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Determination of spatial distribution of ammonia levels in broiler houses

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Abstract. Ammonia concentration plays a significant role in broiler performance. High concentration of ammonia impairs the immune system and increases cases of respiratory disease in birds. Ammonia concentration can be reduced using various chemical additives such as zeolite. In the present study, spatial variability of ammonia concentration was investigated and analysed in two broiler houses. In House 1 (H1) sawdust only was used as litter material whilst sawdust used together with zeolite was used in House 2 (H2). Ammonia concentration measurements were taken from 21 points in each of the broiler houses. The readings were recorded at on a weekly basis using birds' height as height measurement bases. In order to create spatial distribution maps, Inverse Distance Weighted (IDW) and Radial Basis Functions (RBF) methods were used and analysed. The performances of these techniques were assessed by using validation test methods (root mean square error (RMSE) and mean absolute error (MAE)) with the best performing method (lowest RMSE and MAE) being selected for creating ammonia spatial distribution maps. The results indicated that spatial ammonia distribution is more uniform in H2 compared to H1. It was also observed that ammonia levels were lower in H2 than H1. The presence of zeolite as a litter addition can be attributed to study findings positively affected the broiler performance. It was considered that using zeolite with sawdust as litter material significantly reduced ammonia concentration. In H1, higher ammonia concentrations of greater than 25 ppm were recorded near ventilation fans and at the centre of the house. Because of this it is recommended to install additional fans at middle of the house for remove harmful ammonia.

Key words: Ammonia concentration, Interpolation, Litter, Zeolite.

INTRODUCTION

High ammonia concentrations in broiler houses have negative effects on bird performance, feed efficiency and welfare. In order to maximize flock performance and health, the ammonia concentration must remain at the level of 25 to 50 ppm (Miles et al., 2004). Ammonia concentrations inside broiler houses are usually higher than recommended levels. Ammonia concentrations are influenced by many factors such as temperature, humidity, litter properties and management. Several studies demonstrated the importance of using various chemical additives to reduce ammonia emission (Shreve et al., 1995; Burgess et al., 1998; Do et al., 2005; Li et al., 2008; Kaoud, 2013). Zeolite is one of these properties and has been used widely in broiler houses due to its high ammonia and humidity absorption capability. Loch et al. (2011) and Eleroglu & Yalçın (2005) stated that zeolite can be safely used as litter material. These above stated research findings positively contribute on importance of reducing ammonia levels in litters, however they did not highlight on the use of geostatistical analyses for litter-ammonia levels determination. Geostatistical analysis has been applied in many different disciplines (Jing & Cai, 2010; Wallgren, 2013; Arslan, 2014a; Arslan, 2014b; Guler, 2014; Stevens, 2014), however few studies concentrated on the spatial variability of ammonia concentrations in broiler houses. Miragliotta et al. (2006) applied spatial analysis of thermal, aerial and acoustic environmental conditions in a tunnel broiler house and determined probable in-house stress zones. Miles et al. (2011) spatially evaluated the physical and chemical properties of a litter material in a broiler house under different rearing seasons. In geostatistical analyses, temporal and spatial variation of desired parameters can be visually mapped for better interpretation.

In geostatistics, different interpolation methods can be performed for estimating any data set. However, the key issue is to select the most appropriate interpolation method (Burrough & McDonnell, 1998). The most widely used deterministic methods are Inverse Distance Weight (IDW) and Radial Bases Function (RBF), which create surfaces based on measured points. This study investigates spatial distribution of ammonia levels in broiler houses having different litter material using the above mentioned common interpolation methods (IDW and RBF). The objectives of this work were,

- to select the most appropriate interpolation method using IDW and RBF to visualize spatial variability of ammonia in two broiler houses;
- to compare the effects of different litter materials consisted of sawdust and sawdust/zeolite mixture on environmental parameters and chickens described above,
- and to determine the areas in broiler houses where the worst environmental conditions (more than 50 ppm ammonia concentration) are observed.

MATERIALS AND METHODS

The study was conducted in two commercial broiler houses (H1: Sawdust, H2: Sawdust+Zeolite), in Bafra (Samsun). Bafra is located in the province of Samsun in northern Turkey (41° 31' latitude and 35° 53' longitude). Prevailing wind direction is South-East (SE). The broiler houses, oriented North-East, have the same dimensions (12 m wide, 124 m long and 2.4 m high) and capacities of 24,250 birds at the beginning of the study. Sawdust and sawdust/zeolite mixture were used as alternative litter materials. In both houses feeding, watering, lighting and ventilation are controlled automatically. The buildings are composed of insulated roof and side walls. The buildings have 12 air inlets, which are 0.6 m high and 3 m wide and are placed on the northeast and southwest sides of the buildings as shown on Fig. 1. The building has four exhaust fans with a total ventilation efficiency of 35,000 $m^3 s^{-1}$. The birds were housed for 48 days before slaughtering.

The ammonia concentrations were measured at birds' height (0.2–0.3 m) on a weekly basis using a digital gas detector. Measurement were taken from 21 points at 3 locations across the width (3 m apart) and 7 locations along the length of the building (15 m apart) (Fig. 1). ArcGIS software was used to create ammonia contour maps.

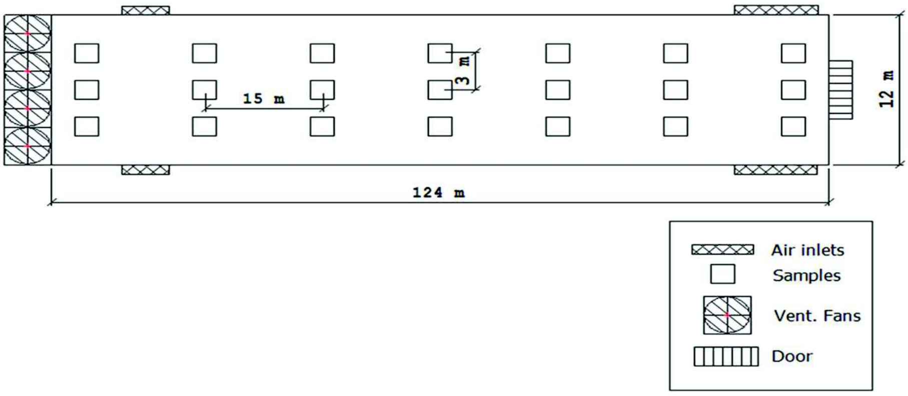

Figure 1. Grid samples in broiler houses.

Interpolation Methods

In the current study, different interpolation methods were applied for predicting the spatial distribution of ammonia. The IDW method estimates cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance (Childs, 2004). Estimates are determined using the formula:

$$Z = \frac{\sum_{i=1}^{n}(Z_i/d_i^m)}{\sum_{i=1}^{n}(1/d_i^m)} \quad (1)$$

where Z is the estimation value, Zi is the measured value at point i, di, is the distance between estimation value (Z) and data value (Zi), m is the weighting power that ranges from 1 to 5. In the current study, estimates of IDW by using common weighting powers (1, 2 and 3) were compared.

The RBF is a deterministic interpolation method used to represent two-dimensional curves on three-dimensional surfaces. It can be linked to using a mathematical function to fit a rubber -sheeted surface through known points. The RBF method has five different basis functions: completely regularized spline (CRS), spline with tension (ST), multiquadric function (MQ), inverse multiquadric function (IMQ) and thin plate spline (TPS) (Xie et al., 2011). The most widely used two radial basis functions (CRS and ST) were selected in the present study to determine spatial distribution of ammonia.

Cross-validation

This research used cross-validation to assess the accuracy of the interpolation. Cross validation is based on calculating the value of the variable at locations where the actual (measured) value is known, but has been temporarily omitted from input data, and then measuring the cross-validation error by comparing the estimated value with the actual (measured) value (Davis, 1987).

The precisions of different techniques were assessed by root mean square error (RMSE). The RMSE measures how much error there is between two datasets. The RMSE usually compares an estimated value and a measured value. Lower values of RMSE indicate better accurate prediction. The RMSE is defined mathematically as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z - Z_i)^2} \quad (2)$$

where, Z is the estimation value at point i, Zi is the measured value at point i, n is the number of samples.

The mean absolute error (MAE) is another useful measure widely used in model evaluations. The MAE measures the average magnitude of the errors in a set of forecasts, without considering their direction. Lower values of MAE indicate better accurate prediction. The MAE is determined by using this formula:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|Z_i - Z| \quad (3)$$

in which, Z is the estimation value at point i, Zi is the measured value at point i, n is the number of samples.

This study assessed different interpolation methods, namely IDW (p = 1, 2 and 3) and RBF (CRS and ST). The RMSE and MAE were used to compare the precisions of different interpolation methods and best method was selected for the creation of spatial ammonia level distribution map in broiler houses.

RESULTS AND DISCUSSION

Descriptive statistics including minimum values, maximum values, average values, standard deviations and coefficient of variation are summarized in Table 1. The average ammonia concentrations generally increased with age of birds, as described in literature (Miles et al., 2008; Miles et al., 2011). At week 3, the litter amendment (zeolite) in H2 seemed to be responsible for lesser average ammonia concentration estimate, 18.74 ppm vs. 67.54 ppm in H1.

Table 1. Ammonia concentrations (ppm) in two broiler houses

Birds	House 1					House 2				
Age (weeks)	Min.	Max.	Avg.	SD.	CV(%)	Min.	Max.	Avg.	SD.	CV(%)
	Ammonia (ppm)									
1	5.00	25.00	13.87	4.46	32.15	5.00	16.00	9.66	2.40	24.84
2	12.00	54.00	26.11	10.14	38.84	4.00	34.00	19.35	9.73	50.28
3	27.00	121.00	67.54	26.13	38.69	0.00	39.00	18.74	11.71	62.49
4	27.00	63.00	44.09	9.31	21.11	8.00	51.00	31.13	11.13	35.75

The broiler performances at two houses are summarized in Table 2. The live weight of broilers was higher at H2 than those of the H1 (1,861 g vs. 1,647 g). Feed intake of broilers in the H2 was higher 701 gr. than those of the H1. This is reflected in a higher feed conversion in H2 (2.08 vs 1.93). The death rate in the building with sawdust zeolite mixture litter was lower than in the broiler house only with sawdust litter (7.42 % vs.

9.15 %) this can be attributed to the presence of zeolite. This hypothesis was confirmed by several authors (Karamanlis et al., 2008; Nikolakakis et al., 2013).

Table 2. Broiler performances in two broiler houses

Broiler House	Capacity (birds)	Number of dead birds	Feed Intake (g)	Live weight (g)	Feed conversion	Mortality (%)
H 1	24,250	2,220	3,175	1,647	1.93	9.15
H 2	24,250	1,800	3,876	1,861	2.08	7.42

Comparison of Interpolation Methods

Comparison of the used interpolation methods for ammonia concentrations are provided in Table 3. There are five different combinations for two different interpolation methods in the table. Three common weighting powers (1, 2 and 3) of IDW method and two most widely used radial basis functions (CRS and ST) of RBF method were tested and the most appropriate method was selected.

The best values are indicated in bold as shown in Table 3. Of the five methods examined, IDW (1) showed the best precision in week 1 in H1 and in week 3 in H2; IDW (2) performed the best in week 4 in H1 and H2. At week 2–3 in H1 and week 1–2 in H2, the best results were obtained from RBF (ST) with the lowest MAE and RMSE values. Fig. 3 shows the ammonia concentration levels maps that were created from the selected best interpolation methods.

Table 3. The MAE and RMSE statistics of IDW and RBF in two broiler houses

	Weeks	IDW (1)		IDW (2)		IDW (3)		RBF-CRS		RBF-ST	
		MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE
House 1	1	**4.23**	**5.26**	4.23	5.63	4.48	6.10	4.25	5.42	4.27	5.40
	2	5.28	6.58	5.40	6.81	5.52	6.92	5.30	6.55	**5.27**	**6.57**
	3	13.79	16.38	13.48	17.12	14.23	18.06	13.95	16.93	**13.61**	**16.02**
	4	6.90	8.59	**6.34**	**8.00**	6.59	8.16	6.37	8.05	6.61	8.38
House 2	1	4.34	5.39	4.23	5.63	4.25	5.78	4.78	6.28	**4.27**	**5.39**
	2	5.31	6.44	4.85	6.65	5.17	7.09	5.10	6.52	**5.00**	**6.64**
	3	**13.80**	**16.39**	13.44	17.09	14.24	18.06	14.02	17.00	14.14	16.86
	4	6.90	8.59	**6.36**	**8.01**	6.58	8.15	6.39	8.04	6.37	8.06

Mapping Spatial Distribution of Ammonia Concentration

As the research was carried out during the winter season, only two fans were operated and a few inlets were opened with the objective of avoiding the cold weather from affecting the housed broilers. It was noted that during week 3 and 4 shown in Fig. 3 ammonia concentration levels in H1 were much higher compare to those in H2, this is likely attributed to the absence of zeolite in the former and poor ventilation as bird age increased. In H1, mean ammonia concentration ranged from 13.87 to 67.54 ppm, but in H2, the range was 9.66 to 31.13 ppm ammonia (Table 1).

In H1, throughout the rearing period ammonia concentration below the ideal limit (25 ppm) was observed only in week 1. In the second week, ammonia concentrations measured at fan areas exceeded 25 ppm and continued to increase up to week 3, due to poor ventilation. As observed by Wheeler et al. (2006), ammonia concentration was higher during winter season when low ventilation rates provided less fresh air dilution of ammonia. Towards the end of the rearing period, higher ammonia levels (above 50 ppm) were observed in the centre part of the H1 (Fig. 3). This was thought to be a result of uneven distribution of air flow in the building. As seen in Fig. 2 of air flow pattern, because of the cold fresh air entering first through the inlets, ammonia levels in this first section of buildings were lower. Ammonia concentrations tend to be higher at centre of the broiler house, because of inefficient air exchange in this section. Similar results were obtained by Miles et al. (2006) using kriging method. They found out that higher ammonia levels were in the centre of the house, near the end wall and cooling pads and attributed this to stagnant airflow in these areas.

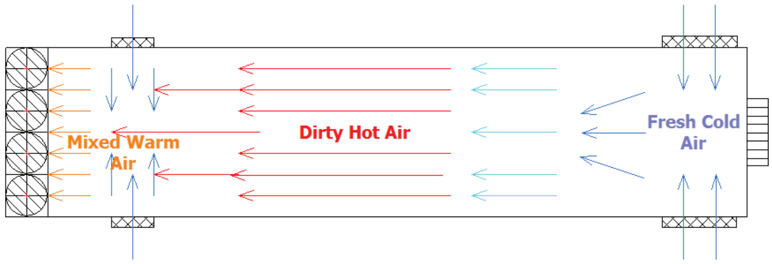

Figure 2. Air flow pattern in the broiler houses.

In H2, litter treatment (zeolite) seemed to be responsible for a lower ammonia concentration. Similar results were found by Lefcourt et al. (2001). They stated that zeolite treatment can reduce ammonia volatilization. At the beginning of the flocks' rearing period, ammonia levels were at their lowest (below 12.5 ppm). During weeks 2 and 3, ammonia was about 10 ppm within the first 30 metre length of building and increased (25–37.5 ppm) towards the fans region. At the end of the flocks' rearing in week 4, ammonia levels were even higher (37.5–50 ppm) from the centre region and towards the end of the broiler house (Fig. 3).

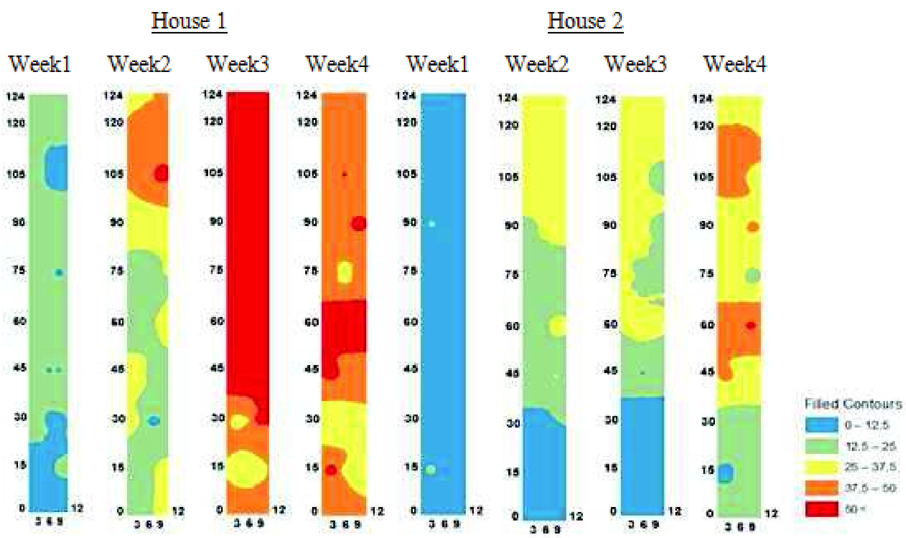

Figure 3. Ammonia concentrations contour maps in two commercial broiler houses.

CONCLUSIONS

In this study, litter addition (zeolite) was used to reduce ammonia concentration in the broiler house. Spatial changes of ammonia concentrations in two broiler houses having different litter materials (H1: sawdust, H2: sawdust+zeolite) were determined using interpolation methods. Ammonia concentration level maps were created using the best interpolation methods which were determined using R^2 and RMSE statistics.

Result of this experiment concludes that using zeolite together with sawdust as litter material significantly reduces ammonia concentration levels and improves production performances of broilers. It was also determined that variable ammonia concentration levels were present along the length of the house, with highest levels occurring at the centre of houses and near the end of the house. Because of this, it is recommended that additional fans should be installed in these two regions for remove of harmful ammonia. These findings may be helpful in designing broiler house to control ammonia concentration and emission (e.g. litter amendment, adequate ventilation).

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