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Mitigating Particulate Matter Emissions of a Commercial Cage-free Aviary Hen House

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ABSTRACT. *Concerns over animal welfare among general public and marketing decisions have led to pledges by a number of U.S. food retailers and restaurants to source only cage-free (CF) eggs in the foreseeable future, e.g., by 2025. Compared to conventional cage production system, CF hen housing offers hens more space and opportunities to exercise their natural behaviors (e.g., perching, dust bathing, and foraging). However, CF housing poses many inherent environmental challenges, among which are high levels of particulate matter (PM) and ammonia (NH_3). Spraying liquid agent (e.g., 125 mL m^{-2} per cm litter depth) has been shown to effectively mitigate the generation of PM by 60-70% from CF henhouse litter in our previous lab-scale tests. The objectives of this study were to verify the lab-study findings of PM reduction with liquid spray on a commercial CF farm and to evaluate the indoor air and litter quality before and after liquid spray. This field verification study was conducted with a commercial aviary CF house (50,000 laying hens, L×W×H = 154 × 21.3 × 3.0 m) in Iowa during winter of 2017-2018. A water sprinkling system was installed in half of the experimental henhouse in the length direction (treatment section), whereas the other half of the henhouse served as the control. In each trial, the spray dosage (125 mL H_2O m^{-2} per cm litter depth) was adjusted according to the initial litter depth before the spray. A total of three trials were conducted in this study. Results show that the PM concentration was reduced by 37-51% PM in the commercial aviary henhouse. The lower reduction efficiency in the field than the values obtained in the lab tests was partially attributed to the fact that water spray was applied to only the open litter area, and the litter area under the aviary system was not sprayed. Adjusting spray dosage according to litter depth is necessary for maintaining a certain reduction efficiency. Litter moisture content of the treatment sections was 9-14% higher than control (i.e., 15.6% vs. 14% for Trial 1, 14.6% vs. 12.2% for Trial 2, and 17.7% vs. 14.9% for Trial 3), but NH_3 concentrations in treatment and control were similar during the test.*

Keywords: *Alternative hen housing; animal welfare; worker health; air quality.*

Introduction

Concerns over animal welfare among general public and marketing decisions have led to pledges by a number of U.S. food retailers and restaurants to source only cage-free (CF) eggs by certain year (e.g., 2025). According to the current number of pledges, it would take more than 70% of the current US layer inventory to meet the demand by 2025 (Xin, 2016; UEP, 2017). Compared to conventional cage production system, CF hen housing offers hens more space and opportunities to exercise their natural behaviors (e.g., perching, dust bathing, and foraging). However, CF housing poses many environmental challenges, such as high levels of particulate matter (PM) and ammonia (NH_3), especially during cold weather when the house has limited ventilation (Takai et al., 1998; Hayes et al., 2013; Zhao et al, 2013, 2015; Shepherd et al., 2015).

Zhao et al. (2015) reported that PM_{10} levels (~4 mg m^{-3}) in aviary CF houses were 6-9 times higher than conventional cage manure-belt and enriched colony houses. The PM_{10} levels in CF henhouses are far higher than the 24h concentration threshold of 150 µg m^{-3} set by U.S. EPA to protect public welfare (U.S. EPA, 2015). Higher levels of PM or dust in CF house air can carry more airborne microorganisms and endotoxins which, once inhaled, may cause infection or trigger respiratory diseases to animals and/or their caretakers (Cambra-López et al., 2010). Therefore, mitigating PM levels is imperative to protecting the health and well-being of the animals and the caretakers; and improving the environmental stewardship of CF egg farms (Xin et al., 2011; EPA, 2015).

The high PM levels in CF hen houses primarily stem from the hen activities on litter floor. Spraying liquid agents onto litter floor, such as tap water, acidic water, electrolyzed water, and mixture of water and soybean or canola oil, has been shown to reduce dust level or disinfect poultry houses (Ellen et al., 2000; Zheng et al., 2014; Adell et al., 2015; Winkel, et al., 2016). Zheng et al. (2014) sprayed regular tap water and slightly acidic electrolyzed water at 80 mL m^{-2} onto laying-hen litter, which reduced PM by 49%. There was no difference between tap water and AEW in PM reduction. Chai et al. (2017) reported that spraying acidic electrolyzed water at dosages of 25, 50, and 75 mL [kg dry litter]$^{-1}$d^{-1} could reduce PM levels by 71%, 81%, and 89%, respectively, immediately after spraying. The PM reductions were still significant after 24h of spraying, averaging 57-83%. However, high dosage of spray enhanced NH_3 emissions as litter moisture content (LMC) was increased in proportion to the spray dosage. Ogink et al. (2012) reported that spraying 150-600 mL m^{-2} water on the litter increased NH_3 emissions by 21-65%, although the PM level was reduced by 18-64% in CF henhouses in Europe. Application of low pH liquid to the litter would help control PM and ammonia at the same time, but concerns arise about the potential corrosive effect of acidic liquid on the housing equipment. Chai et al. (2018a) conducted research in dynamic emission chambers by spraying neutral electrolyzed water (pH=7-8) at 125 mL m^{-2} (corresponding to litter depth of 1 cm) and applying PLT^{TM} litter additive at 30 g per kg dry litter onto CF henhouse-collected litter, which reduced the generation of PM by 60-70% and NH_3 by 70-80%, respectively. Properly controlling the water spray dosage could maintain over 50% PM reduction efficiency without causing NH_3 issue.

The objectives of this study were (1) to verify the lab findings of PM reduction with specific spray dosage (e.g., 125 mL m^{-2} per cm litter depth) of neutral water or farm tap water in commercial CF henhouse; and (2) to assess the litter and air quality before and after liquid spray in the commercial production system.

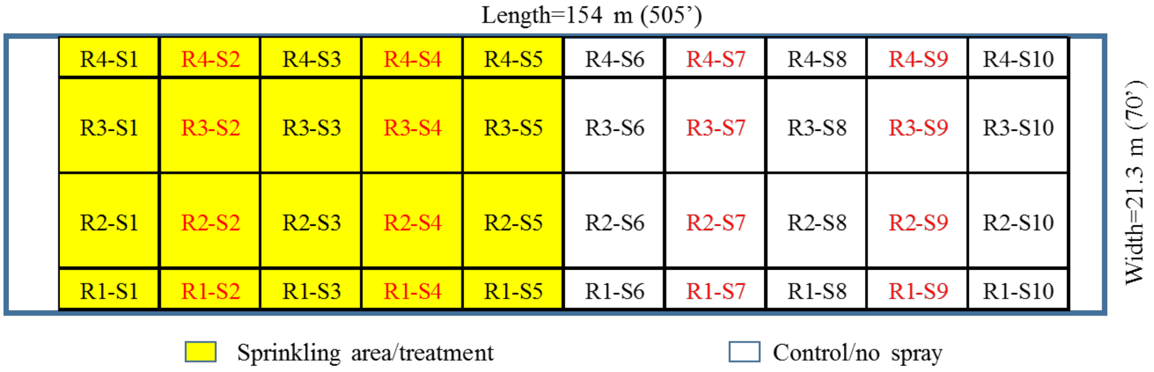
Materials and Methods

Laying-hen house and sprinkling system

This PM mitigation verification study was conducted in a commercial aviary CF henhouse (50,000 hens-DeKalb White, 155 L × 21 W × 3 H m) in central Iowa. A sprinkling system (Weeden Environments Inc., Ontario, Canada) was installed in half of the house in the length direction (treatment) (fig.1), and the other half of the house (without spray) served as the control. The CF house had four rows of litter floor in the width direction (denoted as R1-R4, fig. 2). The two outside rows (R1 and R4) each had 1.2 m wide open litter and the two middle rows (R2 and R3) each had 2.8 m wide open litter. Each row was further divided into 10 sections (S1-S10) in the length direction by metal wire mesh with pass-through doors; hence totally there were 40 zones of litter floor (fig. 2). S1-S5 were treatment sections (highlighted in yellow) and S6-S10 were control sections. No sprinklers were installed for the litter area beneath the aviary structure system due to space limitation.

For the different-width rows, different types of sprinklers were installed at the height of 2.2 m above the litter floor. Twelve box tie sprinklers (each covering an area of 1.0 m × 4.2 m) was installed for each of R1 and R4 (the narrow litter rows). For each of two middle (wider) rows (R2 and R3), 29 spiral sprinklers were installed (each covering an area of 2.8 m × 2.8 m). All sprinkler lines had the water pressure of 276 kPa (40 psi). The sprinklers had a rated water output of 43 L hr^{-1} and 35 L hr^{-1} for the box tie and spiral sprinklers, respectively. Commercial litter additive (PLT) was prepared in case the liquid spray would cause high NH_3; but it was not used because the treatment section did not show significantly higher NH_3 than the control during the test. In addition, the farm tap water (pH=7.7) was sprayed during the test, although a tank and a pump was designed for this system (see fig. 1a) so that other types of liquid agents (e.g., electrolyzed water or slightly acidic electrolyzed water) may be sprayed as well in the future.

Figure 1. The dust reduction sprinkling system (a) in a commercial aviary cage-free henhouse (b).



R4-S1	R4-S2	R4-S3	R4-S4	R4-S5	R4-S6	R4-S7	R4-S8	R4-S9	R4-S10
R3-S1	R3-S2	R3-S3	R3-S4	R3-S5	R3-S6	R3-S7	R3-S8	R3-S9	R3-S10
R2-S1	R2-S2	R2-S3	R2-S4	R2-S5	R2-S6	R2-S7	R2-S8	R2-S9	R2-S10
R1-S1	R1-S2	R1-S3	R1-S4	R1-S5	R1-S6	R1-S7	R1-S8	R1-S9	R1-S10

🟨 Sprinkling area/treatment ☐ Control/no spray

Figure 2. Sprinkling and control litter floor zones of the experimental commercial aviary cage-free henhouse (R-row, S-section; zones with red labels were monitored for environmental conditions).

During the lab study that preceded the field verification test, a spray dosage of 125 mL m^{-2} corresponding to 1 cm litter depth had been shown to achieve over 50% PM reduction without causing NH_3 problem (Chai et al., 2017, 2018a). This spray dosage was used as the base and adjusted according to the litter depth (table 1).

Table 1. Spray dosage corresponding to litter depth

	Trial 1	Trial 2	Trial 3
Start time (first spray)	10/26/2017	11/24/2017	12/29/2017
Initial litter depth	0.5 cm	1 cm	1.4 cm
Spray dosage	62.5 mL m^{-2}	125 mL m^{-2}	175 mL m^{-2}

Note: Each trial lasted for 28 d (14 d continuous spray, once-per-day, & 14 d dry period – without spray).

Enviromental factors monitoring

Eight representative spots (indicated in red labels in Figure 2) per control and treatment side were monitored continuously for T/RH (HOBO MX2300, ONSET, Bourne, MA) and periodically for NH_3 and PM (monitored on d0, d1, d4, d7, d10, d13, d15, and d18 in each trial). The NH_3 concentrations were monitored with portable NH_3 sensor (GasAlert, BW Technologies Ltd., Arlington, TX). Two locations (R3S3 and R3S8) were monitored for CO_2 (HOBO MAX Logger, ONSET, Bourne, MA). The CO_2 sensors and GasAlert NH_3 sensor were zero-span checked with standard calibration gases biweekly. 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), in 8 representatives spots of both treatment and control. The TSI PM monitor was zero calibrated weekly and sent back for manufacture calibration (multi points) twice during the test (once immediately before the test and once in the middle of the test).

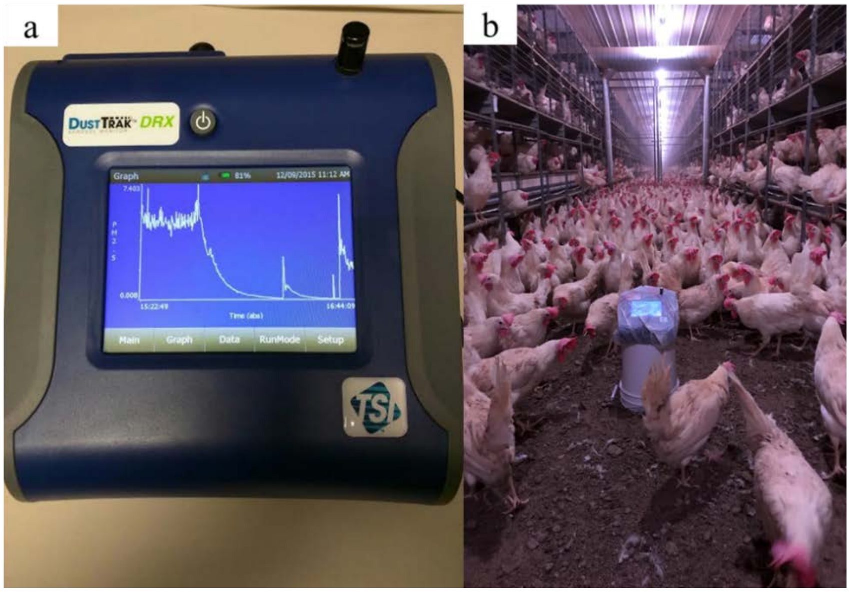


Figure 3. PM monitoring in the aviary cage-free henhouse: (a) TSI monitor; (b) placement of the PM monitor at 0.35 m above floor (near the birds level).

Litter sampling and moisture content (LMC) measurement

Litter on floor was sampled periodically (d0, d1, d4, d7, d10, d13, d15, and d18 in each trial) with new zip-loc bags from 8 representative spots of both control and treatment as shown in Figure 2. 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 LMC was calculated with the following equation.

$$LMC = 100 \times \frac{LWW - LDW}{LWW} \qquad \text{Eq.1}$$

where LMC – litter moisture content, %;
LWW – litter wet weight, g;
LDW – litter dry weight, g.

Data analysis

Statistical analyses were performed using R software version 3.3.3 (R Core Team, 2014). Tukey's honest significant difference (HSD) and linear model (lm) were applied to test the effect of water spray on PM and NH_3 emissions. Equation 2 lists the statistical model for the data analysis. Differences were considered significant at $p<0.05$.

$$Y_i = \mu + L_i + e_i \qquad \text{Eq.2}$$

Where Y_i denotes the independent observation (PM or NH_3 concentration) for water spray dosage i;
μ is the overall mean;
L_i is the water spray effect (fixed);
e_i is the random error with $N \sim (0, \sigma^2)$.

Results and Discussion

Henhouse thermal environemnt and CO_2 concentration

Air temperature (T) and RH of the control and treatment sections along with the outdoor are shown in Figure 4. The indoor T was maintained relatively constant (20-24ºC and RH of 55-70%) through adjustment of the building ventilation rate (VR) and supplemental heating (liquid propone) as needed. The control and treatment sections had similar indoor T (fig. 4-a), RH (fig. 4-b) and CO_2 concentrations (fig. 5) during the test (winter of 2017-2018). CO_2 concentrations spiked in late December 2017 when outside temperatures were low and VR was presumably reduced to the minimum.

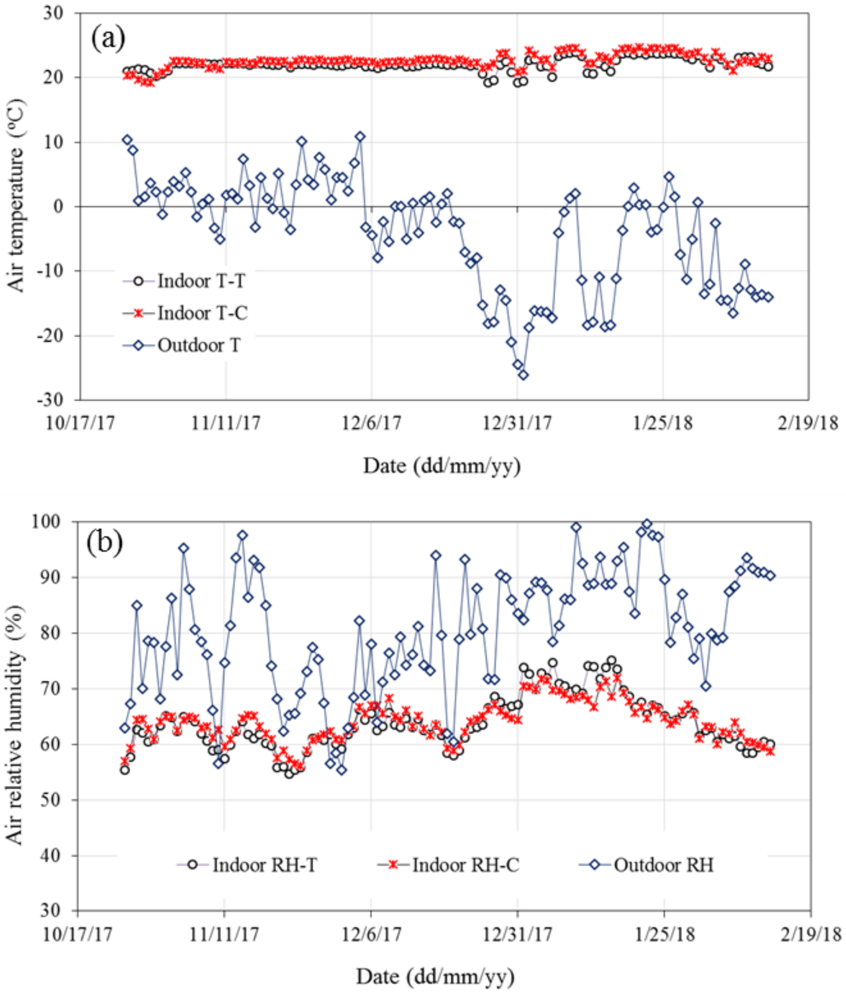


Figure 4. Air temperature (a) and RH (b) during the test (T-T and T-C represents air temperature in treatment and control section; RH-T and RH-C represents air relative humidity in treatment and control section, respectively).

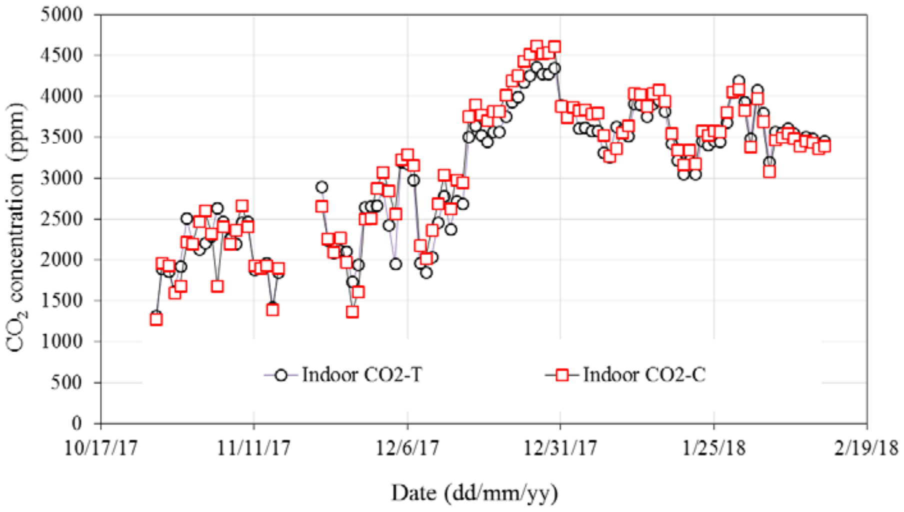


Figure 5. CO_2 concentrations in treatment and control (CO_2-T and CO_2-C represents CO_2 concentrations monitored in the treatment and control sections, respectively).

Litter moisture content (LMC) and NH_3 concentration

Treatment and control had similar LMC before water spray, i.e., 14.1% *vs.* 14.4% for Trial 1, 11.6% *vs.* 11.4% for Trial

2, and 13.2% *vs.* 13.5% for Trial 3. After spraying water once-a-day, LMC in the treatment increased gradually. LMC in the treatment and control were 15.6% *vs.* 14% for Trial 1, 14.6% *vs.* 12.2% for Trial 2, and 17.7% *vs.* 14.9% for Trial 3 (fig. 6). Generally, LMC in the treatment was 9-14% higher relative to the control. Besides liquid spray, the outdoor T variation could also affect LMC due to changes in VR or indoor heating operation.

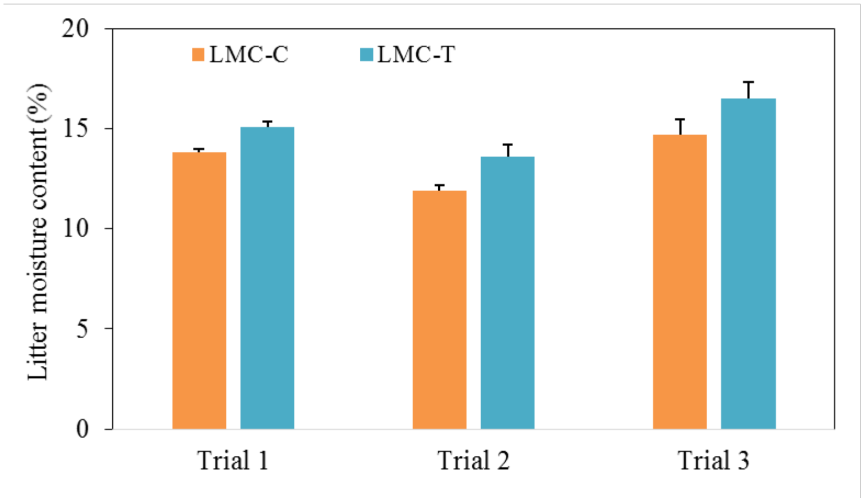


Figure 6. Litter moisture content (mean ± SE of d1 to d14 with once-a-day spray; LMC-T and LMC-C represents litter moisture content in the treatment and control section, respectively).

Figure 7 shows the NH_3 concentration measured in the treatment and control sections during the test. The treatment and control had similar level of NH_3 across each trial, i.e., 6.6 ppm *vs.* 6.8 ppm for Trial 1, 5.6 ppm *vs.* 5.5 ppm for Trial 2, and 15.8 ppm *vs.* 15.4 ppm for Trial 3. The spray dosage of 125 mL m^{-2} per cm litter depth tested in the aviary CF henhouse did not elevate the NH_3 level (p=0.104). Among the trials, Trial 3 had higher level indoor NH_3 than the precious two due to colder outdoor T and reduced VR from late December of 2017 to early January of 2018.

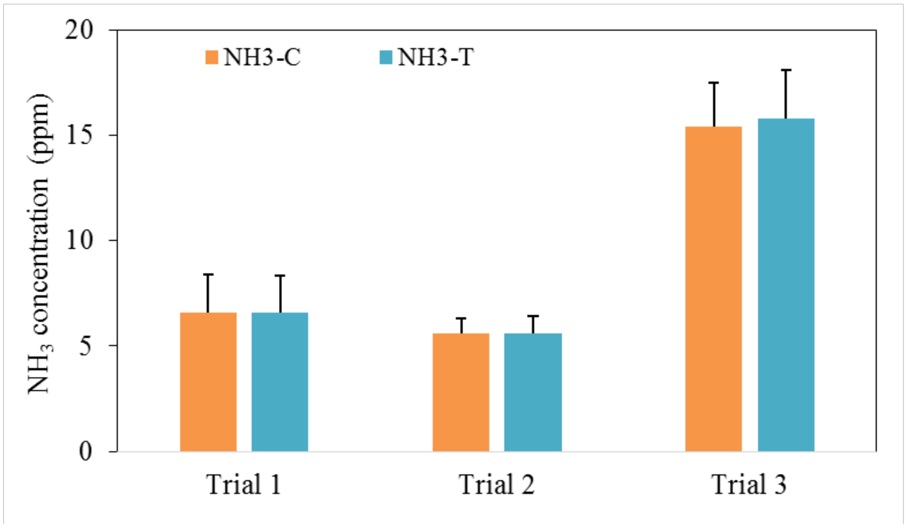


Figure 7. Ammonia concentration in the treatment and control (mean ± SE of d1 to d14 with once-a-day spray; NH_3-T and NH_3-C represents NH_3 concentration measured in the treatment and control section, respectively).

Particulate matter (PM) concentration and reduction efficiency

Figure 8 is an example of PM levels in the aviary CF henhouse over 24 h in late October of 2017. The PM levels within the day varied over time, especially during feeding, lights on/off, and litter-access periods. The PM levels also show vertical stratifications, with higher levels being closer to the litter floor (fig. 9) – the primary source of dust generation.

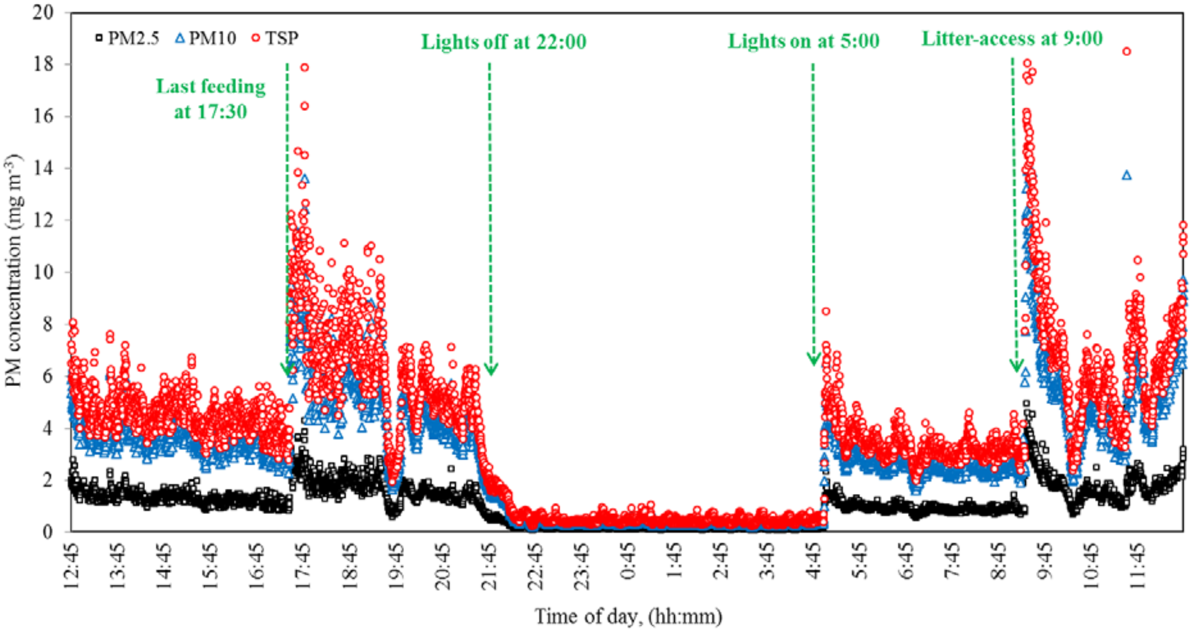


Figure 8. Diurnal particulate matter concentrations near litter level (0.25 m above) (Oct. 24-25, 2017).

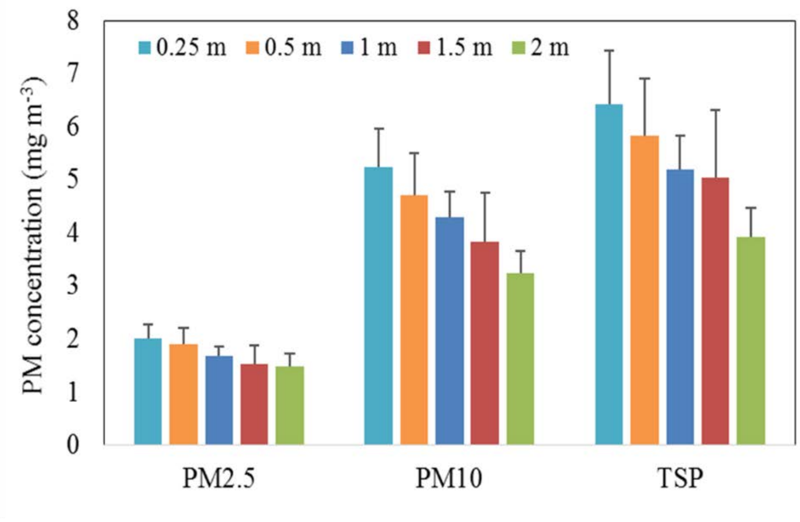


Figure 9. Vertical distributions of PM2.5, PM10 and TSP concentrations in the aviary cage-free henhouse.

Before spray (d0) of each trial, PM levels in the treatment and control were similar (fig. 10). After starting spray (d1-d14), the difference became clear, and the treatment had significantly lower PM levels ($p<0.05$). One day after stopping the spray (d15), there was still slight difference between the two regimens; but the difference disappeared 3d after stopping the spray (d18). The reduction efficiency during three trials is shown in Figure 11. The PM of different sizes in the treatment was 37-51% lower than in the control for the three trials. Higher spray dosages reduced dust level further, but not proportionally because the birds would mix the top and bottom of the litter during foraging and dust bathing. Therefore, adjusting spraying dosage according to litter depth is necessary. In addition, reduction efficiency in the field was lower than that in the lab test (60-70%) because of less spray coverage. In the field, the water was just sprayed onto the open area of the litter floor. The litter area under the aviary structures did not receive spray due to limited space for installation of the sprinkling system. Another reason for not installing sprinklers under the system was the concern over the birds pecking on and damaging the sprinklers.

The PM reduction efficiency of the current field study is close to but slightly lower than the reduction efficiency (i.e., 49%) reported by Zheng et al. (2014) with 80 mL m^{-2} tap water spray. But the efficiency is higher than the result (i.e., 18%) reported by Ogink et al. (2012) at 150 mL m^{-2} water spray for a CF hen house in the Netherlands and the result (i.e., 34%) reported by Zheng et al. (2012) at 216 mL m^{-2} for a layer breeding house in China. A number of reasons may contribute to the difference in PM reduction at the similar spray dosage, such as spreader/sprinkler installation (coverage area, and installation height), initial litter quality (e.g., LMC, litter depth, and bedding materials used), and flock management (e.g, lighting and feeding schedule, laying hen breed/age and activity level). A primary consideration in the current study is adjusting the spray dosage according to the litter depth.

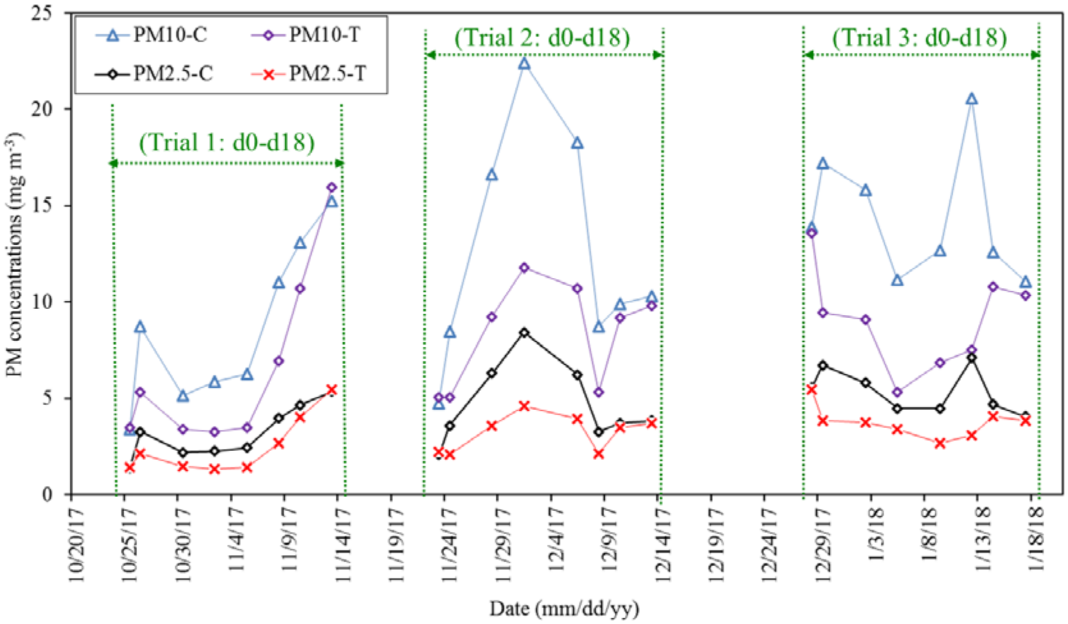


Figure 10. PM levels in the treatment and control (monitored on d0, d1, d4, d7, d10, d13, d15, and d18 in each trial).

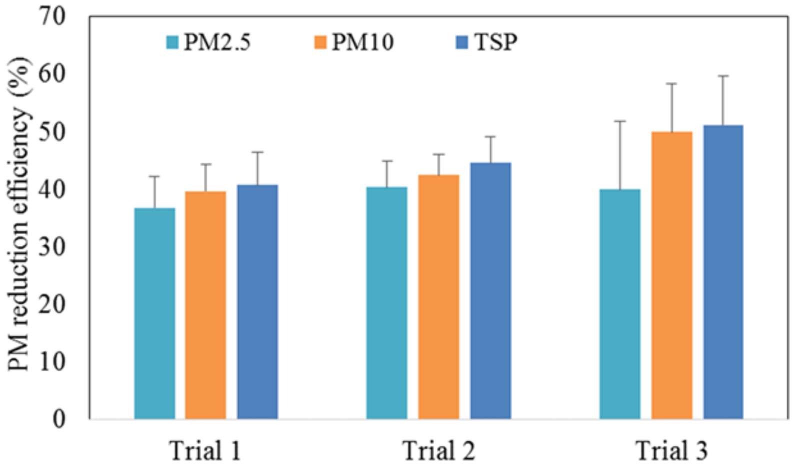


Figure 11. PM reduction efficiency (mean ± SE of d1 to d14 with once-a-day spray).

Besides PM reduction to improve air quality, the sprinkling system can and will be used to alleviate heat stress in the CF house in summer. Surface wetting has been proven effective to cool birds (Chepete & Xin, 2000; Tao and Xin, 2003; Liang et al., 2014). This heat stress relief method is expected to improve the animal welfare and production performance during hot weather. We intend to collect the relevant data in the upcoming summer.

Conclusions

Spraying water at 125 mL m^{-2} per cm litter depth, once a day, reduced PM by 37-51% as compared to no-spray in a commercial aviary cage-free henhouse during the winter of 2017-2018. Higher spray dosages reduced dust level further, but reduction efficiency was not directly proportional to spray dosage because of mixing activities by the laying hens when foraging and/or dust-bathing on the litter. Adjusting spray dosage according to litter depth is necessary to maintain a certain reduction efficiency. Under the current spray scheme of once-a-day spray over 14 d, litter moisture content in the treatment was 9-14% higher relative to the no-spray. Ammonia level was not affected by the water spray. Further evaluation of the system's additional function to alleviate laying-hen heat stress during hot weather is warranted.

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