Evaluation of a Novel Poultry Litter Amendment on Greenhouse Gas Emissions

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Abstract: Gaseous emissions from poultry litter causes production problems for producers as well as the environment, by contributing to climate change and reducing air quality. Novel methods of reducing ammonia (NH₃) and greenhouse gas (GHG) emissions in poultry facilities are needed. As such, our research evaluated GHG emissions over a 42 d period. Three separate flocks of 1000 broilers were used for this study. The first flock was used only to produce litter needed for the experiment. The second and third flocks were allocated to 20 pens in a randomized block design with four replicated of five treatments. The management practices studied included an unamended control; a conventional practice of incorporating aluminum sulfate (referred to as alum) at 98 kg/100 m²; a novel litter amendment made from alum mud, bauxite, and sulfuric acid (alum mud litter amendment, AMLA) applied at different rates (49 and 98 kg/100 m²) and methods (surface applied or incorporated). Nitrous oxide emissions were low for all treatments in flocks 2 and 3 (0.40 and 0.37 mg m⁻² hr⁻¹, respectively). The formation of caked litter (due to excessive moisture) during day 35 and 42 caused high variability in CH₄ and CO₂ emissions. Alum mud litter amendment and alum did not significantly affect GHGs emissions from litter, regardless of the amendment rate or application method. In fact, litter amendments such as alum and AMLA typically lower GHG emissions from poultry facilities by reducing ventilation requirements to maintain air quality in cooler months due to lower NH₃ levels, resulting in less propane use and concomitant reductions in CO₂ emissions.

Keywords: alum; alum mud litter amendment (AMLA); poultry; litter; greenhouse gas (GHG); methane emissions; nitrous oxide emissions

1. Introduction

Poultry farms have been implicated as having a negative impact on air quality and the environment due to large amounts of atmospheric ammonia (NH₃) being emitted from poultry litter (combination of bedding material, feces, and urine; [1]) during production. It is believed that NH₃ emissions from poultry litter account for 27% of the total atmospheric NH₃ emissions in the U.S from animal husbandry. [2]. Although NH₃ is the largest atmospheric contaminant with respect to poultry production, poultry farms are also a source of greenhouse gas (GHG) emissions such as nitrous oxide (N₂O), carbon dioxide (CO₂), and methane (CH₄), which contribute to global climate change [3].

According to the latest report by the U.S. Environmental Protection Agency (USEPA), the Agriculture sector accounts for 9.3% of the total GHG emissions in the U.S. [4]. Greenhouse gases in agriculture are mainly emitted from animal waste, in housing facilities, in storage facilities, during animal grazing through enteric fermentation, or during manure spreading [5]. Methane and N₂O have high global warming potentials, which are 28 and 265 times greater than CO₂, respectively [6]. According to USEPA [4], in 2018, CH₄ emissions from manure management and enteric fermentation represent approximately 10 and 28% of total anthropogenic activities, respectively. The largest contributors of N₂O emissions in the agriculture sector are livestock manure, application of synthetic and organic fertilizers, and growing N-fixing plants [4].
In the poultry industry, litter management during and after production contributes to GHG emissions. Given the assumption that 1.05 kg of litter is produced per bird [7], nearly 13 million Mg (14 million tons) of broiler litter is produced on U.S. poultry farms [1]. In contrast to NH$_3$ emissions, fewer studies have researched GHG emissions from poultry houses [8–10]. The data from these studies show that poultry production is responsible for a relatively small percentage of GHG emissions [8–10]. Broilers have monogastric digestive systems, and therefore do not produce a significant amount of CH$_4$ through enteric fermentation compared to cattle; instead, the main source of CH$_4$ being emitted is through poultry litter [9,11]. The formation of CH$_4$ occurs through anaerobic decomposition of poultry litter where oxygen, water contents, pH levels, and nutrient availability play a key role in CH$_4$ production. Methane emission from the surface of poultry litter is often reported as being very minimal [8,10]. Since the majority of poultry litter within poultry houses is in a solid state, aerobic conditions lead to only minimal CH$_4$ emissions being formed from the surface of the litter [9]. Nitrous oxide emissions mainly occur after poultry production, during storage and field application, through the process of nitrification and denitrification [12]. The storage of poultry litter under aerobic conditions with pockets of anaerobic conditions leads to N$_2$O volatilization while poultry litter stored in predominantly anaerobic conditions leads to the production of methane causing a trade-off between the two GHG emissions [13]. Carbon dioxide emissions from poultry litter occurs from the aerobic break down of uric acid as well as other organic compounds [14]. Calvet et al. [15] conducted a study on CO$_2$ balances in broiler production and reported that broiler litter accounted for 20% of the total CO$_2$ produced from a broiler facility.

Chemical amendments such as aluminum sulfate (Al$_2$(SO$_4$)$_3$·14H$_2$O)), otherwise referred to as alum, are used to reduce NH$_3$ emission from poultry litter, but only one study has evaluated the effects of alum on GHG concentrations and emissions in poultry houses. In the study, Eugene et al. [16] found no differences in CH$_4$ and N$_2$O emissions from alum-treated and untreated litter. However, Eugene et al. [16] did report significantly lower CO$_2$ emissions from broiler houses treated with alum compared to untreated litter, which was due to less propane use during winter months because of lower NH$_3$ levels which allowed reduced ventilation rates.

The substantial price increase of alum over recent decades has created a need for a cheaper litter amendment to control NH$_3$ levels in poultry houses. One cheaper alternative that was patented by Moore [17] is alum mud litter amendment (AMLA). Alum mud litter amendment is a mixture of bauxite, sulfuric acid, and alum mud, which is an acidic solid residue formed as a byproduct during the manufacturing of alum [18,19]. Alum mud litter amendment, also called Al+Clear Plus, was manufactured by Chemtrade logistics INC. (Toronto, Ontario; Canada). Laboratory studies conducted on this new amendment showed that it was comparable to alum in reducing NH$_3$ emissions [17,19]. A pen trial conducted by Anderson et al. [20] on the effects of AMLA on NH$_3$ emissions from poultry litter showed AMLA reduced cumulative NH$_3$ from litter as much as, and in some cases more than alum applied at the same rate. Since this amendment is manufactured mainly using alum mud (a waste product that is normally landfill at $32 USD ton$^{-1}$), it should be much more cost-effective than alum. The effect of AMLA on GHG emissions has not previously been studied; therefore, the main objective of this study was to evaluate GHG emissions from poultry litter treated with AMLA in comparison to alum and untreated litter.

2. Materials and Methods
2.1. Design and Treatments

Pen trials were conducted at the poultry farm at the University of Arkansas Agricultural Research Station in Fayetteville, Arkansas. Three separate flocks of five hundred male and five hundred female 1-day-old Cobb x Cobb broiler chicks were randomly allocated to 20 pens at a density of 0.08 m$^2$ bird$^{-1}$. The pens (2.1 × 1.8 m; 50 birds per pen) were in a single room where the atmosphere was mixed. The chicks were reared with an automatically controlled light, temperature, and ventilation (0.85 m$^3$ h$^{-1}$ per bird)
system that had two fans producing negative pressure. The lights in the room were on for twenty-three hours and off for one hour during the night. The temperature of the room followed industry standards, starting at 32.2 °C at the beginning of the flock and was lowered over time to 22.2 °C at six weeks. Heat lamps were used during the first 7 days to provide the chicks with warmer temperatures. The pens had concrete floors and were equipped with one tube feeder and an automatic bell drinker and started with 5 cm of clean pine wood shaving for bedding (17.2 kg per pen). Each flock of birds was raised for 42 d. Chicks were fed starter diets during the first two weeks (0 to 14 d), grower diets during the next three weeks (14 to 35 d), and finisher diets the last week (35 to 42 d). The diets contained corn (64.2%), soybean meal (27.7%), 50% meat and bone meal (2.5%), poultry oil (2.65%), sodium chloride (0.31%), sodium bicarbonate (0.05%) limestone (0.74%), dicalcium phosphate (1%), along with vitamins, amino acids, trace metals, xylanase and phytase. Unlike the European poultry industry, where litter is cleaned out and replaced with each flock of birds, the United States poultry industry reuses litter for several flocks of birds. Due to biosecurity protocols, litter from outside sources was not allowed to be brought into the facility, and therefore the purpose of the first flock of 1000 birds was to produce the poultry litter needed for the experiment. The second flock of 1000 birds was placed one week after the first flock was removed. The third flock of 1000 birds was placed one year after the removal of the second flock (due to the longest government shutdown in U.S. history and the fear of another shutdown). The litter was tilled between each flock to break up any cake that may have formed and to enhance drying.

There were four replicates of five experimental treatments laid out in a randomized complete block design. Each of the 20 pens contained only one treatment. The five treatments used in this study were: (1) control (untreated litter), (2) 49 kg AMLA/100 m² incorporated, (3) 98 kg AMLA/100 m² incorporated, (4) 98 kg AMLA/100 m² surface applied, and (5) 98 kg alum/100 m² incorporated. Three days prior to the placement of birds for flocks two and three, litter amendments were added to the designated pens. All litter amendments were evenly spread on the litter surface. The surface applied treatments were left untouched, while the incorporated amendments had the top 2 to 3 cm of the litter homogenized using a pitchfork.

2.2. Flux Measurements and Litter Analyses

Nitrous oxide, CH₄, and CO₂ flux measurements and litter samples were collected from each pen at days 0, 7, 14, 21, 28, 35, and 42, during the second and third flocks. A plastic flux chamber attached to an Innova 1512 Photo-acoustic Multi-gas Analyzer (Innova Air Tech Instruments, Ballerup, Denmark) was used to measure NH₃ and GHG gas emissions from the litter at three random locations within each of the pens; NH₃ emissions were reported by Anderson et al. [20]. The static flux chamber was a cylindrical plastic container, 35 cm high with a 14.5 cm radius; with a small battery powered fan mounted inside the container to stir the air within the flux chamber. Although a static flux chamber was used it was only on the litter for a very short period where changes in gas concentrations were linear, hence, it is unlikely that the static chamber was significantly affecting the concentration gradients of the gases being measured. Greenhouse gases were measured above the litter surface at time zero. The flux chamber was then placed on the litter surface and gas measurements were recorded at 60 s as was done by Choi and Moore [21]. The difference between the concentration at time zero and 60 s was used along with the ideal gas law to estimate the gas flux for each GHG being emitted from the litter. The flux measurements were then converted to an aerial basis (mg m⁻² hr⁻¹). Cumulative fluxes were calculated by multiplying hourly fluxes by 168 to convert to a weekly flux, then successively adding each weekly flux. A litter sample was collected using clean gloves and a putty knife (used to cut through the cake layer) from the entire litter profile at each of the three locations where fluxes measurements were taken. The depth of the litter sample changed each week as more manure was added by the birds. The litter samples were thoroughly homogenized in a clean bucket, and a subsample was refrigerated for analysis;
the excess litter was returned to the pen. Litter samples were analyzed for moisture content, pH, electrical conductivity (EC), ammonium-N (NH$_4$-N), nitrate-N (NO$_3$-N), and total N (TN). Only moisture content and NO$_3$-N litter data will be reported in this paper. For all other litter parameter data, see Anderson et al. [20]. Moisture content was determined by oven drying a subsample of litter at 65 °C for 1 week. Fresh litter samples were extracted using a 1:10 (litter: water) ratio and filtered through a 0.45 um filter paper according to Self-Davis and Moore [22]. The litter extracts were analyzed for NO$_3$-N colorimetrically on a Skalar auto-analyzer (Skalar, Buford, GA); using the salicylate-nitroprusside USEPA Method 351.2 [23].

2.3. Data Analysis

Statistical analyses were conducted to evaluate the effect of litter amendments on GHG fluxes and litter characteristics using the GLIMMIX procedure in SAS 9.4 [24]. The experimental design was a randomized complete block design with a two-factor, factorially arranged treatment design. Analysis of variance (ANOVA) was conducted on main effects (litter amendments and sampling date), while blocks were considered random effects. Flocks 1 and 2 were analyzed separately. Differences in means were separated using Fisher’s least significant difference (LSD) test at the 0.05 probability level.

3. Results and Discussion

3.1. Nitrous Oxide Emissions and Litter Nitrate Concentrations

Nitrous oxide-N emissions ranged from 0.08 to 0.68 mg m$^{-2}$ hr$^{-1}$ during flock 2 and from −0.09 to 1.27 mg m$^{-2}$ hr$^{-1}$ during flock 3 (Table 1). There were no trends observed for average N$_2$O-N fluxes during either flock. These data are consistent with an emission study by Moore et al. [25] which reported low N$_2$O variation per flock. Average and cumulative N$_2$O-N emissions (Table 1 and Figure 1, respectively) from both flocks were not affected by the additions of AMLA or alum to poultry litter. The study conducted by Eugene et al. [16] on the effects of alum on GHG emissions, also found no significant differences in N$_2$O levels between alum and untreated litter. Nitrous oxide is produced during the denitrification portion of the N cycle. Denitrification is an anaerobic process where NO$_3$ is serially reduced to nitrite (NO$_2$), nitric oxide (NO), N$_2$O, and finally N gas. Bacteria play an essential role in the N cycle, since oxygen is excluded during denitrification, bacteria can use NO$_3$, NO$_2$, and NO as terminal electron acceptors for respiration [4]. For large levels of N$_2$O to be emitted, poultry litter must first be aerobic, which results in the mineralization of organic matter releasing NH$_3$, which is then converted to NO$_3$ through nitrification. Before the start of each flock and prior to the application of the treatments, litter was tilled to break up cake that formed during the previous flock, which likely created aerobic conditions within the litter. Such aerobic conditions are ideal for the formation of N$_2$O, however, under high litter moisture, denitrification is expected to form N$_2$ with little to no N$_2$O being produced [5]. There were no treatment effects on the moisture content of litter for either flock [20]. If the moisture content of the litter would have varied by treatment, then perhaps differences in N$_2$O emissions would have been observed.

Litter NO$_3$-N concentrations as a function of time for flock 2 and 3 are shown in Figure 2a,b, respectively. The highest concentrations of NO$_3$-N were observed during the first 2 weeks (0 to 14 d) of flock 3. Chastain et al. [26] noted aerated poultry litter will result in a significant amount of NO$_3$-N. The increased aeration from tilling prior to the start of flock 3, along with the low moisture content (Table 2) of the litter, created perfect conditions for high NO$_3$-N levels in the litter. There were no significant differences in NO$_3$-N concentrations between untreated control litter and litter treated with AMLA or alum, during flock 2. However, during the first 2 weeks (0 to 14 d) of flock 3, high rates of incorporated and surface applied AMLA, and alum litter treatments resulted in significantly lower NO$_3$-N concentrations compared to the control litter. From day 0 to 14 of flock 3, litter treated with AMLA and alum reduced the pH of litter below pH 7 [20]. The optimal pH for nitrifying bacteria is between pH 7.0 and 8.0 [27]; therefore, the control litter,
which had a pH greater than 7, had higher NO$_3$-N levels. When the moisture content of the litter was greater than 30%, (Table 2), the NO$_3$-N within the litter was readily converted to N gas and was emitted into the air, thus explaining the near zero NO$_3$-N values observed for the majority of flock 3 (days 21 through 42).

Table 1. Average nitrous oxide flux (mg N$_2$O-N m$^{-2}$ hr$^{-1}$) for flock 2 and 3 by treatment by day.

| Treatment                        | Day  | Avg. |
|----------------------------------|------|------|
|                                  | 0    | 7    | 14  | 21  | 28  | 35  | 42  |
| Control                          | 0.43a† | 0.28a | 0.48a | 0.50a | 0.42a | 0.68a | 0.08a | 0.41a |
| 49 kg AMLA/100 m$^2$ incorporated | 0.50a | 0.44a | 0.54a | 0.62a | 0.38a | 0.19a | 0.23a | 0.41a |
| 98 kg AMLA/100 m$^2$ incorporated | 0.22a | 0.32a | 0.58a | 0.56a | 0.37a | 0.46a | 0.28a | 0.40a |
| 98 kg AMLA/100 m$^2$ surface applied | 0.48a | 0.44a | 0.52a | 0.59a | 0.48a | 0.16a | 0.15a | 0.40a |
| 98 kg alum/100 m$^2$ incorporated | 0.48a | 0.47a | 0.47a | 0.50a | 0.31a | 0.22a | 0.22a | 0.38a |

† Values in columns followed by different letters indicate significant ($p < 0.05$) differences in means within each date and flock.

Figure 1. Cumulative nitrous oxide flux (mg N$_2$O-N m$^{-2}$) for (a) flock 2 and (b) flock 3 as a function of time. Treatments on day 42 not sharing a common letter are significantly different ($p < 0.05$).

Figure 2. Average nitrate litter concentrations (mg NO$_3$-N kg$^{-1}$) for (a) flock 2 and (b) flock 3 as a function of time. Treatments not sharing a common letter are significantly different ($p < 0.05$).
3.2. Methane Emissions

Methane emissions, like N$_2$O-N emission, were also low, ranging from $-7.84$ to $81.8$ mg m$^{-2}$ hr$^{-1}$ during flock 2 and from $-167.2$ to $178.9$ mg m$^{-2}$ hr$^{-1}$ during flock 3 (Table 3). These low CH$_4$ emissions are consistent with emission studies by Wathes et al. [10], Miles et al. [8], and Burns et al. [28], who also reported low levels of CH$_4$ being emitted from poultry litter. Since CH$_4$ is produced by an anaerobic process and poultry litter is typically aerobic, high CH$_4$ emissions are not expected. An increase in CH$_4$ emissions was observed during the first 3 weeks (0 to 14 d) of flock 2 and during the first 5 weeks (0 to 35 d) for most treatments of flock 3. The increase in the moisture of the litter (Table 2) played a role in the increase in CH$_4$ emissions, especially during the third flock (Table 3). Miles et al. [8] also saw an increase in CH$_4$ from placement of chicks until mid growout, corresponding to increased moisture. The negative CH$_4$ fluxes observed during day 42 for both flocks was likely caused by a thick layer of cake that started forming during week 5. The layer of cake acted as a barrier creating lower emissions of CH$_4$ from the litter surface. Large variability in CH$_4$ flux measurement within pens were also observed during this period since the cake did not cover the entire pen, and therefore, the CH$_4$ flux was very much dependent on the placement of the flux chamber. There was no significant difference in average (Table 3) or cumulative CH$_4$ (Figure 3) emissions observed between treatments for either flock. Eugene et al. [16] also did not report any significant differences in CH$_4$ flux between untreated and alum-treated litter.

### Table 2. Average litter moisture (%) flock 2 and 3 by treatment by day.

| Flock | Day    | Avg. |
|-------|--------|------|
|       | 0      | 7    | 14   | 21   | 28   | 35   | 42   |       |
| Flock 2 | 36.0  | 30.6 | 30.1 | 30.0 | 37.9 | 43.0 | 43.4 | 35.9 |
| Flock 3 | 16.4  | 15.4 | 26.8 | 37.4 | 40.9 | 47.7 | 50.2 | 33.5 |

### Table 3. Average methane flux (mg CH$_4$ m$^{-2}$ hr$^{-1}$) for flock 2 and 3 by treatment and sampling date.

| Treatment                                      | Day  | Avg. |
|-----------------------------------------------|------|------|
|                                               | 0    | 7    | 14   | 21   | 28   | 35   | 42   |       |
| Flock 2                                       |      |      |      |      |      |      |      |       |
| Control                                       | 32.0a| 44.4a| 81.8a| 38.1a| 22.2a| 20.4a| −7.48b| 33.1a |
| 49 kg AMLA/100 m$^2$ incorporated              | 25.7a| 34.5ab| 55.5a| 47.1a| 32.3a| 24.4a| 17.5a | 33.9a |
| 98 kg AMLA/100 m$^2$ incorporated              | 10.8a| 36.1ab| 73.9a| 44.3a| 23.9a| 23.6a| 8.12a | 31.5a |
| 98 kg AMLA/100 m$^2$ surface applied           | 14.8a| 29.3b | 82.0a| 41.3a| 22.5a| 27.2a| 19.3a | 33.9a |
| 98 kg alum/100 m$^2$ incorporated              | 18.9a| 28.3b | 78.4a| 42.7a| 27.0a| 13.6a| 14.2a | 31.9a |
| Flock 3                                       |      |      |      |      |      |      |      |       |
| Control                                       | −7.15b| 19.0a| 25.5a| 35.5a| 29.7a| 94.1a| −167.2a | 4.21a |
| 49 kg AMLA/100 m$^2$ incorporated              | −2.04ab| 15.7a| 21.4a| 31.6a| 46.4a| 94.1a| −8.81a | 28.3a |
| 98 kg AMLA/100 m$^2$ incorporated              | 4.03a| 21.8a| 19.5a| 33.7a| 42.6a| 178.9a| 3.97a | 43.5a |
| 98 kg AMLA/100 m$^2$ surface applied           | 6.47a| 20.8a| 20.5a| 28.0a| 55.3a| 131.7a| 72.4a | 47.9a |
| 98 kg alum/100 m$^2$ incorporated              | −7.00b| 24.1a| 26.0a| 47.7a| 31.1a| 87.7a| −1.98a | 29.7a |

† Values in columns followed by different letters indicate significant ($p < 0.05$) differences in means within each date and flock.

3.3. Carbon Dioxide Emissions

Carbon dioxide emissions were the highest of the three GHGs measured in this study, ranging from 10.1 to 47.3 g m$^{-2}$ hr$^{-1}$ during flock 2 and from 0.18 to 50.5 g m$^{-2}$ hr$^{-1}$ during flock 3 (Table 4). At the start of flock 2 (0 d), CO$_2$ emissions were still elevated from the previous flock (flock 1), which was removed only one week prior to the placement of flock 2 chicks. After the first week, CO$_2$ levels decreased by more than half and then started increasing over the next 4 weeks (14 to 35 d), corresponding to broiler growth. Average CO$_2$ emissions on day 0 (of flock 3) were much lower compared to day 0 of flock 2 since
a year had passed between the end of flock 2 and the beginning of flock 3. As with flock 2, flock 3 CO₂ emissions increased over the next 4 weeks (7 to 28 d) corresponding to broiler growth. A study by Miles et al. [8] also reported increased CO₂ levels in broiler houses over time with bird growth and respiration. The decrease in CO₂ emissions on day 42 of flock 2 and days 35 and 42 of flock 3, was likely a result of caking that also affected CH₄ emissions. During the 42-day broiler life cycle, averaged across flocks, CO₂ represented 95% of total GHG emissions, while CH₄-CO₂-equivalent emissions accounted for 3% with N₂O-CO₂-equivalent emissions making up the remaining 2%. Alum mud litter amendment and alum did not influence average (Table 4) or cumulative CO₂ flux (Figure 4) during either flock. Eugene et al. [16] found that adding alum to poultry litter significantly lowered CO₂ emissions from poultry houses. Unlike this study, Eugene et al. [16] did not measure fluxes from litter but measured emissions from poultry houses that were either controls or treated with alum treatments, which included CO₂ produced from propane heaters. The control poultry house had higher ventilation rates (because of high NH₃ levels) which resulted in more propane being used to maintain optimum temperatures for poultry production, resulting in higher CO₂ emissions compared to the poultry house with alum-treated litter [16].

Figure 3. Cumulative methane flux (g CH₄ m⁻²) for (a) flock 2 and (b) flock 3 as a function of time. Treatments on day 42 not sharing a common letter are significantly different (p < 0.05).

Table 4. Average carbon dioxide flux (g CO₂ m⁻² hr⁻¹) for flock 2 and 3 by treatment and sampling date.

| Treatment                           | Day 0 | Day 7 | Day 14 | Day 21 | Day 28 | Day 35 | Day 42 | Avg.  |
|-------------------------------------|-------|-------|--------|--------|--------|--------|--------|------|
|                                    |       |       |        |        |        |        |        |      |
| **Flock 2**                         |       |       |        |        |        |        |        |      |
| Control                             | 29.1a | 12.6a | 23.4a  | 19.8a  | 33.0a  | 47.3a  | 18.9a  | 26.3a|
| 49 kg AMLA/100 m² incorporated      | 27.5a | 13.2a | 24.2a  | 21.9a  | 41.7a  | 41.0a  | 18.9a  | 26.9a|
| 98 kg AMLA/100 m² incorporated      | 28.2a | 11.3a | 21.6a  | 22.8a  | 39.1a  | 35.4a  | 23.2a  | 26.0a|
| 98 kg AMLA/100 m² surface applied   | 29.0a | 10.1a | 19.9a  | 21.7a  | 32.0a  | 37.1a  | 22.5a  | 25.0a|
| 98 kg alum/100 m² incorporated      | 26.8a | 10.2a | 20.0a  | 18.5a  | 35.4a  | 41.1a  | 18.5a  | 24.4a|
|                                    |       |       |        |        |        |        |        |      |
| **Flock 3**                         |       |       |        |        |        |        |        |      |
| Control                             | 0.61a | 1.25a | 18.3a  | 42.9a  | 40.4a  | 29.7a  | 21.6a  | 22.1a|
| 49 kg AMLA/100 m² incorporated      | 0.46a | 0.69a | 20.1a  | 39.8a  | 39.6a  | 25.7a  | 17.6a  | 20.6a|
| 98 kg AMLA/100 m² incorporated      | 0.25a | 0.50a | 19.8a  | 45.0a  | 50.5a  | 25.5a  | 17.5a  | 22.7a|
| 98 kg AMLA/100 m² surface applied   | 0.61a | 0.46a | 16.8a  | 36.0a  | 39.5a  | 22.4a  | 14.4a  | 18.6a|
| 98 kg alum/100 m² incorporated      | 0.18a | 0.79a | 19.0a  | 35.5a  | 43.4a  | 25.3a  | 12.4a  | 19.5a|

† Values in columns followed by different letters indicate significant (p < 0.05) differences in means within each date and flock.
3.4. Effect of Litter Accumulation on Greenhouse Gas Emissions

In the United States, poultry litter is only cleaned out and replaced in poultry houses once a year, with some parts of the country cleaning out once every 3 to 5 years. The addition of fresh manure during new flocks affects GHG emissions in several ways. One of the primary ways is by adding organic compounds that are very labile, so there will be more microbial activity as they decompose the easily decomposable compounds. The rise in microbial activity will greatly increase CO2 production. If the litter is dry enough, some of the NH3 will be nitrified to NO3. As more and more manure builds up and the moisture content of the litter gets higher, particularly in the cake, oxygen diffusion into the litter will be slower than oxygen demand by microbes, causing anaerobic microsites to develop in the litter. When this happens, bacteria will begin to use NO3 as an electron acceptor, causing it to be denitrified (NO3 → NO2 → NO → N2O → N2), a process that will likely increase N2O emissions. Under very reduced conditions, CO2 can be used by microbes as an electron acceptor for respiration, resulting in methanogenesis, which would cause an increase in CH4 fluxes for the litter (CO2 + 4H2 → CH4 + 2H2O).

4. Conclusions

The objective of this study was to evaluate the effect of a new litter amendment, AMLA, on GHG emissions from poultry litter. Both N2O and CH4 emissions from the surface of poultry litter were low. The moisture content of the litter played a role in NO3 concentrations, with NO3-N observed to be near zero when the litter moisture was greater than 30%. As the moisture increased during growout, CH4 emissions also increased. As expected, CO2 fluxes from the litter increased with broiler growth. The cake that formed during week 5 of both flocks caused greater variability in CH4 and CO2 emissions. Overall, the pen trial showed no significant differences in GHG emissions (N2O-N, CH4, and CO2) being emitted from poultry litter treated with AMLA or alum compared to untreated litter. However, it is expected that the use of AMLA should reduce CO2 emissions from poultry facilities, as do other ammonia-control chemicals, such as alum, by lowering atmospheric NH3 levels in the houses, allowing lower ventilation rates during winter and concomitant decreases in propane use [16]. Since this novel poultry litter amendment was observed to have no significant impact on GHG emissions, addressing the concerns regarding the global warming potential of poultry production will require other strategies than those used to address air quality concerns.

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