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AMMONIA EMISSIONS FROM BROILER HOUSING FACILITY: INFLUENCE OF LITTER PROPERTIES AND VENTILATION

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ABSTRACT At present, the European Union regulations allow to keep broiler chickens on litter covered floors only. Properties of litter (litter temperature, litter age) with ventilation rate are therefore important parameters influencing ammonia (NH_3) concentrations and emissions in broiler houses. Litter temperature, litter age, and ventilation rate were measured in commercial grow-out facility with deep litter, designed for 25,000 broilers, during 6 consecutive flocks. Birds were housed from hatching to 40 days of age. Litter temperature and litter age positively correlated ($P<0.001$) with production of ammonia gas. The amount of ammonia emissions increased with increasing litter age ($P<0.001$), as a consequence of which both the ammonia concentration and ventilation rate ($P<0.001$) also increased. The lowest concentrations of NH_3 were observed during summer, although ammonia emissions tended to be higher in summer months due to higher ventilation rates. The elevated levels of ammonia in winter were attributed to the lower ventilation rates during cold weather. From the ammonia emission data, it can be concluded that during the grow-out period of broilers kept on renewed litter there is an average loss of 6.18 g ammonia per bird and/or 0.043 kg of ammonia per bird yearly. Increasing litter temperature during grow-out periods is a process, which could be controlled to prevent excessive ammonia volatilization from housing.

Keywords: ammonia, litter, broiler chickens, grow-out period, ventilation rate

INTRODUCTION Broiler production is a prime example of high density animal production. Broilers are often grown in production houses containing 20,000 or more birds at densities of 0.06 m^2 per bird. Broiler litter typically contains 4 to 6 % nitrogen, much of which is in the NH_3 or NH_4^+ form. The mixture of litter and manure is effectively a nitrogen storehouse. Under proper conditions, a considerable quantity of this nitrogen is released as ammonia (Carr et al., 1990). Many factors, such as season of the year, ambient temperature and humidity, bird health, and management practices can influence ammonia volatilisation from broiler rearing facilities (Coufal et al., 2005). Ammonia is formed as a result of the breakdown of nitrogenous waste products in poultry manure (undigested proteins and uric acid) brought about by exogenous enzymes produced by microorganisms. Factors that exhibit direct control over these processes have been identified as pH, temperature, and moisture (Elliot and Collins, 1982). Ammonia release is depressed at pH<7 but is very high at pH>8 (Parker et al., 2005). Therefore, in a commercial broiler grow-out facility, pH would seldom be a factor in determining NH_3 volatilization since the pH of broiler litter is normally greater than 8 unless acidifying agents have been applied to the litter (Lacey et al., 2003). This fact leaves temperature and moisture as the second most important factors affecting the variability of NH_3 volatilization in commercial setting (Coufal et al., 2005). During breeding periods, high indoor temperatures required for baby chicks tend growers to conserve fuel by reducing ventilation rates, thereby elevating the NH_3 concentration (Brewer and Costello, 1999). It is also important to point out that litter age significantly affects N retention in the litter, and, consequently, influences N loss (Coufal et al., 2006).

At present, the European Union permits to keep broiler chickens on littered floor only (Council Directive 2007/43/EC, 2007). The way of bird keeping directly influences the pollution with dangerous compounds, dust emissions and microbiological pollution on farms. Chemical pollutants are risk factors for the health of human beings and animals (Vaičionis et al., 2006). The piled up straw is gradually enriched by excrements, rests of feed, water and feathers. Thus poultry manure is formed and thus begins to be the main source of ammonia emissions. Environmental features, such as bulk and surface temperature of the manure, influence ammonia volatilization with higher temperature resulting in increased ammonia volatilization (Richard et al., 2005). Litter moisture, which is mainly influenced by ventilation and drinking system management, may affect the conversion rate of uric acid to ammonium nitrogen (Liu et al., 2006). All the above mentioned factors are strongly influenced by litter age, i.e., by bird age. It has been reported that emission rate of NH_3 increases with the flock age from nearly zero value at the beginning of flock cycle to maximum values at its end (Gates et al., 2008).

According to the 2007 EU Regulation (2007/43 /EC), which shall enter into force in 2010, all chickens should have permanent access to litter which is dry and friable on the surface. However, it can be a problem to keep litter material in such quality. This is caused not only by high stocking density (33 – 42 kg/m^2) but also by other factors related to housing (ventilation intensity, spilled water from drinkers, condensation of water vapour, added litter, diseases of birds, etc.). Litter condition and quality of air can be kept with in bearable limits by proper regulation of ventilation, thermo-technical quality of building structures and heating system efficiency (Wheeler et al., 2006, Lendelova & Botto, 2009). The seasonality and correlation of ammonia concentration and ventilation rate become apparent with lower ammonia concentration and higher ventilation rate during warm summer conditions, while ammonia concentration tend to be higher during cold weather when low ventilation rates provided less fresh air dilution of ammonia (Wheeler et al., 2006). Influence of season on amount of produced emissions is in fact the influence of ventilation rate, which depends on the need to cool the temperature in interior environment. Litter condition and ventilation intensity will probably markedly influence the amount of produced emissions.

The experiment described in this paper was conducted keeping the following objectives in mind: 1) measurement of atmospheric ammonia concentration, 2) examination of the impact of litter temperature, litter age, and ventilation rate on NH_3 volatilization, 3) calculation of NH_3 emission rates over 6 consecutive flocks and annual emission factor in a commercial broiler grow-out facility.

MATERIAL AND METHODS A common broiler rearing facility was monitored for NH_3 emission. The study was carried out a commercial farm and continuous measurements were done over 6 flocks in different seasons. Flow chart of the assessment is presented in Table 1. The impact of litter temperature, litter age, air temperature and ventilation rate on ammonia production was evaluated.

Table 1. Flow chart of assessment

Flock	Date	Number of days	Average number of chickens
summer/autumn I	30.07. - 07.09.	40	23,929
autumn	23.09. - 01.11.	40	24,310
autumn/winter	18.11. - 27.12.	40	24,502
spring/summer	02.05. - 10.06.	40	24,287
summer	16.06. - 25.07.	40	23,908
summer/autumn II	10.08. - 18.09.	40	24,016

Housing description and equipment The house was concrete-floored with breeding area of 1 128 m^2 (94 x 12 m), designed for 25,000 broilers yielding a stocking density of 18 – 22 birds per sq. m. The number of birds placed in each flock is given in Table 1.

One day old broiler chickens of "Ross 308" commercial hybrid were reared till 40 days of age and fed diets obtained from commercial broiler feed producer. Final weight of broilers (approx. 2 kg) corresponds to load on breeding area of 36 – 42 kg/m^2 at the end of the grow-out period.

The house was mechanically ventilated with combined tunnel and cross two-sided ventilation. Six ceiling axial fans, with maximum capacity of 12,000 m^3/h and four frontal fans with maximum capacity of 35,000 m^3/h were installed for assuring air exchange in the chicken house. At maximum ventilation rate the ventilation system could exhaust 212,000 m^3/h. Fresh air inlets were placed on both side walls of the hall. Evaporative cooling pads were used in hot weather to cool the birds, and natural gas furnaces (70 and 120 kW) were used as supplemental heating in winter. A thermostat override controlled the fans to remove excess heat from the building if the maximum set point temperature was reached at any time. The override thermostat was set at approximately 32°C at chick placement and was reduced by approximately 2°C each w

A breeding area was equipped with 4 nipple drinker lines and 3 tube-style pan feeder lines that were filled automatically. Feed and water were provided *ad libitum*. Diets were changed at the bird age as directed by the farmer.

Litter management A chopped wheat straw (20-30 cm) was used for each subsequent flock with old litter removed between flocks. The age of litter corresponded with the age of birds. Fresh new straw was added to a breeding area to a depth of 5 to 10 cm (approx. 1.6 kg/m^2). No additional litter material or amendments were added to the litter at any time throughout the study.

Data and sample collection Fattening lasted 40 days with technological break of 10 days between periods. The beginning and end dates are provided for each flock to document the time of year when each flock was reared.

The concentrations of ammonia were determined on the device 1312 Photoacoustic Multi-gas Monitor, which is based on the principle of photo-acoustic infrared detection method. Air samples for NH_3 concentration analysis were taken from air stream at two ceilings, two frontal fans and from outdoor surroundings.

At the same points, air temperature was measured by thermocouple probes. Two thermocouple probes were placed also in litter (approx. 30 mm under the surface), in the front and back part of the breeding area to evaluate temperature variations of litter.

Concentrations of NH_3 and temperature values were recorded continuously at hourly intervals during the whole rearing period.

Emission rate determination Emissions were calculated from hourly concentration of gases in interior and exterior environments and air flow through measuring fans using the equation:

$E = Q \cdot (c_i - c_e)$ (mg/h)

E – Emission of gas

Q – Air flow through the fans

$(c_i - c_e)$ – Difference between concentrations of gas in interior and exterior environments

Determination of air flow through the ventilation system was based on current ventilation capacity (%) and known rate of air flow at 100 % efficiency (212,000 m^3/h) and was used for calculation of total emissions.

Obtained data was processed by Spearman correlation coefficient method using SAS 9.1 computer programme. The results are accepted as reliable at $P<0.05$.

RESULTS AND DISCUSSION From the data in Table 2 and Figure 1, it can be concluded that the temperature of litter increased ($P<0.001$) by the age of litter and the difference between the first and the fourth quarter of rearing period was 6.5 ^oC on average. Flock "autumn" did not follow this trend and cannot be fully explained.

Table 2. Litter and air temperature variations during individual grow-out periods

Days of grow-out period			1. to 10.			11. to 20.			21. to 30.			31. to 40.			1. to 40.		
Parameter		flock	n	x	s	n	x	s	n	x	s	n	x	s	n	x	s
Litter temperature	°C	summer/autumn I	480	26.7	0.49	480	27.9	0.89	480	31.1	1.56	480	34.4	0.97	1920	30.0	3.19
		autumn	480	30.7	1.52	480	27.1	1.96	480	25.3	1.58	480	29.0	0.89	1920	28.0	2.56
		autumn/winter	480	25.2	1.26	480	28.1	1.04	480	30.5	0.85	480	33.3	0.72	1920	29.3	3.15
		spring/summer	480	26.9	1.76	480	27.1	1.76	480	30.3	2.12	480	32.9	1.05	1920	29.3	3.03
		summer	480	26.2	2.09	480	27.7	1.42	480	30.0	1.76	480	33.5	1.35	1920	29.3	3.24
		summer/autumn II	480	28.7	1.04	480	28.1	1.78	480	30.8	2.12	480	32.2	1.01	1920	29.9	2.27
Air temperature	°C	summer/autumn I	960	29.2	1.6	960	26.5	2.0	960	25.1	1.8	960	24.7	1.8	3840	26.4	2.5
		autumn	960	29.7	1.8	960	26.1	2.1	960	21.3	1.6	960	23.7	2.5	3840	25.2	3.7
		autumn/winter	960	32.5	3.9	960	24.7	1.6	960	21.7	1.4	960	19.7	1.4	3840	24.7	5.4
		spring/summer	960	29.3	2.2	960	23.5	2.3	960	24.3	2.7	960	22.8	2.3	3840	25.0	3.5
		summer	960	29.2	3.8	960	25.2	2.1	960	23.7	1.8	960	23.8	1.8	3840	25.5	3.4
		summer/autumn II	960	28.6	2.3	960	24.9	1.7	960	24.4	2.7	960	23.3	2.5	3840	25.3	3.1

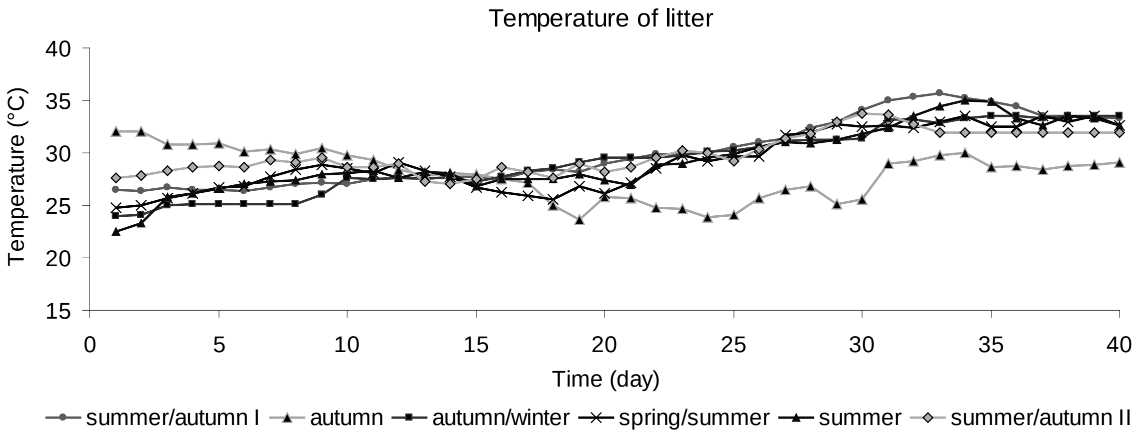

Figure 1. Changes in internal temperature of litter during individual periods

Warmth in the litter is created by bacterial fermentation and partly by contact with chickens. Results obtained by Reiter and Bessei (2000) confirm this. They found different temperatures of litter at different stocking densities of broilers. Warmer temperatures also stimulate microbial activity in the litter, thereby increasing the potential for the enzymatic degradation of uric acid and proteins to NH_3 (Coufal et al., 2006).

The temperature of air showed a decreasing trend (Figure 2). Both the temperature of litter and temperature of air were in antagonistic relationship ($P<0.001$) in four observed flocks (Table 3).

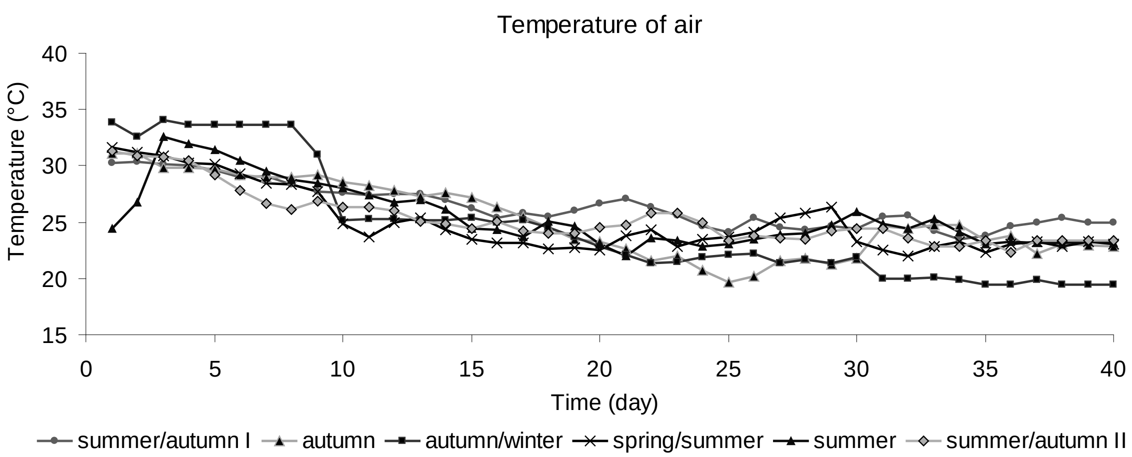

Figure 2. Changes in air temperature in the housing area

Ammonia concentrations were measured between 0.0 and 29.1 ppm and increased with bird age. Ammonia concentration had rising tendency in all periods (Figure 3). Vučemilo et al. (2007) associated the increase of air concentration of ammonia with the increase in animal age and air humidity. He reported almost septuple higher level of NH_3 concentration between the first and the fifth week of age (litter – mixture of wooden sawdust and shavings). In our measurement we found approximately triple increase in ammonia concentration between the first and the last quarter of grow-out period. Very high statistical reliability was found between the age of litter and ammonia concentration as well as between the age of litter and ammonia emissions ($P<0.001$). Wheeler et al. (2003, 2006) also came to the same conclusion.

Table 3. Correlations among studied factors influencing ammonia production

Parameter	Period	NH_3 emissions	Air temperature	Litter temperature	Age of chickens	Amount of exhausted air
NH_3 concentration	summer/autumn I	0.85159^{xxx}	-0.65235^{xxx}	0.69925^{xxx}	0.64015^{xxx}	0.49261^{xx}
	autumn	0.90844^{xxx}	-0.44897^{xx}	0.00281 $^{-}$	0.72289^{xxx}	0.69803^{xxx}
	autumn/winter	0.86885^{xxx}	-0.80878^{xxx}	0.82104^{xxx}	0.92368^{xxx}	0.75421^{xxx}
	spring/summer	0.90300^{xxx}	-0.09191 $^{-}$	0.75779^{xxx}	0.62293^{xxx}	0.60674^{xxx}
	summer	0.88028^{xxx}	-0.28434 $^{-}$	0.74765^{xxx}	0.70269^{xxx}	0.68581^{xxx}
	summer/autumn II	0.90459^{xxx}	-0.71000^{xxx}	0.71508^{xxx}	0.78864^{xxx}	0.74108^{xxx}
NH_3 emissions	summer/autumn I		-0.82158^{xxx}	0.89268^{xxx}	0.85685^{xxx}	0.77386^{xxx}
	autumn		-0.64653^{xxx}	-0.22852 $^{-}$	0.90882^{xxx}	0.89853^{xxx}
	autumn/winter		-0.93315^{xxx}	0.95023^{xxx}	0.94125^{xxx}	0.92988^{xxx}
	spring/summer		0.32531 ^{x}	0.80460^{xxx}	0.79231^{xxx}	0.85386^{xxx}
	summer		-0.44328 ^{xx}	0.88914^{xxx}	0.86049^{xxx}	0.89205^{xxx}
	summer/autumn II		-0.81206^{xxx}	0.80210^{xxx}	0.89319^{xxx}	0.89504^{xxx}
Air temperature	summer/autumn I			-0.86998^{xxx}	-0,87167^{xxx}	-0.66992^{xxx}
	autumn			0.81707^{xxx}	-0.76191^{xxx}	-0.73378^{xxx}
	autumn/winter			-0.97895^{xxx}	-0.91712^{xxx}	-0.92599^{xxx}
	spring/summer			-0.36237 ^{x}	-0.68543^{xxx}	-0.47424 ^{xx}
	summer			-0.57309^{xxx}	-0.70232^{xxx}	-0.44555 ^{xx}
	summer/autumn II			-0.61222^{xxx}	-0.92488^{xxx}	-0.79356^{xxx}
Litter temperature	summer/autumn I				0.95722^{xxx}	0.84422^{xxx}
	autumn				-0.41689 ^{xx}	-0.38101 ^{x}
	autumn/winter				0.98815^{xxx}	0.94918^{xxx}
	spring/summer				0.85264^{xxx}	0.72238^{xxx}
	summer				0.90984^{xxx}	0.89885^{xxx}
	summer/autumn II				0.78967^{xxx}	0.80858^{xxx}
Age of chickens	summer/autumn I					0.90220^{xxx}
	autumn					0.98213^{xxx}
	autumn/winter					0.93074^{xxx}
	spring/summer					0.83932^{xxx}
	summer					0.87958^{xxx}
	summer/autumn II					0.92446^{xxx}

^{xxx} very highly significant $P<0.001$, ^{xx} highly significant $P<0.01$, ^{x} significant $P<0.05$,
$^{-}$ non-significant

We did not notice marked differences in temperatures of litter when comparing the summer and winter period (Table 2). Since the temperature of litter was quite stable during the whole year, lower concentrations of ammonia during the summer periods must have been caused by other factors (intensive ventilation, dried litter, and crust on its surface). Increase of litter temperature was significant ($P<0.001$) with ammonia concentrations as well as with ammonia emissions in five individual flocks.

Ammonia emission rates were higher in “summer/autumn II” (187.5 kg) than in “autumn” and “spring/summer” (125.6 and 127.2, respectively), although NH_3 concentrations were lower in “summer/autumn II”. On the other hand, we found no significant differences in ammonia emission between the cold period “autumn/winter” (156.5 kg and 6.39 g/head) and warm period “summer/autumn I” (154.8 kg and 6.47 g/head). Liang et al. (2003) reported generally higher emission rates in summer than in winter because of highest ventilation capacity, even at the lower concentrations. A number of authors (Coufal et al., 2006; Redwine et al., 2002) recorded similar seasonal changes in emissions. The highest concentrations of ammonia were in flocks “autumn” and “autumn/winter”, the lowest ones being in “spring/summer” and “summer” (Table 4).

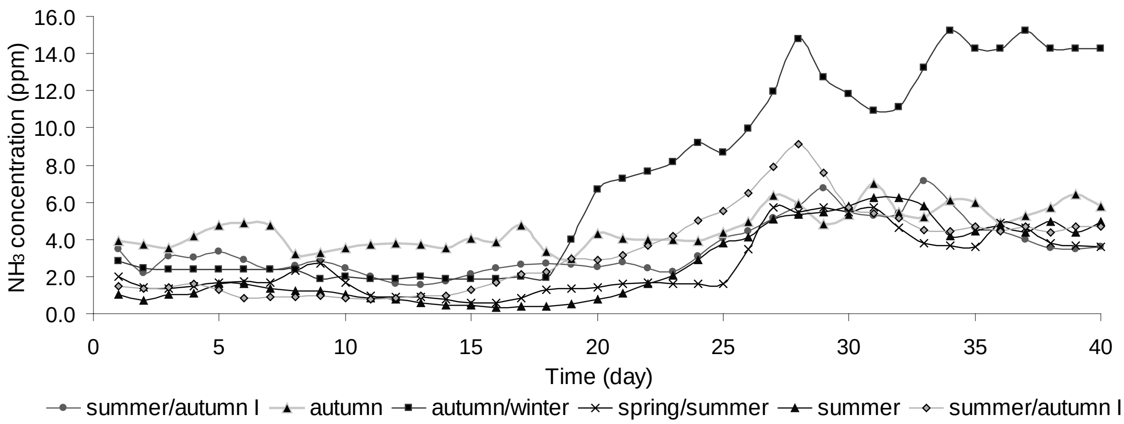

Figure 3. Changes in ammonia concentrations

Table 4. Parameters of environment in hall during individual grow-out periods

Days of grow-out period			1. to 10.			11. to 20.			21. to 30.			31. to 40.			1. to 40.		
Parameter		Flock	n	x	s	n	x	s	n	x	s	n	x	s	n	x	s
NH_3 concentration	ppm	summer/autumn I	960	2.8	0.96	960	2.2	0.71	960	4.2	1.96	960	4.7	1.85	3840	3.5	1.80
		autumn	960	4.0	0.79	960	3.8	0.75	960	4.8	1.33	960	5.8	0.93	3840	4.6	1.25
		autumn/winter	960	2.3	5.27	960	2.6	1.58	960	10.2	2.48	960	13.7	2.42	3840	7.2	5.27
		spring/summer	960	1.8	0.55	960	1.0	0.32	960	3.4	2.20	960	4.2	1.37	3840	2.6	1.84
		summer	960	1.2	0.82	960	0.5	0.23	960	3.7	2.05	960	5.0	1.57	3840	2.6	2.27
		summer/autumn II	960	1.2	0.39	960	1.7	0.89	960	5.8	2.71	960	4.7	0.91	3840	3.3	2.49
Ventilation rate	$m^3.h^{-1}$	summer/autumn I	240	39 079	27 921	240	73 361	49 373	240	114 772	49 642	240	130 725	58 893	960	89 484	59 724
		autumn	240	28 284	7 503	240	34 159	4 173	240	46 349	10 328	240	90 524	18 899	960	49 829	27 001
		autumn/winter	240	25 581	5 029	240	32 330	2 525	240	35 060	2 227	240	39 406	2 287	960	33 094	5 970
		spring/summer	240	22 711	7 580	240	39 061	14 191	240	126 458	58 806	240	102 387	41 257	960	72 654	56 594
		summer	240	27 322	19 426	240	68 105	44 233	240	98 819	55 572	240	128 764	47 680	960	80 752	57 714
		summer/autumn II	240	30 873	13 656	240	66 877	41 550	240	124 594	64 793	240	145 785	55 652	960	92 032	66 165

The ventilation rate showed a rise in all periods (Figure 4). The ventilation system operated at much higher capacity during summer (average of 34 to 43 %) but at much reduced capacity during cold weather (average of 16 to 24 %) to maintain the inside temperature (Table 5). Carr et al. (1990) observed decreasing ammonia concentrations with increasing ventilation rate. Increased ventilation rate diluted the release of ammonia thus producing lower concentrations. Ammonia concentration and amount of air exhausted through the ventilation system were in positive correlation ($P<0.001$). It means that in spite of rising ventilation rate towards the end of the grow-out period, the ammonia concentration did not decrease in individual periods but it had even slightly increasing tendency.

Table 5. Amount of ammonia contained in exhausted air

Days of period			1. to 10.	11. to 20.	21. to 30.	31. to 40.	1. to 40.
Parameter		Period					
Ventilation intensity	%	summer/autumn I	18	35	54	62	42
		autumn	13	16	22	43	24
		autumn/winter	12	15	17	19	16
		spring/summer	11	18	60	48	34
		summer	13	32	45	61	38
		summer/autumn II	15	32	59	69	43
Amount of exhausted air	$m^3.10^6$	summer/autumn I	9.379	17.607	27.545	31.374	85.905
		autumn	6.788	8.198	11.124	21.726	47.836
		autumn/winter	6.140	7.759	8.414	9.457	31.770
		spring/summer	5.451	9.375	30.350	24.573	39.748
		summer	6.557	16.345	23.716	30.903	77.522
		summer/autumn II	7.409	16.051	29.903	34.988	88.351
NH_3 emission	kg	summer/autumn I	9.46	14.02	58.81	72.51	154.8
		autumn	14.35	16.64	29.56	65.03	125.58
		autumn/winter	7.72	12.14	54.31	82.33	156.5
		spring/summer	5.89	5.04	62.64	53.58	127.15
		summer	4.38	4.91	51.18	82.94	143.41
		summer/autumn II	4.121	15.15	82.49	85.78	187.54

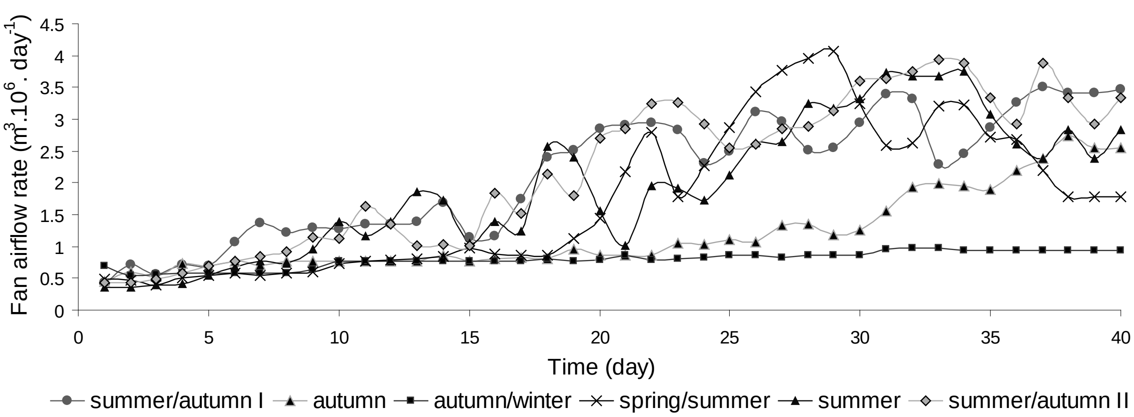

Figure 4. Ventilation performance in individual grow-out periods

The trend for emission rates closely resembled that for ventilation rates during warm weather but followed the NH_3 concentration pattern during the minimum ventilation periods. Carr et al. (1990) related higher concentrations of NH_3 in winter months with reduced ventilation rates to conserve as much heat as possible.

Starting mechanism of ventilation was due to the temperature of surrounding and not the content of harmful gases. Therefore, a situation occurred when the maximum permitted

NH_3 concentration f 20 ppm (EU Regulation 2007/43 /EC (2007) was exceeded for a short time in the third (26.9 ppm) and fourth (29.1 ppm) quarters of the “autumn/winter” period. Ammonia did not achieve critical values during other studied periods.

The NH_3 emission rates averaged 6.18 g NH_3 per bird over individual grow-out periods (emission factor ranged from 5.17 g/head to 7.81 g/head). Gates et al. (2008) reported almost 3 times higher ammonia emission (17.4 g/head for one period in fattening to life weight 2.1 kg housed on sawdust litter). Lacey et al. (2002) emphasized that different values of emission factors published by American and European authors are caused by different climatic conditions and differences in average live weight of animals. They reported emission factor of 19.8 g NH_3/head for 49 days fattening cycle (average life weight of chickens being 1.03 kg).

CONCLUSION It is possible to obtain precise result only if the data are collected over a long period of time (seasonal influence). Therefore, an experiment was conducted for 6 consecutive flocks. Quality of litter and quality of air related with intensity of ventilation and production of ammonia emissions were main parameters observed in this study.

Very high statistical reliability was found between the age of litter and ammonia concentration as well as between the age of litter and ammonia emissions ($P<0.001$). Summer time was associated with higher NH_3 emission rates than winter time, even though the concentrations were lower. This can be mainly attributed to the increased ventilation rates of the building. In individual grow-out periods the emission factor for NH_3 out of the average number of animals was determined: 6.47; 5.17; 6.39; 5.24; 6.00 and 7.81 g/head respectively. Resulting annual emission factor of 0.043 kg/head was calculated for 7 periods, i.e., for one production year.

On the basis of obtained results it can be concluded that from a poultry house with capacity of 25,000 broiler chickens placed onto litter, about 1,000 kg of ammonia is emitted yearly. The design of the current experiment was focused on real commercial conditions. In this manner, the obtained data are relatively precise and applicable to other similar broiler rearing facilities.

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