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Mitigating Ammonia Emissions from Liquid-Sprayed Litter of Cage-Free Hen House with a Solid Litter Additive

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ABSTRACT. *A number of restaurant chains, retailers, and grocers in the US have pledged to source cage-free (CF) eggs only in the foreseeable future (e.g., by 2025 or 2030) due to marketing reasons or concerns over animal welfare. However, CF housing has some inherent challenges and a predominant one is poor air quality (ammonia gas – NH_3 and particulate matter – PM) and increased emissions. The high NH_3 levels primarily arise from the extended accumulation of manure on the litter floor, whereas the high PM levels are generated from dustbathing and foraging activities of the birds on the litter. Spraying liquid agent such as electrolyzed water (EW) has been shown to effectively suppress PM from litter of CF hen houses. However, liquid spray could enhance NH_3 emissions as it increases the litter moisture content (LMC). Application of low pH liquid to the litter would help control NH_3 while suppressing PM, but concerns arise about the potential corrosive effect of acidic liquid on the housing equipment. To overcome this dilemma, this study evaluated the effect of applying a commercial poultry litter additive (LA, PLT®) on NH_3 emissions of CF hen litter sprayed with neutral EW (NEW) at dosage of 25 mL (kg dry litter)$^{-1}$ d^{-1}. The PLT application rates were 0.3, 0.6, and 0.9 kg m^{-2}, denoted as Low-LA, Med-LA, and High-LA, respectively. The litter samples were placed inside dynamic emission chambers (DECs) and stirred to mimic hen scratching. PLT was topically applied onto the litter on day 1; NEW was sprayed daily for 11d, followed by a 3-d non-spray period (i.e., 14 d per trial); and each regiment was replicated four times. Ammonia emission rate (ER) of the control-no LA, Low-LA, Med-LA, and High-LA regimens (mean±SE) was 0.76±0.05, 0.55±0.06, 0.37±0.04, and 0.16 ±0.02 g (kg dry litter)$^{-1}$d^{-1}, respectively, namely 28-79% reduction by the treatments. The NH_3 reduction efficiency is linearly proportional to the PLT® application rate, with higher application rate resulting in significantly lower litter pH ($P<0.05$). On the last day of each trial (d14), the Med-LA and High-LA regimens continued to show relatively low NH_3 emissions, suggesting the need for a longer measurement period in the field verification that will follow. The NEW spray increased LMC by up to 60% after 11 once-a-day sprays, which reduced $PM_{2.5}$, PM_{10}, and TSP levels from 3.83, 6.39, and 7 mg m^{-3} to 0.07, 0.14, and 0.15 mg m^{-3}, respectively. After a 3-day spray suspension, the PM levels rebounded to 0.72, 1.02, and 1.12 mg m^{-3} for $PM_{2.5}$, PM_{10}, and TSP due to decreased litter moisture. The trade-off between NH_3 emission reduction and the cost associated with the litter additive application needs to be assessed under commercial CF production conditions.*

Keywords: Air quality; alternative hen housing; litter treatment; animal and worker health

1. INTRODUCTION

A number of restaurant chains, retailers, and grocers in the US have announced transition to sourcing cage-free (CF) eggs only in the foreseeable future (e.g., by 2025 or 2030) (Xin, 2016; UEP, 2016). According to the current number of pledges, it would take more than 70% of the current US layer stock to meet the pledged demand by 2025. While CF housing allows birds to better perform their natural behaviors (e.g., foraging, dustbathing, wing-flapping) which are limited in conventional cage housing systems, an inherent challenge with CF housing is the poor indoor air quality such as high ammonia (NH_3), particulate matter (PM) and airborne bacteria (AB) levels especially during cold weather and higher emissions of these aerial pollutants (Xin et al., 2011; Adell et al., 2015; Zhao et al., 2015; Winkel et al., 2016). The recommended NH_3 threshold in pullet and layer houses is 25 ppm (18 mg m^{-3}) (UEP, 2016), and NOISH's guidelines for 8-hr average and short-term (15 min) exposure limits for workers are 25 ppm (18 mg m^{-3}) and 35 ppm (27 mg m^{-3}), respectively (NIOSH, 2016). However, studies demonstrated that daily mean NH_3 levels in CF hen houses (e.g., aviary hen houses) are considerably higher than in conventional cage (CC) and enriched colony (EC) housing systems, which can exceed the recommended (required in some cases) NH_3 threshold in wintertime (Hayes et al., 2013, Shepherd et al., 2015; Zhao et al., 2015). In addition, the 2008 US EPA rule of CERCLA-EPCRA (Comprehensive Emergency Response Compensation and Liability Act-the Emergency Planning and Community Right to Know Act) that exempted all animal feeding operations from reporting air emissions from animal waste was just vacated (UEP, 2017). As a result, animal farms of any size and with ammonia emissions in excess of 100 lb (45.5 kg) per day are required to report their emissions to federal, state and local emergency response authorities. Besides high NH_3 levels, PM levels measured in CF houses (3.95±2.83 mg m^{-3} of PM_{10}) were high as well and they far exceed the 24h concentration threshold of 150 μg m^{-3} set by U.S. EPA to protect public welfare (U.S. EPA, 2015; Zhao et al., 2015). Therefore, mitigating NH_3 and PM levels is imperative to protecting the health and well-being of the animals and the caretakers, as well as improving the environmental stewardship of the CF egg production operation.

In CF houses, the high NH_3 levels primarily arise from the extended accumulation of manure on the litter floor, whereas the high PM levels primarily arise from dustbathing and foraging activities of the birds on the litter. As a result, reducing NH_3 and PM levels in CF houses is far more complex than in manure-belt cage or enriched colony houses. Spraying liquid agent such as electrolyzed water (EW) has been shown to be conducive to suppressing PM and airborne bacteria (AB) from litter in CF setting (Zhao et al., 2014; Zheng el al., 2014; Chai et al., 2017). The reduction efficiencies for PM and AB reached 50-70% after spraying acidic EW at dosage of 80-125 mL m^{-2}. However, spraying liquid on litter can enhance NH_3 emissions because of increased litter moisture content (LMC). Application of low pH liquid to litter would help control PM and NH_3 at the same time, but concerns arise about potential corrosive effect of acidic liquid on the housing equipment (Chai et al., 2017). Therefore, improved litter handling methods need to be identified for reducing NH_3 generations while spraying neutral pH liquid agents (e.g., neutral EW or NEW) to control PM and AB levels in CF houses.

Moore et al. (1995, 1996, 2000) found that a number of minerals (e.g., calcium hydroxide, aluminum sulfate, and ferrous sulfate) could be applied to reduce NH_3 emissions from poultry manure/litter. Terzich et al. (1998) identified that poultry litter treatment (PLT®, a mixing of 93.2% sodium hydrogen sulfate and 6.5% sodium sulfate) could improve health and body weight of broilers significantly ($P<0.03$) by reducing indoor NH_3 levels. Liang et al. (2005) tested the surface application of clinoptilolite zeolite onto layer manure at a rate of 0, 2.5%, 5% or 10% (0, 3.125, 6.25, 12.5 kg·m^{-2}, respectively), which reduced NH_3 emissions by 20%, 50% and 77%, respectively, over a 2-week storage period. Li et al. (2008) systematically tested litter treatment agents including zeolite, two forms of Al^+ Clear (48.5% liquid and granular aluminum sulfate $Al_2(SO4)_3·14H_2O$), Ferix-3 (ferric sulfate, $Fe_2(SO_4)_3·9H_2O$), and PLT for NH_3 reduction, and reported the NH_3–reduction efficiencies of 33% to 94% for stored layer manure. Li et al. (2013) tested PLT for reducing NH_3 emissions during broiler brooding period; and the results showed that application rates of 183 and 366 g m^{-2} could reduce cumulative NH_3 emissions up to 55-64.5%, with no significant difference in body weight or feed conversion of the birds as compared with the control. Fairchild et al. (2006) evaluated NH_3 reduction with increased application rates of sodium bisulfate (PLT) to determine the lifespan mitigation ability in commercial broiler houses, and reported that NH_3 reduction is positively correlated to the amount of litter additive applied to the house.

Most of the documented studies on efficacy of litter additives focused on broiler or turkey houses where the litter has considerably different physiochemical characteristics (e.g., litter depth, litter moisture content (LMC), and pH value) from CF hen houses. For example, litter in CF hen house has lower LMC than that in meat-type poultry housing (e.g., 10-15% for aviary litter vs. 25-35% for broiler or turkey litter) (Zhao et al., 2013), which could result in different litter pH when the same amount of litter additive is applied. In addition, litter depth on the floor of CF houses can vary considerably over time, depending on the accumulation time or removal frequency of the litter/manure. Furthermore, there is no report on application of litter additive together with electrolyzed water to simultaneously control NH_3 and PM levels in CF houses.

The objectives of this study were (1) to assess ammonia reduction efficiency of applying a commercial litter additive on litter of CF hen house together with intermittent spray of neutral electrolyzed water (NEW); and (2) to identify the optimal application rate of the litter additive at specific litter depth in terms of ammonia reduction.

2. Materials and Methods

2.1 Experimental setup

The experiment was carried out with four identical dynamic emission chambers (DECs, each measuring 86 cm long, 46 cm wide, and 66 cm high, **Figure 1**) located in an environmentally-controlled room. Litter was collected from a commercial CF farm in Iowa and stored in containers. One DEC served as control (without litter additive) and other three used for treatments. The litter was tilled automatically with a rake driven by a stepper motor to mimic activities of birds on the litter. The tilling time was 12:00 to 22:00 h, corresponding to the typical litter-access period for the birds in commercial CF houses. Air temperature and relative humidity (RH) in all DEC's were controlled to similar CF house conditions (22ºC and 60% RH).

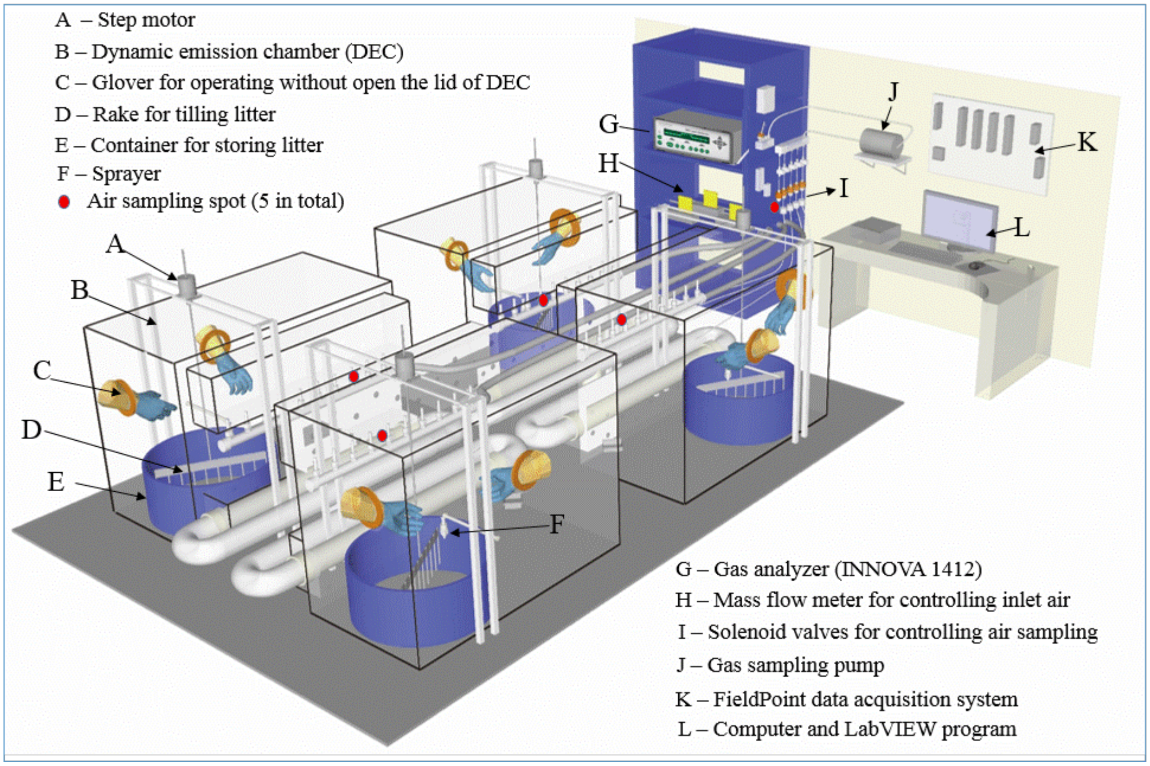

Figure 1. Experimental setup for NH_3 mitigation test with dynamic emission chambers.

The granular PLT® (sodium bisulfate- $NaHSO_4$) was chosen for this study as it is one of the cost-effective and safe litter acidifiers to animals (Knueven, 1999; Li et al., 2013). When PLT® is applied it breaks down into sodium, hydrogen and sulfate. The hydrogen ion lowers pH and converts ammonia (NH_3) into ammonium (NH_4). The application rate of PLT® recommended by the manufacturer is 0.37-0.74 kg m^{-2} (75-150 lb per 1000 ft^2) for broiler or turkey houses to control NH_3 levels up to two weeks. In each DEC, 5 kg litter (dry-basis) was stored in a 50 L container (with a depth of approximately 4.5 cm) and it received topical application of PLT at the rate of 0.01, 0.02, or 0.03 kg (kg dry litter)$^{-1}$ (i.e., 0.3, 0.6, and 0.9 kg m^{-2}). The three application rates were considered as low, medium and high levels, denoted as Low-LA, Med-LA, and High-LA, respectively (**Figure 2**). In each trial run, three LA application rates were compared to the control for 14 d, and four trial runs were conducted per regimen. The DECs were cleaned completely after each trial run, and a minimum of 3 d downtime was used before running the next trial. Assignments of the control or treatments were randomized among the DECs to avoid potential DEC effect (**Table 1**).

Table 1. Assignment of treatment and control regimens among the four dynamic emission chambers (DECs)

DEC #	Experimental Regimen of Trial Runs			
	Trial run 1	Trial run 2	Trial run 3	Trial run 4
1	Control (no LA)	High-LA	Med-LA	Low-LA
2	Low-LA	Control (no LA)	High-LA	Med-LA
3	Med-LA	Low-LA	Control (no LA)	High-LA
4	High-LA	Med-LA	Low-LA	Control (no LA)

Notes: (1) DEC# – the number of dynamic emission chambers; (2) Control (no LA), Low-LA, Med-LA, and High-LA represent no litter additive (LA), low, med, and high LA application rates at 0.01, 0.02, and 0.03 kg (kg dry litter)$^{-1}$, respectively; (3) The same dosage [25 mL (kg dry litter)$^{-1}$] of neutral electrolyzed water (NEW) was sprayed in each DEC once a day.

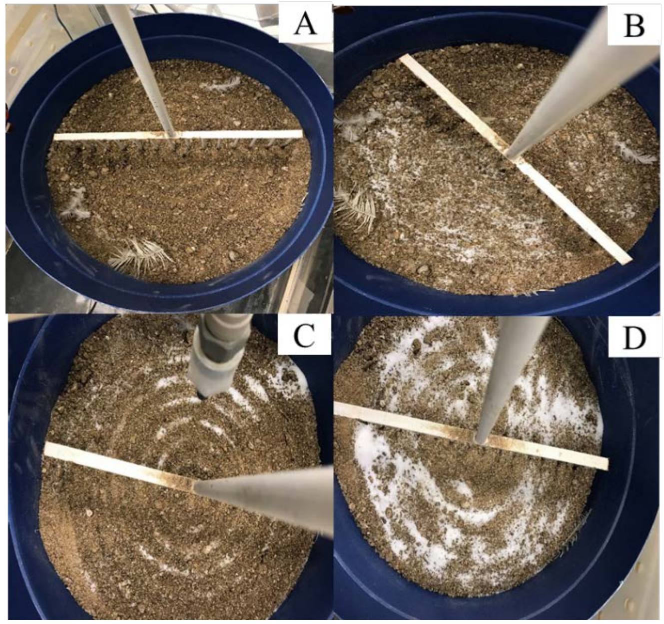

Figure 2. Topical application or absence of PLT® on litter in control and treatment DECs (A: Control-no LA, B: Low-LA, C: Med-LA, and D: High-LA, with the PLT application rate of 0, 0.01, 0.02, and 0.03 kg per kg dry litter, respectively).

Neutral electrolyzed water (NEW) at dosage of 25 mL (kg dry litter)$^{-1}$ was sprayed once a day on the litter of both the control and treatment DECs between 11:30 and 12:00 h for 11 consecutive days, then stopped for three days (i.e., d12- d14). This arrangement was intended to assess the change on the levels of NH_3 and PM after stopping the liquid spray for some time. The NEW spray dosage of 25 mL (kg dry litter)$^{-1}$ had been shown to result in relatively low increase in NH_3 emissions and 60-70% PM reduction in a previous study (Chai et al., 2017).

2.2 Litter handling and NEW preparation

Litter collected from a commercial CF farm in Iowa was packaged with polyethylene plastic bags to prevent nutrient and moisture loss during handling, then stored at -20ºC to preserve the nutrients/moisture before experiment use. For each trial run, about 20 kg (dry basis, 5 kg dry litter for each DEC) was transferred to a cold room (4ºC), thawing for two days, and then placed under room temperature for one day before experiment use. The thawed litter was completely mixed, equally divided, and randomly assigned to the four DECs for testing. The LMC at start and each of the experimental days was measured by oven-drying approximately 10 g litter samples at 105ºC for 24 h. The litter pH was determined with a pH meter (XL15, Fisher Scientific, Hampton, NH) after mixing the litter sample with deionized water (10% solution: 2 g litter and 20 mL water).

The NEW agent was produced by using an electrolyzing container with 0.1% NaCl solution (Zhao et al., 2014). The free chlorine (FC) was produced at a rate of 4.9 mg L^{-1} min^{-1} at 8 VDC, and a FC concentration of 200 mg L^{-1} was generated and used in the current study as it had been shown to have a high disinfection effect in a previous study (Chai et al., unpublished data). The newly generated NEW was stored in a cold room (4ºC) before each spray, during which its pH values were tested once every two days.

2.3 Monitoring of ammonia and PM levels

Concentrations of NH_3 in the exhaust air of each DEC were measured continually with a fast-response and precision photoacoustic multi-gas analyzer (model 1412, INNOVA AirTech Instruments, Denmark). As one gas analyzer was used to measure all four DECs, the air samples from all locations were taken sequentially using an automatically controlled gas sampling system (as shown in Figure 1). Considering the response time of the analyzer, each DEC was sampled for 12 minutes, with the first 10 min for stabilization and the last 2 min for measurement. This sequential measurement yielded hourly data of NH_3 concentrations of four DECs exhaust air and one inlet air. The INNOVA analyzer was checked weekly with standard zero and span gases. Ammonia emission rate of each DEC was determined from ventilation rate and concentration difference between exhaust air and inlet air of each DEC, as described in the following equation (Liang et al., 2005; Chai et al., 2017).

$$ER_{\mathrm{NH3}i} = \frac{1}{M} \times Q_i \times \left(C_{NH3,ex} - C_{NH3,in}\right) \times 10^{-6} \times \frac{W_{NH3}}{V_{m,NH3}} \times \frac{T_{sd}}{T_i} \times \frac{P_a}{P_{sd}} \tag{1}$$

where ER_{NH3i} – NH_3 emission rate of DEC *i* (i=1, 2, 3, 4), g (kg dry litter)$^{-1}$ d^{-1};
M – amount of litter (dry weight) used in each DEC, kg;
$C_{NH3,in}$ and $C_{NH3,ex}$ – NH_3 concentrations of inlet and exhaust air, ppm;
Q_i – ventilation rate of DEC *i*;
W_{NH3} – molar mass of NH_3 gas, 17.031 g mole^{-1};
$V_{m,NH3}$ – molar volume of NH_3 at standard temperature (ºC) and pressure (101.325 kPa), 0.022414 m^3 mole^{-1};
T_{std} – standard temperature, 273.15 K;
T_{ai} – absolute temperature in DECs, K;
P_{std} – standard barometric pressure, 101.325 kPa;
P_a – atmospheric barometric pressure at the site, 98 kPa.

An optical PM sensor (Dusttrak Drx Aerosol Monitor 8533, TSI Incorporated, Shoreview, MN) was used to measure PM concentrations of different particle sizes, i.e., PM_1, $PM_{2.5}$, PM_4, PM_{10} and total suspended particulate (TSP), simultaneously in DECs after spraying NEW to assess the PM reduction efficiency. The measurable range of the Dusttrak is 0.001 - 150 mg m^{-3} for PM concentration. Besides air quality, air temperature, RH, and ventilation rate of DECs were monitored as well with a LabVIEW program and associated I/O hardware (Figure 1) (National Instruments Co., Austin, TX, USA). The LabVIEW program was also used to control the operations of the mixing-rake motor and gas sampling solenoid valves.

Statistical analysis was performed to delineate the effect of litter additive use on litter pH and NH_3 emissions with Tukey HSD and lm functions/packages of R software version 3.3.3 (R Core Team, 2014).

Results and Discussion

3.1 Thermal environment

Air temperature and RH in DECs of control and treatments during 14 d measurement are shown in **Table 2**. Averagely the air temperature were 21.7±0.2 ºC, 22±0.2 ºC, 21.8±0.2 ºC, 21.7±0.2 ºC (mean±SD, n=14); RH were 58±3%, 59±2%, 58±3%, 58±4% (mean±SD, n=14) in DECs of control, Low-LA, Med-LA, and High-LA, respectively. Air temperature and RH were generally close to the set points of 22ºC and 60%. The VR in DECs of control, Low-LA, Med-LA, and High-LA were 6.03±0.18, 6.09±0.18, 6.05±0.2, and 6.00±0.19 L min^{-1} (mean±SD, n=14), respectively, agreed well to the setting of 6 L min^{-1}.

Table 2. Temperature and RH in DECs over 14-d measurement (mean±SD, n=4)

Day	T/Control (ºC)	T/Low-LA (ºC)	T/Med-LA (ºC)	T/High-LA (ºC)	RH/Control (%)	RH/Low-LA (%)	RH/Med-LA (%)	RH/High-LA (%)
d1	21.8±0.3	22.0±0.3	21.7±0.3	21.9±0.1	55±5	55±3	54±3	53±5
d2	21.6±0.2	21.9±0.5	21.6±0.1	21.7±0.1	56±5	58±4	57±5	57±4
d3	21.7±0.2	21.9±0.5	21.7±0.1	21.7±0.2	56±6	58±4	57±5	57±6
d4	21.8±0.2	22.0±0.4	21.7±0.1	21.8±0.1	57±5	59±3	58±5	59±7
d5	21.8±0.3	22.0±0.5	21.8±0.2	21.8±0.2	62±4	62±2	61±3	62±6
d6	21.8±0.3	22.0±0.5	21.8±0.2	21.8±0.2	61±3	62±2	59±2	61±6
d7	21.7±0.3	21.9±0.4	21.7±0.2	21.8±0.2	61±5	61±6	62±6	61±5
d8	21.7±0.2	21.9±0.3	21.7±0.1	21.8±0.1	60±6	60±4	60±4	61±5
d9	21.9±0.3	22.1±0.4	22.0±0.3	22.0±0.4	62±4	62±2	60±3	61±5
d10	22.2±0.7	22.4±0.3	22.2±0.7	22.0±0.7	61±4	61±4	59±5	59±6
d11	21.8±0.2	22.0±0.5	21.8±0.1	21.6±0.1	60±5	60±4	61±5	61±5
d12	21.6±0.1	21.8±0.7	21.7±0.1	21.5±0.1	58±4	57±5	58±6	57±6
d13	21.6±0.2	21.7±0.7	21.6±0.2	21.4±0.2	56±6	58±5	56±7	53±10
d14	21.5±0.2	21.6±0.8	21.5±0.2	21.2±0.2	52±6	54±6	50±10	49±8

Note: Control represents no LA application; Low-LA, Med-LA, High-LA represent litter additive application rates of Low, Med, and High (i.e., 0.01, 0.02, and 0.03 kg (kg dry litter)$^{-1}$ or 0.3, 0.6, and 0.9 kg m^{-2}), respectively.

3.2 Litter moisture content (LMC) and pH

LMC and pH are two primary factors affecting NH_3 emissions and reduction. The variations of LMC during each trial run are shown in **Table 3**. LMC in all four DECs agreed to each other, as the same dosage of NEW was applied once-a-day across all the regimens. LMC was increased from 10.3±0.1% on d1 before spray to 16.1±0.3 on d10 after 9 consecutive once-a-day sprays, about 60% increase. The LMC on d13 was lower than d10 as the NEW spray had been stopped since d12. After stopping the NEW spray, evaporation of litter moisture and tilling on the litter both accelerated the loss of moisture from litter to air.

Table 3. Averaged litter moisture contents of the four DECs over days (%, mean±SD, n=4)

	Trial run 1	Trial run 2	Trial run 3	Trial run 4	Mean±SD
d1	10.1±0.1	10.3±0.1	10.4±0.2	10.3±0.3	10.3±0.1
d4	13.5±0.3	13.8±0.2	14.2±0.2	14.0±0.2	13.9±0.3
d7	14.9±0.3	15.2±0.2	15.5±0.2	15.1±0.2	15.2±0.3
d10	15.8±0.2	16.2±0.1	16.5±0.2	16.1±0.2	16.1±0.3
d13	14.3±0.2	14.7±0.4	14.9±0.3	14.8±0.2	14.7±0.3

Note**:** (1) spray dosage was 25 mL [kg dry litter]$^{-1}$ d^{-1}; (2) d1, d4, d7, d10 and d13 represents the day when litter was sampled for drying at 10 am.

Litter pH in DECs of control-no LA, Low-LA, Med-LA, and High-LA corresponded well to the application rate of PLT. Higher PLT application resulted in significantly lower litter pH ($P<0.05$) (**Table 4**). In the control DEC where litter had a relatively stable pH between 7.1 and 7.3 over the two-week measurements. In the treatment DECs of Low-LA, Med-LA, and High-LA, litter pH values were 5.7, 3.6, and 3.1, respectively, on d1 immediately after applying PLT. The applied PLT broke down into sodium, hydrogen and sulfate; and the hydrogen ion lowered the pH. After two weeks, litter pH in the treatment DECs increased to 6.9, 5.8, and 5.2, which arose from the continuous reaction of the finite and less available amount of PLT with the mixed litter. In addition, spraying the NEW (pH of 7.9) onto the litter might have contributed somewhat to the elevated litter pH.

Table 4. Litter pH in treatment and control DEC (mean±SD, n=4)

Day	Control-no LA	Low-LA	Med-LA	High-LA	Deionized water
d1	7.1±0.1	5.7±0.2	3.6±0.2	3.1±0.3	8.3±0.1
d3	7.1±0.0	6.0±0.1	4.8±0.2	3.9±0.2	8.2±0.0
d5	7.1±0.1	6.1±0.1	5.1±0.2	4.1±0.2	8.2±0.0
d7	7.2±0.1	6.3±0.1	5.4±0.2	4.6±0.2	8.2±0.0
d9	7.2±0.1	6.5±0.1	5.6±0.3	5.0±0.2	8.2±0.0
d11	7.3±0.1	6.7±0.2	5.7±0.3	5.1±0.2	8.2±0.1
d13	7.2±0.1	6.9±0.1	5.8±0.3	5.2±0.2	8.2±0.1
Mean±SD	7.2±0.1	6.3±0.4	5.1±0.8	4.4±0.8	8.2±0.0

Note: (1) Low-LA, Med-LA, High-LA represent litter additive application rates of Low, Med, and High (i.e., 0.01, 0.02, and 0.03 kg (kg dry litter)$^{-1}$ or 0.3, 0.6, and 0.9 kg m^{-2}), respectively; (2) NEW with pH 7.9±0.1 was sprayed at dosage of 25 mL [kg dry litter]$^{-1}$ d^{-1} once a day; (3) d1- d13 represents the day when litter was sampled at 10 am for pH measurement; (4) Litter additive (i.e., PLT) was tested with pH of 0.7.

3.3 Ammonia and PM reduction efficiency

Daily emissions of NH_3 in control and treatment DECs over the 14 d test period are shown in **Figure 3**. The control regimen showed faster growing NH_3 ERs than treatment regimens. Except for High-LA regimen, all DECs showed gradually increasing NH_3 ERs over days until d12 when the NEW spray stopped. Increased emissions of NH_3 in control and treatment DECs were caused by the LMC change as which was increased by over 60% after two-week once-a-day NEW spray. Similar results of NH_3 elevation had been reported by Ogink et al. (2012) after spraying regular tap water on litter of CF hen house.

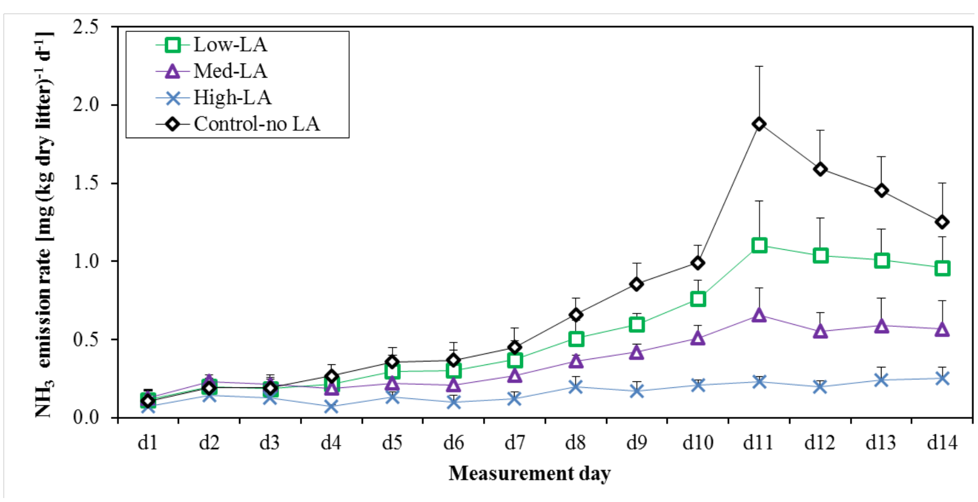

Figure 3. Daily NH_3 emission rate from treatment and control DECs (Mean±SE, n=4) (Control-no LA represents no LA application, Low-LA, Med-LA, High-LA represent litter additive application rates of Low, Med, and High, i.e., 0.3, 0.6, and 0.9 kg m^{-2}, respectively).

After NEW spray stopped, NH_3 ERs started to decline on d12 due to reduced LMC. On d14, NH_3 emissions in the Med-LA and High-LA regimens remained at relatively low level, which implies that the mitigation potential of PLT at higher application rates may last longer than two weeks for the CF hen litter. To quantify the mitigation effect of PLT over a longer period after application, the measurement period will be extended (e.g., four weeks) during the subsequent field verification study.

The cumulative emissions of NH_3 in the control and treatment regimens were 53.1±4.4, 38.3±5.2, 25.6±3.0, and 11.3±1.4 g (mean±SE), respectively, from 5 kg dry basis litter over the 14 d period (**Figure 4)**. Daily mean NH_3 ER of control, Low-LA, Med-LA, and High-LA were 0.76±0.05, 0.55±0.06, 0.37±0.04, and 0.16 ±0.02 g (kg dry litter)$^{-1}$d^{-1} (mean±SE). Treatment DECs showed significantly lower NH_3 emissions than control ($P<0.05$). Higher LA application rate resulted in lower NH_3 emissions. NH_3 reduction efficiency of the Med-LA regimen averaged 33% lower than the Low-LA regimen, trending significantly different ($P=0.08$).

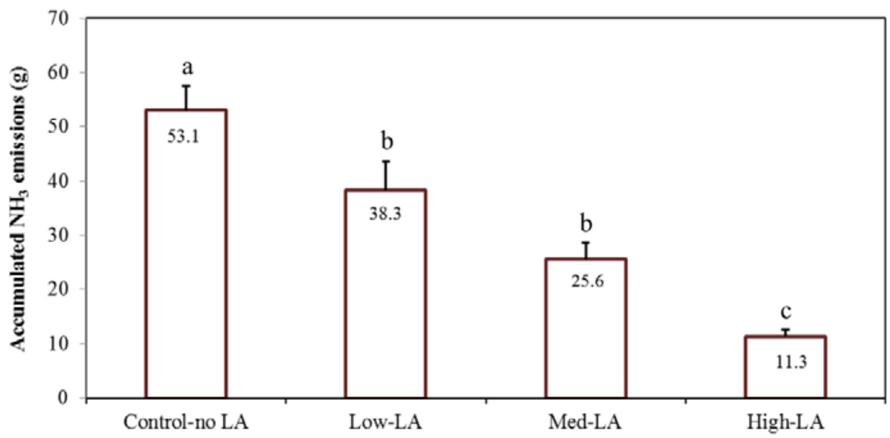

Figure 4. NH_3 emissions in treatment and control DECs during 14-d test (mean±SE, n=4) (Control, Low, Med, and High represent litter additive application rates of 0, 0.3, 0.6, and 0.9 kg m^{-2}, respectively. Different superscripts represent different NH_3 emissions significantly at $P<0.05$).

The current study showed that NH_3 reduction efficiency is directly proportional to the application rate of PLT ($P<0.05$). This outcome agrees with the conclusions made by Fairchild et al. (2006) for commercial broiler houses. As shown in **Figure 5**, the reduction efficiency of Low-LA (0.01), Med-LA (0.02), and High-LA (0.03) were 28%, 52%, and 79% as compared to control-no LA (0). The relationship follows a linear equation of Y (NH_3 reduction efficiency, %) = 262.9 (±10.8) X (PLT rate, kg/kg dry litter) ($R^2 = 0.9978$).

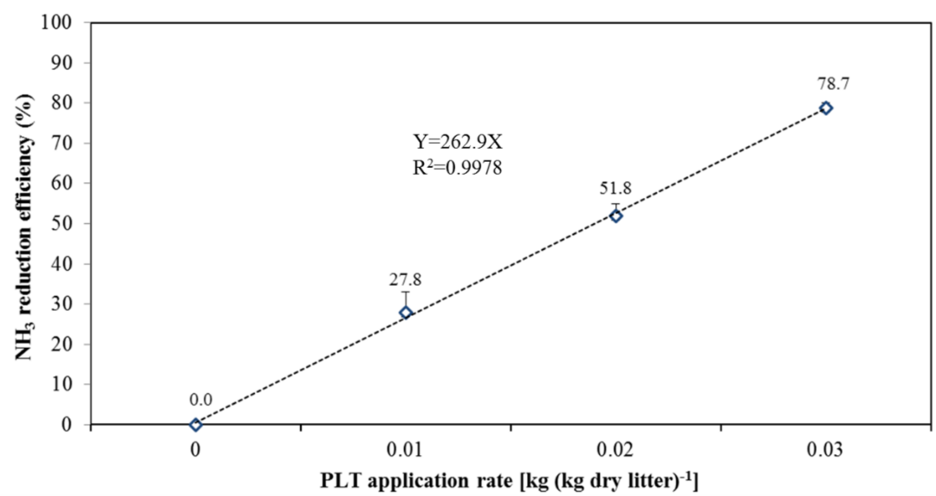

Figure 5. NH_3 reduction efficiency (Y, mean±SE, n=4) and regressed equation for assessing it based on PLT application (X).

NH_3 reduction efficiency of PLT observed in the current study (i.e., 28-79%) is lower than the results of 74-92% reported by Li et al. (2008). The difference was believed to stem from the higher application rate of PLT (0.5-1.5 kg m^{-2}) in the comparison study. In addition, litter in the current study was tilled to mimic birds' activities on the floor in CF hen houses, while the litter was stored under static conduction without disturbing in the comparison study. Tilling litter to mimic birds' behavior of dust bathing/foraging is expected to accelerate NH_3 emissions as air exchange between air and litter is increased.

In commercial CF house, the litter depth on floor varies with time, depending on flock age, litter removal frequency, and bird management schemes (e.g., daily length of litter access). A large litter depth range of 0.7 to 5.4 cm has been reported by Campbell et al. (2016). Thus, application rate of litter additive should be adjusted accordingly based on actual litter depth on the floor. Litter depth in the current laboratory test was 4.5 cm, and the PLT application rates of low, medium, and high could be standardized as 0.067, 0.133, and 0.2 kg m^{-2} per cm depth or 13.6, 27.3, and 40.9 lb per 1000 ft^2 at a litter depth of 1 cm.

The levels of $PM_{2.5}$, PM_{10}, and TSP were reduced from 3.83, 6.39, and 7 mg m^{-3} to 0.07, 0.14, and 0.15 mg m^{-3} after 11 one-a-day sprays due to increase in LMC, as shown in **Figure 6** and **Table 5**. The PM reduction efficiency after the first spray was about 70% and it agreed with the results reported in an earlier study of our lab (Chai et al., 2017). After the NEW spray stopped, the PM concentrations started to rise due to the loss of moisture from litter (as shown in Table 2). On d14, three days after stopping liquid spray, the levels of $PM_{2.5}$, PM_{10}, and TSP rebounded to 0.72, 1.02, and 1.12 mg m^{-3}, and they are expected to continue to rise and reach the levels before the first spray on d1. The PM reduction efficiency, together with NH_3 reduction efficiency, will be verified in a subsequent field study with a commercial aviary CF hen house. Further information about reduction on different sizes of PM can be found in Table 5.

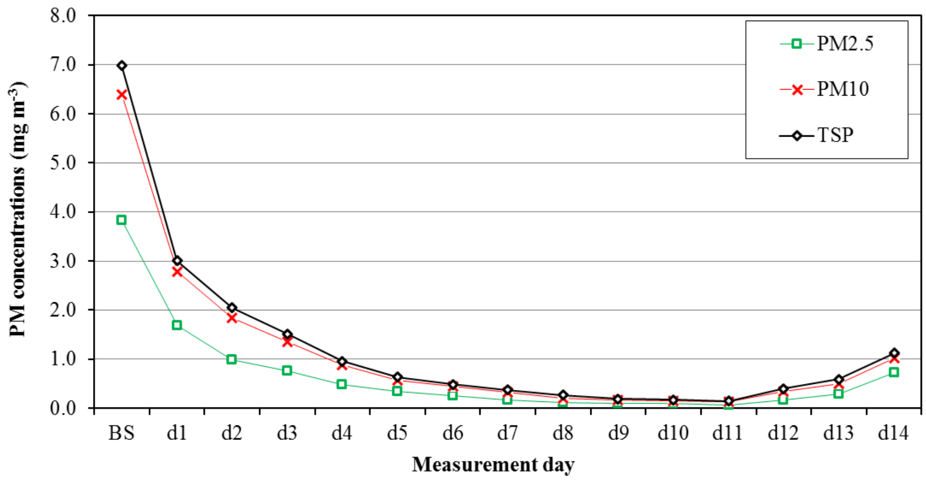

Figure 6. Daily mean concentrations of $PM_{2.5}$, PM_{10}, and TSP in treatment and control DECs.

Table 5. Different size of PM concentrations under NEW spray dosage of 25 mL (kg dry litter)$^{-1}$ once-a-day (mean±SD, n=4).

Day	PM_1	$PM_{2.5}$	PM_4	PM_{10}	TSP
Before spray	3.55±0.63	3.83±0.66	4.47±0.66	6.39±0.55	7.00±0.46
d1	1.53±0.24	1.68±0.30	1.98±0.31	2.78±0.41	3.01±0.44
d2	0.89±0.07	1.68±0.10	1.98±0.12	2.78±0.18	3.01±0.13
d3	0.69±0.12	0.76±0.14	0.90±0.18	1.35±0.24	1.52±0.23
d4	0.44±0.06	0.48±0.06	0.59±0.07	0.88±0.15	0.96±0.17
d5	0.32±0.03	0.35±0.03	0.41±0.04	0.57±0.05	0.63±0.03
d6	0.22±0.01	0.25±0.01	0.30±0.01	0.44±0.03	0.48±0.04
d7	0.15±0.01	0.16±0.01	0.20±0.01	0.33±0.01	0.38±0.02
d8	0.12±0.00	0.12±0.01	0.13±0.02	0.20±0.01	0.27±0.01
d9	0.08±0.04	0.09±0.04	0.11±0.04	0.17±0.02	0.19±0.02
d10	0.09±0.01	0.10±0.01	0.11±0.01	0.15±0.02	0.17±0.03
d11	0.06±0.01	0.07±0.01	0.09±0.01	0.14±0.01	0.15±0.01
d12	0.16±0.01	0.17±0.01	0.20±0.02	0.33±0.02	0.39±0.02
d13	0.26±0.15	0.29±0.14	0.33±0.13	0.50±0.08	0.59±0.08
d14	0.66±0.07	0.72±0.07	0.80±0.06	1.02±0.02	1.12±0.07

Note: PM concentration in the table was monitored between 17:00-18:00 (middle time of litter tilling period of 12:00 to 22:00) from d1-d14 after NEW spray.

Field verification of the lab-test findings is underway at a commercial CF farm in central Iowa where the litter samples used in the current study were collected. Besides verifying mitigation efficiency of NH_3 and PM, economic performance of applying litter additives to reduce NH_3 emissions will be assessed as well. The litter additive (PLT) tested in the current study costs about $800 per metric ton (based on price quote from a local vendor – Best Vet Solutions, Ellsworth IA in March 2017). The operational cost (PLT cost and labor cost) for a commercial CF house (50,000 laying hens with litter floor areas of 2400 m^2) is estimated to be $0.122, $0.239, and $0.356 $bird^{-1}$ yr^{-1} at the PLT application rate of 0.3, 0.6, and 0.9 kg m^{-2} (or 60.8, 121.6, and 184.2 lb. per 1000 ft^2), respectively, and at application frequency of once a month. A trade-off between NH_3 reduction and the litter additive application will be evaluated for commercial CF egg production.

4. Summary and Conclusions

A lab-scale study was conducted to assess the efficacy of PLT® litter additive (LA) at three application rates (Low, Med, High), relative to control (no application) on reducing ammonia (NH_3) emissions from litter of CF hen house together with spray of neutral electrolyzed water (NEW) for PM control. The following observations and conclusions were made.

- Ammonia emission rates of control-no LA, Low-LA, Med-LA, and High-LA averaged 0.76, 0.55, 0.37, and 0.16 g (kg dry litter)$^{-1}$d^{-1}, yielding 28%-79% reduction in NH_3 emission by the treatments. The NH_3 reduction efficiency is linearly proportional to the PLT application rate, with higher application rate resulting in significantly lower litter pH ($P<0.05$).
- The levels of $PM_{2.5}$, PM_{10}, and TSP were reduced from 3.83, 6.39, and 7 mg m^{-3} before the NEW spray to 0.07, 0.14, and 0.15 mg m^{-3} after 11 once-a-day NEW sprays. Following a 3-day suspension of the NEW spray, the PM levels rebounded to 0.72, 1.02, and 1.12 mg m^{-3} for $PM_{2.5}$, PM_{10}, and TSP, respectively, due to reduced litter moisture content.
- While higher application rates of litter additive suppress NH_3 emissions further, a balance between NH_3 reduction and the cost associated with the additive application need to be considered for commercial CF production facilities. This part will be evaluated and identified in the future field verification test, based on these lab-test findings.

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References

Adell, E., Calvet, S., Pérez-Bonilla, A., Jiménez-Belenguer, A., García, J., Herrera, J. and Cambra-López, M., 2015. Air disinfection in laying hen houses: Effect on airborne microorganisms with focus on Mycoplasma gallisepticum. *Biol. Eng*., 129, 315-323.

Campbell, D.L.M., Makagon, M.M., Swanson, J.C. and Siegford, J.M., 2016. Litter use by laying hens in a commercial aviary: dust bathing and piling. *Poult. Sci*., 95:164–175. doi.org/10.3382/ps/pev183

Chai, L., Zhao, Y., Xin, H., Wang, T., Atilgan, A., Soupir, M. and Liu, K., 2017. Reduction of particulate matter and ammonia by spraying acidic electrolyzed water onto litter of aviary hen houses – a lab-scale study. *Trans. ASABE.*, 62 (2), 497-506. DOI:10.13031/trans.12081.

Chai, L., Zhao, Y., Xin, H., Wang, T., Soupir, M., 2017. Mitigating airborne bacteria emissions from cage-free layer litter by spraying acidic electrolyzed water. *Biol. Eng*. (Under Review- manuscript # YBENG-2017-259).

Fairchild, B. D., Worley, J. W., Czarick, M., & Ritz, C. W. (2006). Effects of heavy application of litter amendment on broiler house ammonia concentration. In 2006 ASAE Annual Meeting. July 9-12, Portland, Oregon, USA. Paper# 064187. St. Joseph, MI, ASABE.

Hayes, M. D., Xin, H., Li, H., Shepherd, T. A., Zhao, Y. and Stinn, J., 2013. Ammonia, greenhouse gas, and particulate matter emissions of aviary layer houses in the midwestern United State. *Trans. ASABE.*, 56(5), 1921–1932.

Li, H., Xin, H., Liang, Y., & Burns, R. T. (2008). Reduction of ammonia emissions from stored laying hen manure through topical application of zeolite, Al+ Clear, Ferix-3, or poultry litter treatment. *J. Appl Poult Res*., 17(4), 421-431.

Li, H., Lin, C., Collier, S., Brown, W., & White-Hansen, S. (2013). Assessment of frequent litter amendment application on ammonia emission from broilers operations. *J. Air Waste Manag Assoc*, 63(4), 442-452. Moore, P.A., Daniel, T.C., Edwards, D.R. and Miller, D.M., 1995. Effect of chemical amendments on ammonia volatilization from poultry litter. *J. Environ. Qual*., 24(2), 293-300.

Liang, Y., Xin, H., Wheeler, E.F., Gates, R.S., Li, H., Zajaczkowski, J.S., Topper, P.A., Casey, K.D., Behrends, B.R., Burnham, D.J. and Zajaczkowski, F.J., 2005. Ammonia emissions from US laying hen houses in Iowa and Pennsylvania. *Trans. ASABE.*, 48(5), 1927-1941.

Liang, Y., Xin, H., Li, H., Koziel, J. A., & Cai, L. (2005). Evaluation of treatment agents and diet manipulation for mitigating ammonia and odor emissions from laying hen manure. In 2005 ASAE Annual Meeting. July 17-20, Tampa, Florida, USA. Paper# 20054160. St. Joseph, MI, ASABE.

Moore, P.A., T.C. Daniel, and D.R. Edwards. 2000. Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminum sulfate. *J. Environ. Qual*., 29:37–49.

Moore, P.A., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1995. Effect of chemical amendments on ammonia volatilization from poultry litter. *J. Environ. Qual*., 24:293–300.

Moore, P.A., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1996. Evaluation of chemical amendments to reduce ammonia volatilization from poultry litter. *Poult. Sci*., 75:315–320.

NIOSH. Pocket Guide to Chemical Hazards (NPG). https://www.cdc.gov/niosh/npg/npgd0028.html. (accessed at May 25, 2016).

Ogink NWM, van Harn J, van Emous RA, Ellen HH., 2012. Top layer humidification of bedding material of laying hen houses to mitigate dust emissions: effects of water spraying on dust, ammonia and odor emissions. Proceedings of The Ninth International Livestock Environment Symposium; Jul 8 – 12 2012.Valencia, Spain; St. Joseph, MI, ASABE, 2012.

R Core Team, 2014. R: A language and environment for statistical computing. R Foundation for 831 Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Shepherd, T.A., Zhao, Y., Li, H., Stinn, J.P., Hayes, M.D. and Xin. H. 2015. Environmental assessment of three laying-hen housing systems– Part II: ammonia, greenhouse gas, and particulate matter emissions. *Poultry Sci*., 94(3), 534-543.

Terzich, M., C. Quarles, J. Brown, and M. A. Goodwin. 1998. Effect of Poultry Litter Treatment (PLT) on the development of respiratory tract lesions in broilers. *Avian Pathol*., 27:566–569.

United Egg Producers (UEP). 2016. Animal Husbandry Guidelines for U.S. Egg Laying Flocks (2016 Edition). http://www.unitedegg.org/AnimalWelfare/default.cfm. (Accessed on March 15th, 2017).

US Egg Producers (UEP). http://www.unitedegg.com/newsletter/readfile.cfm?id=569. (Accessed on April 20, 2017).

U.S. EPA .2015. National Ambient Air Quality Standards (NAAQS). https://www.epa.gov/criteria-air-pollutants/naaqs-table (accessed on January 10th, 2017).

Winkel, A., Van Riel, J. W., Van Emous, R. A., Aarnink, A. J. A., Koerkamp, P. G., & Ogink, N. W. M. 2016. Abatement of particulate matter emission from experimental aviary housings for laying hens by spraying rapeseed oil. *Poultry Sci*., 95(12), 2836-2848.

Xin, H., 2016. Environmental challenges and opportunities with cage-free hen housing Systems. The XXV World’s Poultry Congress, September 5-9, Beijing, China.

Xin, H., Gates, R.S., Green, A.R., Mitloehner, F.M., Moore, Jr. P.A. and Wathes, C.M., 2011. Environmental impacts and sustainability of egg production systems. *Poultry Sci.*, 90(1), 263-277. doi:10.3382/ps.2010-00877

Zhao, Y., Shepherd, T.A., Li, H., Stinn, J.P., Hayes, M.D., and Xin. H. 2015. Environmental assessment of three laying-hen housing systems–Part I: monitoring system and indoor air quality. *Poultry Sci.*, 94(3), 518-533.

Zhao, Y., Zhao, D. and Xin, H., 2013. Characterizing manure and litter properties and their carbon dioxide production in an aviary laying-hen housing system. In: ASABE Annual International Meeting, Kansas City, Missouri.

Zhao, Y, Xin, H., Zhao, D., Zheng, W., Tian, W., Ma, H., Liu, K., Hu, H., Wang, T., and Soupir, M.L.2014. Free chlorine loss during spray of membrane-less acidic electrolyzed water and its antimicrobial effect on airborne bacteria from poultry house. *Ann. Agric. Environ. Med.*, 21(2), 249-255.

Zhao, Y., Zhao, D., Ma, H., Liu, K., Atilgan, A. and Xin, H., 2016. Environmental assessment of three egg production systems–Part III: Airborne bacteria concentrations and emissions. *Poultry Sci*., 1-9. http://dx.doi.org/10.3382/ps/pew053.

Zheng, W., Y. Zhao, H. Xin, B. Li, R.S. Gates, Y. Zhang and M.L. Soupir. 2014. Airborne particulate matter and bacteria reduction from spraying slightly acidic electrolyzed water in an experimental aviary laying-hen housing system. *Trans. ASABE.*, 57(1), 229-236.