C-R	4.42	91.04	8.94	0.0151
G-D	3.96	93.18	6.82	0.0068
G-R	4.13	94.00	5.98	0.0152
GS-D	4.11	94.67	5.32	0.0029
GS-R	4.08	92.65	7.34	0.0088
p-value	0.630	0.446	0.447	0.7550

[1]Withing a column, values followed by the same letter are not significantly different (p>0.15). Values which differed at 0.10, <p≤0.15 were considered trends. NS: Non significant, [2]L*M: Litter treatment by management interaction

CONCLUSION

This study represents the first examination of the effects of different litter materials on GHG emissions from broiler houses. In general, use of FGD gypsum had little effect on GHG emissions compared with pine shavings. This indicates FGD gypsum can be used in broiler houses without impacting climate change. Further, NH_3 concentrations tended to be lower with FGD gypsum. Decaking also tended to lower NH_3 concentrations, as well as GHG, emissions due to removal of some of the manure material. However, more research is needed to verify this conclusion. Future research should monitor GHG emissions from bedding placement to removal for FGD gypsum litter management.

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