Ammonia emission and nutrient load in outdoor runs of laying hens

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Abstract

Ammonia emission and nutrient load in outdoor runs of laying hens were measured at a commercial farm with an outdoor run for 3000 hens, and at an experimental farm with two outdoor runs, each for approximately 250 hens. Ammonia emission was recorded at 5, 10, 15 and 20 m from the hen house, using the ventilated chamber technique. Nutrient load was determined by analysing the fresh droppings. The results show ammonia emission to decrease with increasing distance from the hen house. The average emission per hen was 2.0 mg h^{-1} for the run of the commercial farm, and 0.95 and 0.86 mg h^{-1} for the two runs of the experimental farm. The nutrient load within 20 m from the hen house exceeded the threshold value for nutrient supply from manure (170 kg N and 44 kg P per ha) by a factor 15 on both the commercial farm and the experimental farm. The results show that the ammonia emission from the outdoor run of laying hens was relatively small compared with the emission from the hen house and that the nutrient load in the outdoor run near the house by far exceeded maximum acceptable levels.

Additional keywords: organic farming, poultry

Introduction

Protection of the environment is an important objective of organic food production. A closed nutrient cycle is one of the aims of organic farming. However, nutrient losses are inevitable. On organic layer farms nutrient losses occur through ammonia emission from the hen house and the outdoor run, and through leaching and run off of nitrogen, phosphorus and potassium from the soil of the outdoor run.

According to Dutch legislation (Anon., 2004a), which is supplementary to the EU-regulation on Organic Production (Anon., 1991), in summer, organic laying hens should have access to an outdoor run from an age of 8 weeks onwards and in winter from week 14 onwards. During these periods the run's area should measure at least

2.5 m^2 per hen. From week 18 onwards, the area per hen should be at least 5 m^2, which may be divided over two separate runs of 2.5 m^2 per hen, implying that a maximum of 2000 hens can be kept per hectare. The aforementioned EU-regulation also states that the nitrogen threshold for manure (170 kg N per ha per year) is attained by the yearly manure production of 230 layers. This means that with 2000 layers per hectare overloading the outdoor run with nutrients can be avoided if only 11.5% of the manure produced is left in the run, assuming that this manure is evenly distributed over the run's area and that vegetation is present to take up the nutrients.

Little is known about the ammonia emission from not covered outdoor runs. Bussink (1994) found ammonia emissions from grassland to vary from 3.3 to 14.4% of the amount of nitrogen excreted via urine and faeces by cattle. No data on ammonia emission from outdoor runs for laying hens are available.

The objective of this study was to determine ammonia emission and nutrient load in the outdoor run of laying hens. Such information is needed to be able to decide whether more effort should be put in reducing these losses to the environment.

Materials and methods

The study was carried out at two locations: a commercial farm and an experimental farm, both with organic laying hens. At both locations measurements were done during a few days staggered over a number of months.

Locations

The main characteristics of the two farms are listed in Table 1. On the experimental farm, measurements were done in two outdoor runs, one attached to a floor housing system and one attached to an aviary housing system. Figure 1 presents a schematic view of the layout of these outdoor runs.

Table 1. Main features of the experimental locations.

Feature	Commercial farm	Experimental farm	
Housing system	Floor housing	Floor housing	Aviary housing
Number of hens	3000	212	265
Breed of hens	Lohmann Brown	Lohmann Silver	Lohmann Silver
Area outdoor run	ca. 10,000 m^2	1100 m^2	1500 m^2
Use of outdoor run	11:00 h – sunset	11:00 h – sunset	11:00 h – sunset
Soil outdoor run	Sandy soil	Peaty clay mixed with sand	Peaty clay mixed with sand

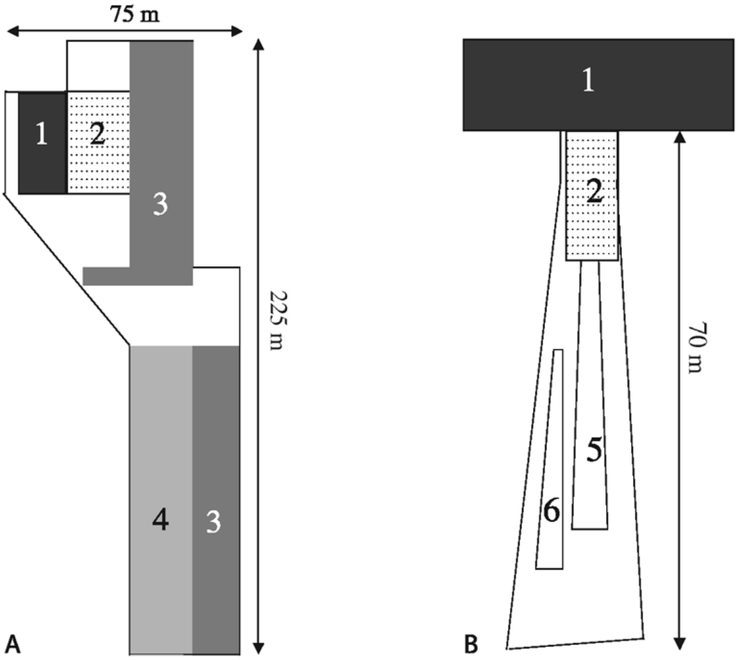

Figure 1. Layout of the outdoor runs. A: situation at the commercial farm; B: situation at the experimental farm. The width of the paddock at the experimental farm is different for the floor system and the aviary system, but the shape is similar. 1 = poultry house; 2 = measuring area; 3 = trees and shrubs; 4 = vineyard; 5 = bushes; 6 = maize.

Measurements

Data on ammonia emission and nutrient load were collected in each of the three outdoor runs at 5, 10, 15, and 20 m from the hen house, at randomly chosen points. On the commercial farm data on nutrient load were also collected at 30 m.

Ammonia emission

Ammonia emission was measured using a ventilated chamber (Aarnink *et al.*, 2002). The chamber covered a soil area of 0.4 m^2. Two identical fans on either side of the chamber ensured an equal pressure throughout the measuring chamber to prevent air leaking. An anemometer calibrated in a wind tunnel measured the volume of air. Ventilation rate was kept at 98 m^3 h^{-1}, giving an average air velocity in the chamber of 0.22 m s^{-1}. After stabilization of the air inside the chamber during 2 minutes, ammonia concentrations of incoming and outgoing air were measured with the denuder method (Mosquera *et al.*, 2002). In this method a small air stream of 1 litre min^{-1} was lead through a denuder during 15 minutes. The amount of ammonia absorbed in the denuders was determined in threefold in a laboratory. For details on days of measuring and number of measurements see Appendix 1.

Nutrient load

Local nutrient loads were estimated by collecting, counting, weighing and analysing the droppings in grids of 1 m^2. The grids were placed at random, at least one at the time, at each of the distances from the hen house. Recordings were made on different days (see Appendix 1). Grids were placed early in the morning before the hens went outside. At 13:30 h the numbers of total droppings, whole droppings and trampled droppings, were counted. Only whole droppings were collected for weighing and chemical analysis. On the commercial farm one or more extra grids were placed at each of the distances. Within these extra grids the old droppings were removed before the hens went out so that only fresh droppings, whole and trampled, were counted. Using the information on total and fresh droppings collected on the commercial farm a conversion factor was determined to calculate the freshly produced droppings from the total number of droppings collected on the experimental farm. This conversion factor was 0.81. The total number of droppings on the commercial and experimental farm and the fresh droppings on the commercial farm were analysed for total N, P, K, ammonium-N, and dry matter.

Statistical analyses

Ammonia emission

To be able to extrapolate the measured ammonia emission levels to other distances from the hen house we determined the relation between distance and ammonia emission by one-way regression analysis for each outdoor run. The average effects of distance, temperature and relative air humidity were determined by multiple regression analysis. All analyses were performed with the Genstat-programme (Anon., 2003).

Nutrient load

The nutrient load of the outdoor run was calculated from the daily manure production and its N, P and K contents. The daily manure production was estimated by linearly extrapolating the amount measured during the measuring period to the period the layers had access to the outdoor run (from 11:00 h until sunset). The nutrient load was determined using the following equation:

$$L_{i,j} = C_i * N * M * t_t / t_c \qquad \text{(g per day per m}^2\text{)}$$

where

$L_{i,j}$ = the load of nutrient i at distance j from the hen house (i = N, P or K in g per day per m^2; j = 5, 10, 15, 20, 30 m);

C_i = the content of nutrient i in the droppings (i = N, P or K g kg^{-1});

N = total number of droppings in a certain area (whole and trampled droppings; m^{-2});

M = the average mass per dropping (kg);

t_t = total time the layers had access to the outdoor run (from 11:00 h until sunset; h day^{-1});

t_c = collection period of the droppings between 11:00 h and 13:30 h (h).

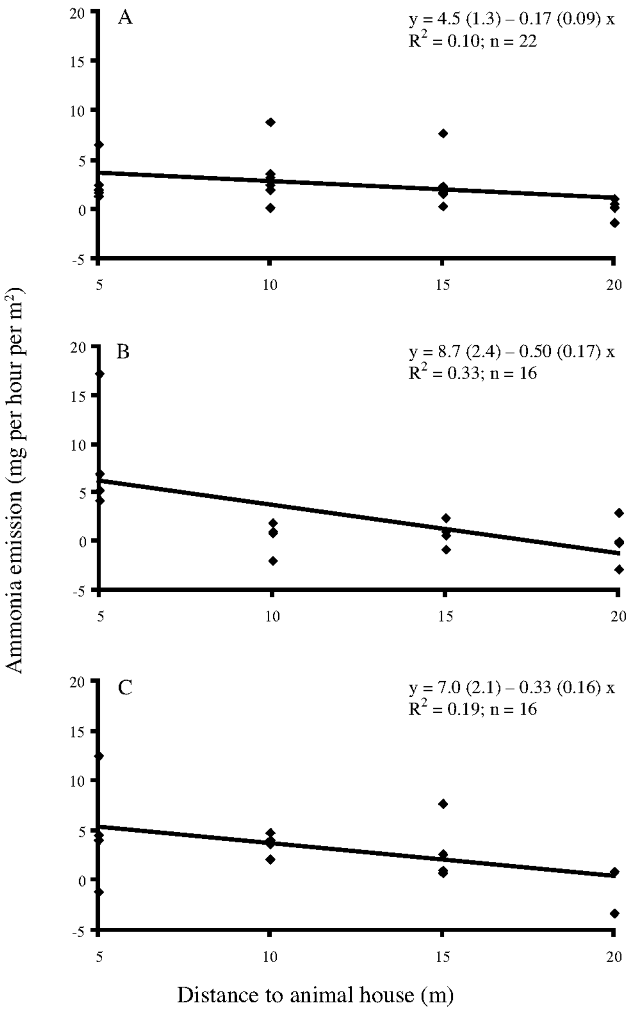

Figure 2. Relation between distance to the animal house and ammonia emission from the outdoor run. The regression line equations are given in the graphics together with the standard errors (in brackets). A = commercial farm; B = experimental farm, floor housing; C = experimental farm, aviary housing

Results

Ammonia emission

The relationship between the distance from the hen house and the ammonia emission from the outdoor runs of the commercial farm and the experimental farm is presented in Figure 2. The graphs show that the variation in emission was large; in some cases even a negative emission was calculated. Because the negative values were within the range of normal variation, these values were included in the analyses. For the three outdoor runs a negative relation was found between ammonia emission and distance from the hen house. The three regression coefficients were statistically or almost statistically different from zero (P = 0.081 for the commercial farm; P = 0.011 for the experimental farm with floor housing; P = 0.061 for the experimental farm with aviary housing).

The multiple regression analysis showed statistically significant regression coefficients for distance from the hen house, temperature and relative humidity on ammonia emission. The following regression equation was determined (standard errors are given in brackets):

$$Y = -3.86\ (4.8) - 0.36\ (0.09)\ D + 0.27\ (0.11)\ T + 0.10\ (0.04)\ RH \qquad (R^2 = 0.28;\ n = 54)$$

where
Y = ammonia emission (mg per hour per m^2);
D = distance from hen house (range: 0–20 m);
T = temperature (range: 5–34 °C);
RH = relative humidity (range: 27–97%).

This regression equation shows that ammonia emission decreases with increasing distance from the hen house and increases with increasing temperature and humidity. Total emission was calculated as the sum of the products of the areas at the different distances from the hen house times the average ammonia emission from these areas. The total ammonia emissions were 2.0 mg per hour per hen at the commercial farm, and 0.95 and 0.86 mg per hour per hen for the experimental farm with floor housing, and aviary housing, respectively.

Nutrient load

Table 2 gives the number of droppings, their chemical composition and the nutrient load at the different distances from the hen house for the different outdoor runs in this study. The results show that for the first 20 m from the hen house the distribution of the droppings was rather uniform and that at 30 m, as measured at the commercial farm, the number of droppings was clearly lower. The N and P contents were comparable for the different outdoor runs, but at the commercial farm K content was lower and ammonium-N and dry matter contents were higher than at the experimental farm. On the basis of the data in Table 2 and the mean weight of the droppings the nutrient load in g per m^2 per day was calculated (Table 3). The mean weights of droppings were 6.8

Table 2. Numbers of fresh and total droppings collected between 11:00 and 13:30 h at the three locations in relation to distance from the hen house, and composition of the total droppings.

Location	Distance from hen house (m)	No. of droppings per m²		Composition total number of droppings [1]					Composition fresh droppings				
		Fresh	Total [2]	N	P	K	NH_4-N	DM	N	P	K	NH_4-N	DM
				(g kg^{-1})									
Commercial farm	5	3.1±0.39	5.1±0.78	11.9±0.50	3.2±0.24	4.2±0.22	3.9±0.39	473±48	9.8±0.3	2.4±0.14	3.7±0.20	4.4±0.42	357±19
	10	3.4±0.34	5.4±0.69										
	15	3.2±0.55	2.7±0.60										
	20	2.4±0.37	2.9±0.82										
	30	1.4±0.27	1.2±0.48										
Experimental farm; floor housing	5	6.5 [3]	8.0±3.7	12.2±1.90	2.8±0.68	7.3±0.67	2.8±0.77	443±56					
	10	7.3	9.0±3.5										
	15	8.9	11.0±3.4										
	20	8.3	10.3±1.9										
Experimental farm; aviary housing	5	6.1	7.5±3.6	13.2±2.50	3.0±0.77	8.4±0.76	2.9±0.75	420±53					
	10	4.1	5.0±2.0										
	15	10.6	13.0±1.8										
	20	6.9	8.5±1.7										

[1] Composition of total number of collected whole droppings pooled over distances from hen house.

[2] Total number may be lower than fresh number due to counts made at different points.

[3] Numbers of fresh droppings on experimental farm were estimated from total numbers × 0.81 (see text).

Table 3. Estimated N, P and K loads [1] in relation to distance from the hen house, at the three locations studied.

Location	Distance from hen house (m)	N	P	K
			(g per m^2 per day)	
Commercial farm	5	0.79±0.10	0.20±0.03	0.30±0.04
	10	0.84±0.09	0.21±0.02	0.32±0.03
	15	0.86±0.15	0.22±0.04	0.33±0.06
	20	0.62±0.09	0.15±0.02	0.23±0.03
	30	0.39±0.07	0.10±0.02	0.15±0.03
Experimental farm; floor housing	5	1.05±0.43	0.24±0.10	0.62±0.25
	10	1.29±0.56	0.29±0.13	0.77±0.33
	15	1.75±0.68	0.40±0.15	1.04±0.4
	20	1.69±0.44	0.38±0.10	1.00±0.26
Experimental farm; aviary housing	5	0.98±0.35	0.22±0.08	0.62±0.22
	10	0.67±0.13	0.15±0.03	0.43±0.08
	15	2.17±0.52	0.50±0.12	1.38±0.33
	20	1.47±0.40	0.34±0.09	0.93±0.25

[1] The amount of manure recorded between 11:00 and 13:30 h was linearly extrapolated to the period the hens had access to the outdoor run.

Table 4. Calculated mean N, P and K loads over the first 20 m of the outdoor run, at the three locations studied.

Location	N	P	K
		(kg per ha per year)	
Commercial farm	2845±199	709±50	1074±75
Experimental farm; floor housing	2637±461	597±104	1562±273
Experimental farm; aviary housing	2412±408	552±93	1530±259

(fresh droppings), 4.3 and 4.2 g for the commercial farm, the experimental farm with floor housing, and the experimental farm with aviary housing, respectively.

The mean nutrient load of the first 20 m from the hen house was extrapolated to 1 ha and 1 year to be able to compare these figures with the available standards for manuring. From the results it can be seen that the nutrient load of the first 20 m of the outdoor run is very high (Table 4). The nutrient loads for the three outdoor runs were comparable.

Discussion

Ammonia emission

The ventilated chamber technique was used to measure ammonia emission. With this technique a constant airflow is generated over the emitting surface. The advantage of the method is that different measurements in time are better comparable, because they are not influenced by differences in outside wind speed. A disadvantage is that extrapolation to yearly emissions is more difficult, because the effect of variations in wind speed is not included in the results. In our study a rather low airflow rate of 0.22 m s^{-1} was used. The main reason for this was to create a larger difference in ammonia concentration between the incoming and outgoing air of the chamber. Generally, the air velocity outside is higher than 0.22 m s^{-1}. A higher air velocity usually means a higher ammonia emission from liquid manure (Aarnink & Elzing, 1998). With poultry manure, a higher air velocity in combination with a high temperature and a low relative humidity also has a drying effect and in that way may reduce ammonia emission (Groot Koerkamp *et al.*, 1995). However, we expect that in the outdoor run with moderate temperatures and a rather high humidity, the lower air velocity in the chamber caused a lower ammonia emission. On the other hand, we only measured emissions during the day. When extrapolating these data to daily emissions the actual emissions might be overestimated, because during night-time no manure is produced in the outdoor run and temperatures usually are lower.

Taking into account the former discussion points we extrapolated our measured ammonia emission data to yearly emissions to be able to make a comparison with the emissions measured from the hen house. In that way we could make an estimate of the contribution of the outside run to the total ammonia emission from the farm. Using the recorded hourly ammonia emissions of 2.0, 0.95 and 0.86 mg per hour per layer from the outdoor runs of the commercial farm, the experimental farm with floor housing, and the experimental farm with aviary housing, respectively, yearly emissions were calculated of 17.5, 8.3 and 7.6 g per layer. A hen house with floor housing is considered to have an ammonia emission factor of 315 g per year (Anon., 2002). For the commercial farm this means that the ammonia emission from the outside run was approximately 5.5% of the emission from the hen house whereas for the experimental farm with floor housing this was 2.6%. An aviary system is considered to have an emission factor of 90 g per layer per year (Anon., 2002). For the experimental farm with aviary system this means that the emission from the outdoor run was approximately 8.4% of the emission from the hen house.

The ammonia emission per layer at the commercial farm was approximately twice as high as the emission at the experimental farm. This might be caused by the higher manure production in the outdoor run at the commercial farm. It was calculated that the manure production in the first 20 m from the hen house was 55 g per day per layer at the commercial farm against 40 and 25 g per day for the experimental farm with floor housing, and the experimental farm with aviary housing, respectively. The lower manure production on the experimental farm was probably caused by the fact that relatively fewer chickens were outside at this farm compared with the commercial farm (based on personal observations). Less natural covering in the outdoor runs of the experimental farm probably caused fewer chickens to go out. Another reason for the lower ammonia emission on the experimental farm could be the lower ammonium-N content of the droppings (Table 2).

From the results it can be concluded that the ammonia emission from the outdoor runs is relatively low compared with the emission from the hen houses. However, this emission cannot be neglected. More measurements distributed over the year and at different air speeds are needed to obtain more accurate information on the yearly emissions from the outdoor runs of layers.

Nutrient load

The nutrient load data from the commercial farm show that the manure produced was similar for the first 20 m from the hen house, but was lower at 30 m (Tables 2 and 3). At the experimental farm no manure production was measured at 30 m, but based on observations it is expected that at this distance the nutrient load on this farm decreased too. Given the relationship between dry matter content of the manure and the average manure production for layers as used in the handbook for poultry production (Anon., 2004b) we estimated a yearly manure production of 45 kg or 123 g per day. This means that in the outdoor runs of the commercial farm, the experimental farm with floor housing, and the experimental farm with aviary housing approximately 45, 33, and 20% of the total manure was produced in the first 20 m of the outdoor run. This is much higher than the maximum amount we calculated earlier (11.5%) assuming evenly distributed manure over the whole run. In addition, because all this manure is excreted in a small area near the hen house, locally a strong overloading with nutrients is caused. Moreover, as there was no plant cover in this area, all nutrients added are in fact in excess, and are lost through run off, leached to the groundwater, or accumulated in the soil.

The nutrient load at the commercial farm was measured in spring and summer, whereas at the experimental farm this was done in spring, summer and autumn. In both cases no measurements were taken in winter. For broilers it is known that they go out less during the winter (Van Harn *et al.*, 2003), but as layers are less susceptible to cold they also will go out in winter. Only on rainy days layers will go out less. To calculate the nutrient load, we linearly extrapolated the values measured during the measuring period (from 11:00 to 13:30 h) to the period the layers had access to the outdoor run (from 11:00 h until sunset). Little is known about the excretion pattern of layers during the day, but we assumed a rather uniform distribution. This assumption is based on results from Hogewerf *et al.* (2004) who found that the number of layers in the outdoor run was rather uniformly spread over the time period they had access to the run. As layers eat during almost the whole day, it is reasonable to assume that also the manure produced is evenly distributed over this time period.

The estimated nutrient load of (part of) the outdoor run is so high that this problem cannot simply be solved by management measures or extra plant cover to increase the distribution of the layers over the run. Drastic measures, like an impermeable layer under the sand, or mobile barns may be necessary to solve this problem

(Rodenburg & Van Harn, 2004). The impermeable layer, e.g. of concrete, is probably only necessary for the first 20 to 30 m from the hen house.

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Appendix 1

Dates and number of times droppings were counted and ammonia emission was measured in the outdoor runs of laying hens at the two types of farms investigated.

Commercial farm				Experimental farm					
Date	Droppings [1]		Ammonia emission [2]	Floor housing			Aviary housing		
	Fresh	Total		Date	Total droppings [2]	Ammonia emission [2]	Date	Total droppings [2]	Ammonia emission [2]
25 Mar '04	50			27 May '04	4	4	27 May '04	4	4
23 Apr '04	15	10		28 Jul '04	4	4	28 Jul '04	4	4
6 May '04	15	10		3 Sep '04	4	4	3 Sep '04	4	4
13 May '04	15	10		3 Dec '04	4	4	3 Dec '04	4	4
9 Jun '04	15	10	8						
14 Jul '04	15	10							
2 Aug '04	15	10							
3 Aug '04	15	10	8						
24 Aug '04	15		6 [3]						

[1] Dividing by 5 gives the number of counts per distance from the hen house.

[2] Dividing by 4 gives the number of counts or measurements per distance from the hen house.

[3] Measured once at 5 and 20 m, and twice at 10 and 15 m from the hen house.