Concentrations and settling rates of particulate matter in laying hen barns in the hot climatic region of Cameroon

Ngwa Martin Ngwabie[1*], Edna Buhnyuy Visiy[1], Pride Ndasi Ngwasiri[2], Theodore Ngwa Chenwi[1]

(1. Department of Agricultural and Environmental Engineering, College of Technology, The University of Bamenda-Bambili, Cameroon; 2. Department of Food and Bio-resource Technology, College of Technology, The University of Bamenda-Bambili, Cameroon)

Abstract: Particulate matter (PM) serves as a carrier of adhesive gaseous compounds, and may result to an underestimation of gas emissions from livestock barns when only filtered air samples are analysed. PM concentrations have hardly been studied in the unique livestock production system of Sub-Saharan Africa. This study was aimed at generating baseline data for PM (total suspended particulates) concentrations and settling rates in laying hen barns with cemented floors and wood shavings added as an initial bedding material. Measurements were conducted in two naturally ventilated laying hen barns in Cameroon; a barn with 4 months old hens that had just stated laying eggs and a barn with 18 months old egg laying hens. PM concentration was determined gravimetrically from the mass collected on a 1.2 µm pore diameter filter. Four plates with a surface area of 0.09 m^2 each, hung at a height of 1.7 m from the floor were used to gravimetrically determine PM settling rates over a fixed duration. Results revealed that PM concentrations were likely depended on the age of the hens, barn type and barn management system. PM concentrations were 6.61 mg m^{-3} and 10.17 mg m^{-2} in the barns with 4 and 18 months old hens respectively. PM settling rates were 53.79 mg m^{-2} h^{-1} and 115.52 mg m^{-2} h^{-1} in the barns with 4 and 18 months old hens respectively. No fixed location within the barn experienced consistently high or low PM settling rates. Temporal and spatial variations in settling rates could be related to management routines and hen activity. The correlation between PM concentrations and settling rates depended on the location of settling plates. This research highlights the need for PM emission mitigation strategies that are applicable to the climate and production system in Sub-Saharan Africa.

Keywords: air pollution, dust, laying hens, total suspended particulates, Cameroon.

Citation: Ngwabie, N. M., E. B. Visiy, P. N. Ngwasiri, and T. N. Chenwi. 2020. Concentrations and settling rates of particulate matter in laying hen barns in the hot climatic region of Cameroon. Agricultural Engineering International: CIGR Journal, 22(1): 40-47.

1 Introduction

Livestock production in confined feeding facilities such as poultry barns is a potentially significant source of particulate matter (PM) emissions, which adversely affect animals, farm workers, residents in the surrounding communities and the environment. A high prevalence rate of obstructive pulmonary disorder has been reported in poultry workers exposed to PM (Viegas et al., 2013), and PM can also cause respiratory problems in broilers (Homidan et al., 2007). PM has also been reported to carry

Received date: 2019-01-06 **Accepted date:** 2019-07-18

***Corresponding author: Ngwa Martin Ngwabie**, author title(Ph.D), Department of Agricultural and Environmental Engineering, College of Technology, The University of Bamenda, Box 39, Bambili, N. W. Region. Cameroon. Tel: +237671643209. Email: ngwabie@yahoo.co.uk

volatile organic compounds and other odorant gases such as NH_3, a pollutant gas, as it is emitted from livestock barns (Carey et al., 2004; Ngwabie, 2005; Lovanh et al., 2012). As such, instruments that measure direct gas concentrations from filtered air inside livestock barns may underestimate emission factors as the portion of gaseous pollutants such as NH_3 that easily adhere to PM is often ignored. While PM emission factors have been established and mitigation strategies tested and proposed for European and North American production systems, such as oil/water application and changes in bedding material (Takai et al., 1996; Gustafsson and Von Wachenfelt, 2006), little can be said regarding the production system in Sub-Saharan Africa with its extreme climatic conditions, predominantly naturally ventilated barns, and different management system. Baseline measurements of PM concentrations and dynamics are the first step toward assessing the magnitude of concentrations, emissions and validating appropriate mitigation strategies as well as assessing the emissions of adhesive gaseous pollutants. As such, this study was aimed at generating baseline data for PM (total suspended particulates) concentrations and settling rates in laying hen barns with cemented floors on which wood shavings was added as the initial bedding material in the hot climatic region of Cameroon.

2 Materials and methods

2.1 Sampling sites

Measurements were conducted in two naturally ventilated laying hen barns located in Bambili and in Nkwen in the North West Region of Cameroon. The Bambili barn was made up of two barns; one serving as an office and storage for feed and eggs while the other barn housed the laying hens. The hen barn had two rooms, separated internally by bamboos to a height of 2 m from the floor, with a surface area of 132 m^2 per room. Laying hens were in one of the rooms only at the time of the measurement, and occupied a surface area of 122 m^2 including the area occupied by feeders and drinkers. The length of the barn (long wall) was made up of mud blocks to a height of 0.60 m from the ground with the remaining top part covered with 2.4 m long bamboos to ease ventilation. The width (short wall) of the barn was completely covered with mud blocks to a height of 4.5 m at the ridge. The floor was concreted, with wood shavings used as bedding material. The barn had a gable roof with two-sided ridge ventilation. Measurements started on 21 June 2016 with 1049 hens that were 15 weeks old and ended on 12 July 2016 with 1044 hens. As such, the density was about 8.5 hens m^{-2} of the floor surface area. The hens had just started laying during the measurement period with an average of 6 eggs collected per day. The hens were fed in the mornings and evenings, consuming 150 kg of feed per day. Feed and water were supplied manually using 19 feeders and 8 drinkers (15 L buckets) evenly distributed in the room. Workers entered the barn within the day only during the feeding periods, with the barn lighted throughout the night from 5:30 p.m to 7:00 a.m.

The Nkwen farm has been described elsewhere (Ngwabie et al., 2018) with only a summary presented here. It had two barns, each partitioned into five rooms with a surface area of about 96 m^2 per room. On average, one barn had 18 months old laying hens (600 layers per room) while the other barn had 6 months laying hens (1000 layers per room). Measurements were conducted in the barn with 18 months old laying hens which had a density of about 6.3 hens m^{-2} of the floor surface area. The long walls of the barn were constructed using mud blocks to a height of 0.8 m from the ground, while the upper section was made of bamboos to a height of 1.6 m. The side walls were covered with mud blocks up to the ridge. The birds were fed twice a day and eggs were collected twice a day (~9 a.m. and 3 p.m.). The barn had a cement floor with wood shavings brought from the brooding room and applied just once before the birds were brought into the barn. No additional wood shavings were used throughout the laying cycle. Manure was removed intermittently based on demand from buyers. Water consumption was through automatic drinkers.

Natural ventilation was through the side walls and ridge with the barn lighted between 4.30 p.m and 7.30 a.m.

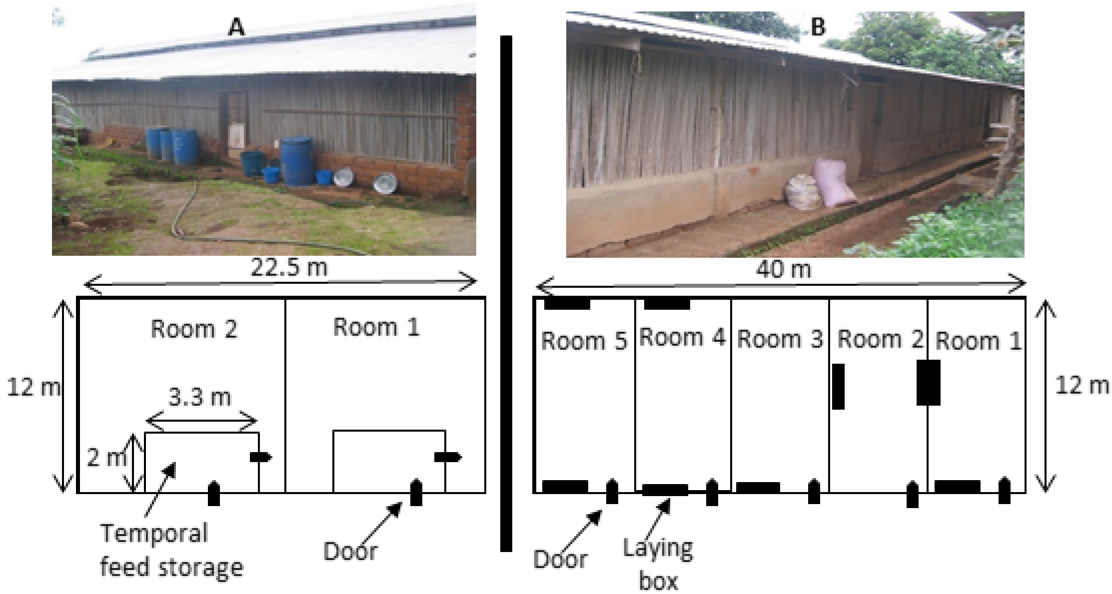

Figure 1 Picture and layout of the laying hen barns in Bambili (A) and Nkwen (B).

2.2 Measurement of particulate matter concentration

The concentration of PM (total suspended particulates) was determined gravimetrically from the mass collected on a filter of known mass through which a known volume of air was passed. Millipore filters with a nitrocellulose membrane having a diameter of 37 mm and a pore size of 1.2 µm (Millipore Corporation, Billenia, Ma, USA) were used to collect PM. A vacuum pump was used to draw air through the filter and the total time of operation measured using an electronic timer. The air flow rate through the pump was controlled at 3 L min^{-1} by a critical orifice. Each filter was weighed before measurements started using an electronic scale with an accuracy of 0.01 g (XY200st, Zhejiang, China). The filter was then placed in a holder which was connected by a teflon tube to the pump inlet. The holder was suspended at the centre of the barn, at a height of about 1.7 m from the ground. The pump and electronic timer were powered at the same time and left to run for 72 h, after which the filter was weighed. The duration of operation of the pump could be shorter than 72 has shown subsequently, due to the intermittent power cuts. Measurements were carried out for 3 weeks in each barn resulting to 7 PM measurements in each barn. The change in mass of the filters was used to determine PM concentration using in Equation 1. Due to the risk of disturbing the PM on the filters during transportation, the filters were weighed in the field, with the assumption that humidity had a minor effect on the filters.

$$C = \frac{m}{v \times c} \quad (1)$$

where C is the PM concentration (mg m^{-3}); m is the net mass increase of the filter after sampling (mg); V is the air flow rate of the vacuum pump (0.18 m^3 h^{-1}) and t is the measurement duration (h).

2.3 Measurement of particulate matter settling rate

The settling rate was determined gravimetrically using four settling plates made up of metal sheets, each with a surface area of 0.09 m^2. The plates were clean, weighed using the electronic scale and hung from the roof at a height of 1.7 m from the floor. Plate locations where evenly distributed along the two diagonals of the barn. After 72 h, the plates were weighed in the field and the change in mass of each plate was used to determine PM settling rate as shown in Equation 2.

$$S = \frac{m}{A \times t} \tag{2}$$

where S is the PM settling rate (mg m-2 h-1); m is the mass of PM that settled on the plate (mg); A is the surface area of the plate (0.09 m2) and t is the measurement duration (72 h). The settling rate calculated here is the average over the entire measurement duration of 72 h.

The relationship between PM settling rates for the different plates in each barn was analyzed using the one-way analysis of variance (ANOVA) test. Linear regression analysis was used to model the relationship between PM concentrations and PM settling rates.

2.4 Environmental data

During afternoon periods when the filters and plates were weighed, instantaneous litter temperature was measured by inserting a compost thermometer (TFA Dostmann, Wertheim, Germany) in the litter. At the same time, the instantaneous air velocity in the barn was measured using a hot wire thermos-anemometer (Extech Instruments, Nashua, USA) held in the center of the barn. Air temperature and relative humidity inside the barns were measured using a Tinytag data logger (Gemini Data loggers, Chichester, UK) at 5 min intervals.

3 Results and discussion

3.1 Indoor environmental data

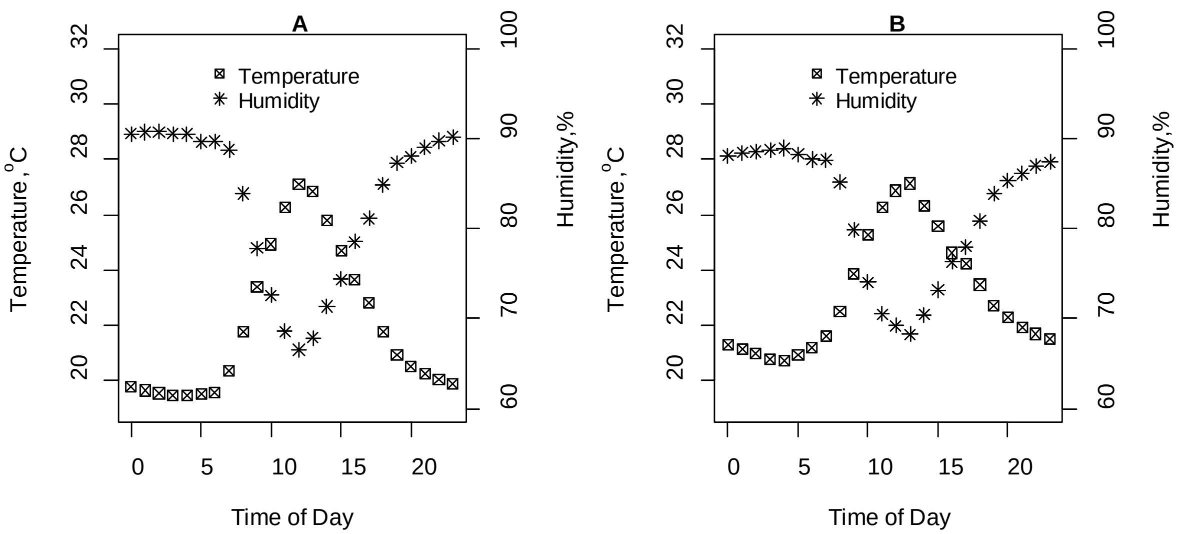

Figure 2 Diurnal variations in indoor air temperature and relative humidity in the Bambili (A) and Nkwen (B) laying hen barns. Data points present hourly averages throughout the experimental period.

Variations in hourly temperature and relative humidity in both barns are presented in Figure 2. The average hourly temperature and relative humidity were in the range of 19.5°C-27.1°C and 66%-91% respectively in the Bambili barn, while average hourly temperatures and relative humidity in the Nkwen barn were in the range of 20.7°C-27.1°C and 68%-89% respectively. Average instantaneous litter temperatures were 25°C and 26°C in the Bambili and Nkwen barns respectively, while the average instantaneous air velocities measured were 0.23 m s^{-1} and 0.27 m s^{-1} inside the Bambili and Nkwen barns in the respectively.

3.2 PM concentrations

PM concentrations as well as the effective sampling durations in both barns are presented in Table 1. A shorter sampling duration (24 h) is likely to provide detailed information about among-day variations. Results showed generally higher PM concentrations in the Nkwen barn compared to the Bambili barn. The mean PM concentration in Bambili was 6.61 mg m^{-3} while a much higher mean value of 10.17 mg m^{-3} was measured in Nkwen. The older hens (18 months old), which were in an advanced stage of egg production in the Nkwen barn compared to the Bambili barn (4 months old hens) probably contributed to the higher PM concentration in the Nkwen barn. There was also a higher worker activity in the Nkwen barn compared to the Bambili barn due to routine egg collection and random manure removal events (present in Nkwen and absent in Bambili), which disturbed the manure as well as the hens, and as such likely influenced PM concentrations (Costa and Guarino, 2009; David et al., 2015). Though not quantified in this study, the ventilation rate was likely not the same in both barns, which could have contributed to the observed differences in indoor PM concentrations. Studies have showed that ventilation rate is also an important factor in the indoor PM concentrations in animal barns (Xu et al., 2016). Although the outdoor background PM concentration was not measured, it was likely not the same in both locations, and as such, could also have contributed to the observed differences in the measured indoor PM concentrations in both barns. Floor design also affects airborne dust levels in poultry houses as solid floors in the present measurement have much higher levels than open-mesh floors (Casey et al., 2006). Table 2 shows that the average PM concentrations in this study were mostly higher compared to literature values, with the exception of measurements in a mechanically ventilated floor housing system in Sweden (Nimmermark et al., 2009).

Table 1 Particulate matter concentration in the aerial environment of two laying hen barns

Barn	Sampling duration (h)	Mass of PM trapped (mg)	Volume of air sampled (m^3)	PM concentration (mg m^{-3})
	68	90	12.24	7.35
	65	120	11.7	10.26
	72	110	12.96	8.49
Bambili	70	60	12.6	4.76
	72	60	12.96	4.63
	72	70	12.96	5.40
	72	70	12.96	5.40
Average	70.14	82.86	12.63	6.61
	28	60	5.04	11.90
	27	60	4.86	12.35
	37	70	6.66	10.51
Nkwen	40	60	7.2	8.33
	39	60	7.02	8.55
	48	70	8.64	8.10
	34	70	6.12	11.44
Average	36.14	64.29	6.51	10.17

Table 2 Particulate matter (total suspended particulate) concentrations in different laying hen barns

Location	Barn description	Concentration (mg m^{-3})	Source
Bambili layer barn	4.5 months old layers with wood shavings on concrete floor as initial bedding material	6.61	This Study
Nkwen layer barn	18 months old layers with wood shavings on concrete floor as initial bedding material	10.17	This Study
Northern Italy	Mechanically ventilated aviary system	0.44	(Costa and Guarino, 2009)
	Mechanically ventilated floor housing system	6.8–18	
Sweden	Mechanically ventilated caged layer house	2.0–2.5	(Nimmermark and Gustafsson, 2005)
	Mechanically ventilated multilevel system	0.71–2.4	
North-central Indiana, USA	Mechanically ventilated caged layer house	1.89±0.6	(Lim et al., 2003)

3.3 PM settling rates

Table 3 presents the average and range of PM settling rates in both barns. The average settling rate was 2 times higher in the Nkwen barn compared to the Bambili barn. This could be related to the higher PM concentrations in the indoor air of the Nkwen barn compared to the Bambili barn.

Spatial and temporal variations in PM settling rates are shown in Figures 3 and 4 for the different barns. It was observed that no fixed location within each barn experienced consistently high or low PM settling rates throughout the measurement duration. Despite the observed temporal and spatial variations, ANOVA tests indicated no statistical difference (alpha = 0.05) in PM settling rates between the different plates within each barn during the measurement duration.

When each 3-day measurement period was considered as shown in Figures 3 and 4, huge differences were noticed in PM settling rates for the different plates in each barn. In the Bambili barn for example, the highest difference in PM settling rates between the plates was 132 mg m^{-2} h^{-1} (Day 3 in Figure 3 and Table 3), while the lowest difference in PM settling rates between the plates was 46 mg m^{-2} h^{-1} (Day 15 in Figure 3 and Table 3). In the Nkwen barn, the highest difference in PM settling rates between the plates was 211 mg m^{-2} h^{-1} (Day 6 in Figure 4 and Table 3), while the lowest difference in PM settling rates between the plates was 22 mg m^{-2} h^{-1} (Day 3 in Figure 4 and Table 3). The uneven distribution of PM settling rates in the plates when each 3-day measurement period was considered, implied differences in the rates of PM accumulation on surfaces within the barns. This could be related to sections where animal or farm worker activity was high/low within the barns, which may impact birds and farm workers differently based on the sections in the barn where more time is spent.

Table 3 Average particulate matter settling rates in the Bambili and Nkwen laying hen barns

Barn	Sampling period number	Time (days)	Average mass (mg)	Average (range) settling rate (mg m^{-2} h^{-1})
Bambili	1	3	407.5	62.88 (3.09-135.8)
	2	6	440	67.90 (46.3-106.48)
	3	9	397.5	61.34 (21.6-121.91)
	4	12	355	54.79 (12.35-117.28)
	5	15	185	28.55 (7.72-54.01)
	6	18	275	42.44 (13.89-86.42)
	7	21	380	58.64 (30.86-92.59)
Mean			**348.57**	**53.79**
Nkwen	1	3	907.5	140.04 (129.63-151.23)
	2	6	972.5	150.08 (43.21-254.63)
	3	9	457.5	100.31 (40.12-146.60)
	4	12	650	70.60 (61.73-197.53)
	5	15	852.5	131.56 (81.79-259.26)
	6	18	555	85.65 (40.12-140.43)
	7	21	845	130.40 (81.80-163.58)
Mean			**748.57**	**115.52**

Note: Plate surface area = 0.09 m^2, sampling duration = 72 h, n = 4 (number of plates)

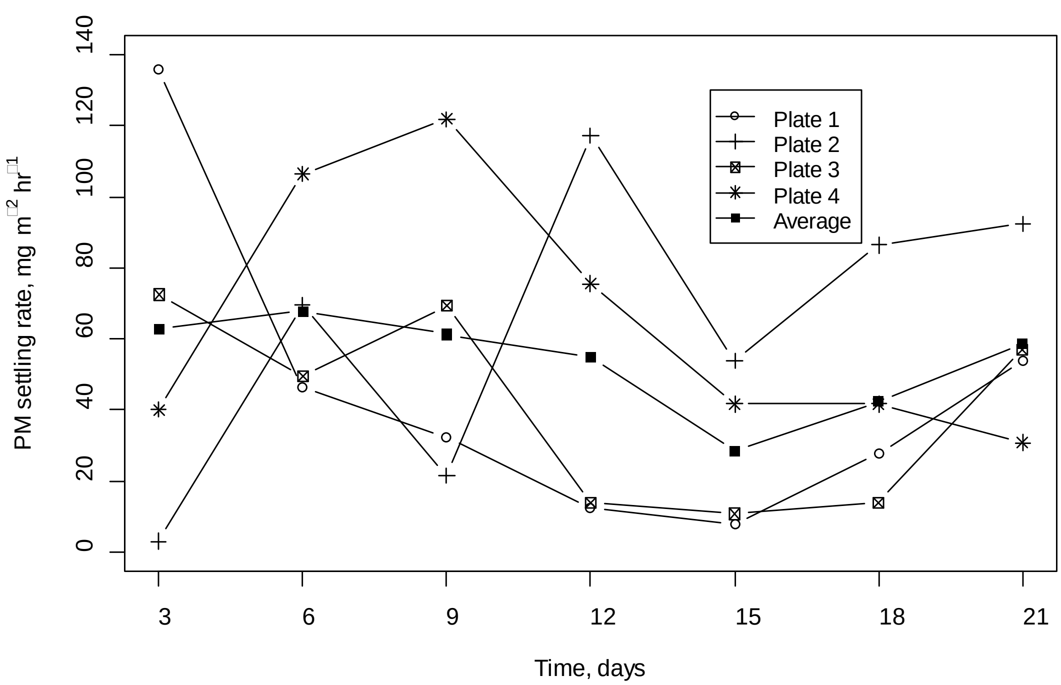

Figure 3 Spatial and temporal variation in particulate matter settling rates inside the laying hen barn in Bambili

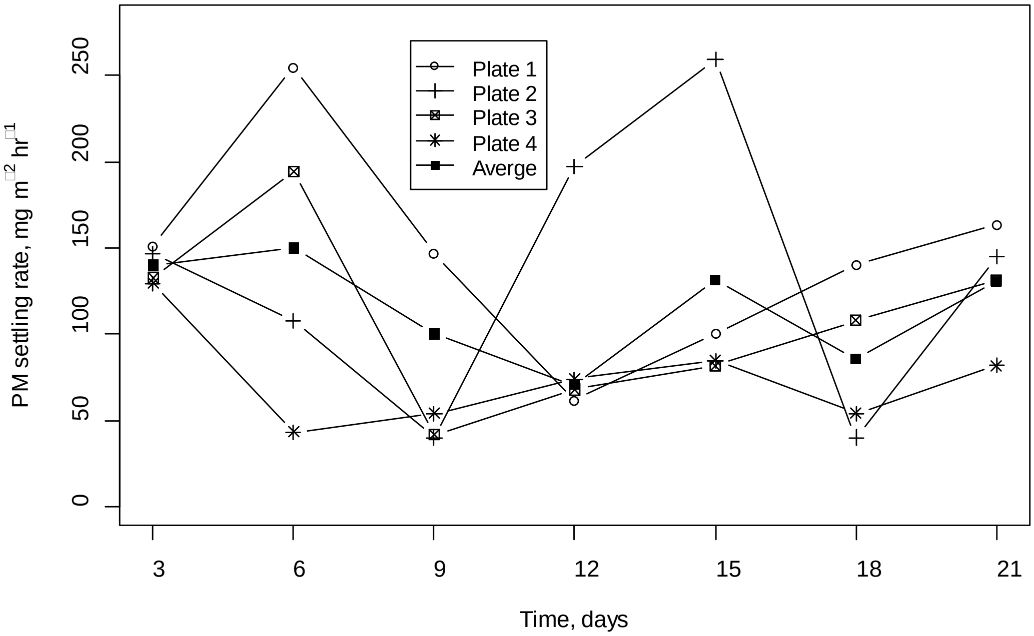

Figure 4 Spatial and temporal variation in particulate matter settling rates inside the laying hen barn in Nkwen.

The relationships between PM concentrations in the indoor air and PM settling rates are shown in Figures 5 and 6 for the Bambili and Nkwen barns respectively. Based on the coefficients of determination (R^2), various levels of correlation between PM concentrations and PM settling rates in different locations within the barns were observed. Significant correlations between PM concentrations and settling rates were observed in some of the plate locations (Plates 3 and 4 in Bambili and Plates 1 and 3 in Nkwen).

The single point measurement of PM concentrations in the present study may not have captured the dynamics of PM settling rates in each location (plate), strengthening the need for multi-location measurement of PM concentrations. Natural ventilation could also influence the indoor environment differently (depending on air inlets and outlets) and hence, the PM settling rates in different locations within the barn.

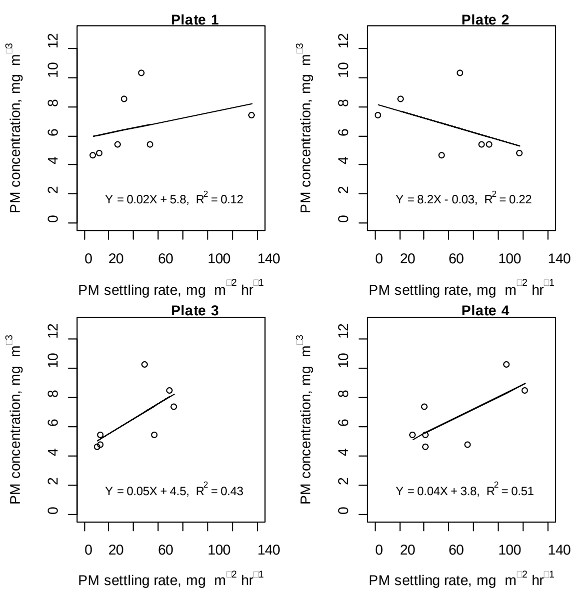

Figure 5 The relationship between particulate matter concentrations and settling rates for each plate in the Bambili laying hen barn.

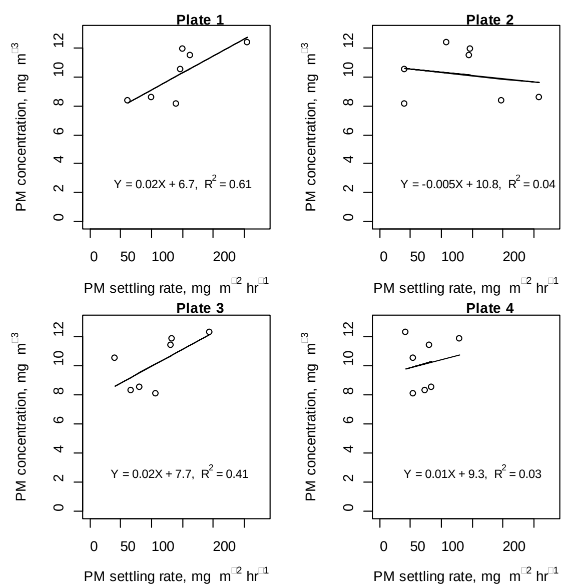

Figure 6 The relationship between particulate matter concentrations and settling rates for each plate in the Nkwen laying hen barn.

4 Conclusions

This research was aimed at quantifying PM concentrations and settling rates in naturally ventilated layer barns with wood shavings on concrete floor as the initial bedding material. The PM concentrations were likely dependent on the age of laying hens, barn type and its management system, with a value of 6.61 mg m^{-3} in the barn with 4 months old hens and 10.17 mg m^{-2} in the barn with 18 months old hens. Particulate matter settling rates were 53.79 mg m^{-2} h^{-1} and 115.52 mg m^{-2} h^{-1} in the barn with 4 months and 18 months old hens respectively. PM settling rates showed large spatial and temporal variations due likely to animal/worker activity. No fixed location within the barn experienced consistently high or low PM settling rates throughout the measurement period. The correlation between PM concentrations and settling rates depended on the location of settling plates. Long term seasonal measurements that also include outdoor PM concentrations will provide a detail understanding of PM load in barns with laying hens.

Acknowledgments

The authors acknowledge cooperation from the Bambili and Nkwen poultry farms where measurements were conducted.

References

Carey, J. B., R. E. Lacey, and S. Mukhtar. 2004. A review of literature concerning odors, ammonia, and dust from broiler production facilities: 2. Flock and house management factors. *The Journal of Applied Poultry Research*, 13(3): 509-513.

Casey, K. D., J. R. Bicudo, D. R. Schmidt, A. Singh, S. W. Gay, R. S. Gates, L. D. Jacobson, and S. J. Hoff. 2006. Air quality and emissions from livestock and poultry production/waste management systems. In *Animal Agriculture and the Environment: National Center for Manure and Animal Waste Management White Papers*, eds. J. M. Rice, D. F. Caldwell, and F. J. Humenik, 1-40. St. Joseph, Michigan: American Society of Agricultural and Biological Engineers.

Costa, A., and M. Guarino. 2009. Particulate matter concentration and emission factor in three different laying hen housing systems. *Journal of Agricultural Engineering*, 40(3): 10-15.

David, B., R. O. Moe, V. Michel, V. Lund, and C. Mejdell. 2015. Air quality in alternative housing systems may have an impact on laying hen welfare. Part I—Dust. *Animal*, 5(3): 495-511.

Gustafsson, G., and E. Von Wachenfelt. 2006. Airborne dust control measures for floor housing systems for laying hens. *Agricultural Engineering International: CIGR Journal*, VIII: Manuscipt BC 05018.

Homidan, A. A., J. F. Robertson, and A. M. Petchey. 2007. Review of the effect of ammonia and dust concentrations on broiler performance. *World's Poultry Science Journal*, 59(3): 340-349.

Lim, T. T., A. J. Heber, J. Q. Ni, J. X. Gallien, and H. Xin. 2003. Air quality measurements at a laying hen house: particulate matter concentrations and emissions. In *Air Pollution from Agricultural Operations III*, ed. H. Keener, 249-256. Research Triangle Park, North Carolina USA: ASABE.

Lovanh, N., J. Loughrin, and K. Sistani. 2012. Volatile fatty acids in suspended particulate matter from a poultry house using rice hulls as bedding materials-a profile of first flock after total cleanout. *Journal of Civil & Environmental Engineering*, 2(4): 1000114.

Ngwabie, N. M. 2005. Volatile Organic Compound emissions from Animal Husbandry. Intittute for Environmental Physics. MSc diss., The Universtiy of Bremen, Bremen, Germany.

Ngwabie, N. M., A. N. Acobta, V. E. Manga, and A. C. VanderZaag. 2018. Emission factors of greenhouse gases from layer and broiler barns in Cameroon. *Atmospheric Environment*, 176: 54-59.

Nimmermark, S., and G. Gustafsson. 2005. Influence of temperature, humidity and ventilation rate on the release of odour and ammonia in a floor housing system for laying hens. *Agricultural Engineering International: CIGR Journal*, 7: Manuscript BC 04 008.

Nimmermark, S., V. Lund, G. Gustafsson, and W. Eduard. 2009. Ammonia, dust and bacteria in welfare-oriented systems for laying hens. *Annals of Agricultural and Environmental Medicine*, 16(1): 103-113.

Takai, H., L. D. Jacobson, and S. Pederson. 1996. Reduction of dust concentration and exposure in pig buildings by adding animal fat in feed. *Journal of Agricultural Engineering Research*, 63(2): 113-120.

Viegas, S., V. M. Faísca, H. Dias, A. Clérigo, E. Carolino, and C. Viegas. 2013. Occupational exposure to poultry dust and effects on the respiratory system in workers. *Journal of Toxicology and Environmental Health*, 76(4-5): 230-239.

Xu, W., K. Zheng, L. Meng, X. Liu, E. Hartung, M. Roelcke, and F. Zhang. 2016. Concentrations and emissions of particulate matter from intensive pig production at a large farm in north China. *Aerosol and Air Quality Research*, 16(1): 79-90.