THE EFFECT OF PIG ACTIVITY ON THE EMISSION OF AMMONIA

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Abstract

Three experiments (Exp.) with a group of 10 pigs were carried out to assess the effect of pig behaviour on the daily emission of NH_3. In Exp.1 under normal housing conditions (flat floor bedded with straw), the correlations (r) between NH_3 emission and duration of feeding or drinking (FD), moving (MO), and lying (LY) were +0.78, +0.73, and -0.77, respectively. The coefficient of determination (r^2) of the model was 0.662. Similar correlation coefficients were observed in Exp. 3 when the air in the stable was ionized: +0.67, +0.54, and -0.67 for FD, MO, and LY, respectively (r^2 = 0.596). Considerably different values were recorded in Exp.2 at an increased air flow rate. The correlations between NH_3 emission and FD, MO, and LY were +0.38, +0.38, and +0.39, respectively (r^2 = 0.350). It was proven that the limiting element was the air flow rate inside the house. The limit value of this element is *ca* 0.30 $m.s^{-1}$. Daily emissions of NH_3 per one animal were 8.16, 9.92, and 5.81 g under normal housing conditions (Exp.1), at an increased air flow rate (Exp.2), and when the air was ionized (Exp.3), respectively.

Key words: Pigs, ammonia, ethology, air flow rate, behaviour, air-ionization

The emission of ammonia from pig fattening operations is influenced by a number of factors, e.g. genetics, feed nutrient utilization, diet composition and its distribution in time, ventilation, micro-climatic conditions, and manure management. Berthiaume et al. (2005) used the above mentioned factors in the mathematic model for the N flow in the fattening system. The error of estimation of this model is 6.4 %. Vranken et al. (2004) improved the accuracy of the model estimating the emission of ammonia by including further parameters (season, air flow rate, number and live weight of housed animals). It resulted in a low prediction error (3 %) between the measured and the calculated NH_3 emission.

It is evident that the behaviour of growing pigs, to a great extent, depends on the ambient temperature. In trials with young sows, Huynh et al. (2005) observed their behaviour within the temperature interval from 16 to 32ºC during 9 days with the daily increase of temperature 2 K. The animals were housed on the solid floor with a slatted area (1 m^2 per 1 sow over 61.7 kg of weight). A higher temperature was associated with a higher number of sows lying on the slatted area ($P \leq 0.001$). Growing temperatures also resulted in more frequent defecations ($P \leq 0.05$) while the number of urinations slightly decreased (p=0.13). At relatively low temperatures (16ºC), the animals preferred lying ($P \leq 0.001$). The thermal behaviour of finishing pigs (from 55 to 105 kg of weight) was analysed by Dolejs et al. (2002). During 24 h there were 5 time intervals explicitly determined by the feeding times (in this case 4:00 and 14:00). These intervals were characterised by specific activities. The longest interval approx. 8 h was taken by lying (20:00 – 4:00). During 24 hours, the pigs spent 10 % of time by feeding and drinking, 10 % by aimless moving around the pen, and 80 % by lying. Behavioural changes due to the temperature (20 K) were small but, because of low standard deviations, highly significant ($P \leq 0.01$). Correlations between ambient temperature and duration of feeding and drinking, moving around the pen, and lying were -0.69, -0.98, and -0.94, respectively.

The complexity of measuring ammonia concentrations in the stable was pointed out by Klement et al. (1995). The values of ammonia concentration are affected by the system of housing (fully slatted, partly slatted, bedded etc.) and by the measurement site (near feeders, in the manure passage). The gas concentration is considerably reduced when the gate to the feeding passage is open. The variability of diurnal NH_3 levels is associated with the daily schedule in the stable. Beginnings of feeding are the main time points affecting the activities of animals. Groenestein et al. (2001) analysed the effect of freedom of movement on the emission of ammonia. They compared the individual housing system for 64 sows with 2.8 m^2 of surface area per sow (A), group housing for 62 sows with 3.3 m^2 per sow (B) and group housing for 65 sows with 3.4 m^2 per sow and sequential feeding (C). The beginnings of feeding were always at 7:30 and 15:30 in A and B while in C the sows were sequentially fed from 15:30. The emissions of NH_3 per sow and the percentages of the emitted nitrogen from the total nitrogen intake were 0.72 $g.h^{-1}$ and 23 %, 0.62 $g.h^{-1}$ and 20 % ($P \leq 0.05$), and 0.70 $g.h^{-1}$ and 23 % for the systems A, B, and C, respectively. The pattern of NH_3 emission was related to the feeding times in A and B. In C this pattern was also related to the feeding time with a small peak after the lights were switched on. Neither the increased surface area per sow nor group housing influenced the emission of NH_3. In the following experiment (Groenestein et al., 2003) the feeding schedule was changed. Feeding times in A and B were 7:30 and 21:30 while in C the feed was available from 7:30. NH_3 emissions, indoor microclimate, and animal activity were analysed considering autocorrelations with a time-series model. Coefficients of determination (r^2) were 0.48, 0.66, and 0.48 for A, B, and C, respectively. The emissions of NH_3 per sow were changed in A from 0.71 to 0.68 g.h^{-1} (p=0.23), in B from 0.60 to 0.61 g.h^{-1} (p=0.75) and in C from 0.69 to 0.76 ($P \leq 0.01$). The results indicate that changing the feeding schedule of sows did not alter the diurnal pattern of the ammonia emissions in the systems A and B. However, different feeding times significantly affected the emission of ammonia in the sequentially fed sows.

The relationship between the emission of ammonia and the activity rate of fattened pigs (deep bedding technology) during the 4-month period was analysed (Delcourt et al. (2001). The activity rate of pigs followed a circadian rhythm and decreased during the fattening period from 22.6 to 8.8 %. In each monthly period, the emissions of NH_3 per hour and the activity rate of animals were observed. The correlation coefficient (r) between the emission of NH_3 and the activity rate was +0.61. Using the same housing technology (uninsulated stable) Jeppsson (2002) carried out an experiment with fattened pigs aimed at the effect of the animal activity on ammonia emission. The stable microclimate, outside temperature and relative humidity, air flow rate, ammonia emission, and pig activity were measured during 6 days of the growing period. At the constant air flow rate the emission varied from 6 to 247 % of the mean with a clear diurnal variation. This variation was correlated to the inside air temperature (r = 0.86-0.91) and the animal activity (r = 0.69-0.83). The effect of the animal activity on the inside ammonia concentration was analysed in 10 pigs fattened from 55 to 80 kg of weight in the housing system with 1.1 m^2 of surface area per animal (partly bedded – 65 % of the total area) (Dolejs et al., 2003). The air flow rate in the stable was also taken into account. The correlations were calculated on the basis of hourly averages of ammonia concentrations and percentages of different pig activities (feeding, moving, and lying). At the air flow rate of 0.18 m.s^{-1}, the correlations (r) between the concentration of NH_3 and different pig activities were +0.74, +0.70, and -0.77 for feeding, aimless moving, and lying, respectively. These correlations were lower (+0.32, +0.66, and -0.55, respectively) at a higher air flow rate of 0.22 m.s^{-1} and the relationships between the NH_3 concentrations and the animal activities were very low (+0.22, +0.17, and -0.20, respectively) at the air flow rate of 0.34 m.s^{-1}.

With respect to the facts mentioned above the following hypothesis was set up for the three experiments described below: Behaviour of pigs and particularly their movement activity influence the diurnal ammonia emission. The problem has to be analysed in relation to stable microclimatic conditions which, besides the daily schedule, affect the behaviour of pigs and thus the emission of ammonia. Due to this, not only standard housing conditions but also some specific conditions like high temperatures with cooling of animals by an increased air flow rate or ionization of air were employed with the objective to reduce the ammonia emission from the stable.

Material and methods

Experiments and microclimatic conditions

Each of the three consecutively organized experiments lasted 14 days. Except for the Experiment 1, different measures were tested in the other trials. In Experiment 2 it was the increase of the air flow rate inside the pen with the aim to reduce the heat stress of animals. In Experiment 3 the ionization of air was used to eliminate the emission of ammonia and other gases. The microclimatic conditions in Experiments 1 and 3 were almost identical. The inside temperature was *ca* 20 ºC, relative air humidity *ca* 55 %, and the air flow rate inside the pen ranged from 0.25 to 0.30 m.s^{-1}. In Experiment 2 the values of microclimate elements were changed with respect to the observation of pig cooling efficiency. The microclimate in the different periods is summarised in Table 1.

Specific conditions in the stable

Experiment 1 (Exp.1):

Standard technological system without additional influencing considered as referential for the remaining experiments.

Experiment 2 (Exp. 2):

An axial ventilator was used to increase the air flow rate. The average air flow rate inside the pen was 1.08 m.s^{-1}. The data from 9 different measurement sites in the pen were used to calculate the average. The measured values ranged from 0.79 to 1.28 m.s^{-1}. The output of the ventilator was 4,000 m^3.h^{-1}.

Experiment 3 (Exp. 3):

The complete set comprises a high-voltage unit and a ionization line with emitters located 0.75 – 1 m from each other. The line was suspended above animals at the height of 2 – 3 m from the floor level. The power consumption was *ca* 0.5 kWh per day. The number of ions was measured once a day (8:00) during this experiment (except for the day of the ethological survey). The average for the given period was 276 n^+ and 375 n^-. Due to possible influencing of animal behaviour, the number of ions was not observed at the time of the emission measurement and the ethological survey.

Housing technology and used animals

Fattened pigs were housed in a pen with a bedded section (64.9 % of surface area) and a slatted section (35.1 % of surface area). The floor was without slope and the total surface area per animal at the beginning of fattening was 1.1 m^2. The urine was collected in the gutter under the slatted floor. The manure was removed twice a day. Pressed straw was provided twice a day at the amount of 1.0 $kg.pig^{-1}.day^{-1}$. A dry feed system was used and a complete diet was put into 2 troughs located on the longer side of the slatted area twice a day (7:00 and 13:00). A drinker was also located in the slatted area. The building was closed and the air flow controlled. The temperature and relative humidity could be changed using an air condition unit.

The initial average live weight of 10 pigs housed in the pen was 54.6 kg. The average live weights of pigs at the times of ethological observations and ammonia emission measurements were 62.1, 70.7, and 75.5 kg in Exp.1, Exp.2, and Exp.3, respectively. The animals were weighed at the beginning of Exp.1 and then regularly at the end of each experiment.

Method of ethological observation and its evaluation

The animals were continually recorded on the CCTV camera and the video recorder. The pen was lighted with fluorescent lamps. With respect to the adaptation of animals for the level of night and day illumination the stable was already lighted 24 hours before the beginning of video recording. All observations started and ended at 9:00, i.e. they started 2 days before the end of the period and ended on the last day of each period with the given stable conditions. At this time, only a stockperson performing standard working tasks was present in the stable as her presence was part of the technological system.

All 24 h observations were evaluated in 5-minute intervals, i.e. 12 values for each life activity per 1 hour were available. The following life activities were assessed: feeding and drinking (=alimentary activities), moving around the pen, and lying (resting). The objective was to determine the average duration of different activities expressed in minutes/1 hour or minutes/24 hours.

Measurements of ammonia concentration, air flow and indoor microclimate

The concentration of NH_3 was measured by chemical sensors (Aseko) located near the ventilator in 10-minute intervals. The air flow rate was measured on the outlet ventilator (Babuc system). In the life zone of animals (1.0 m above the floor) the temperature and relative humidity were also measured in 10-minute intervals (Commeter system). The air flow rate in the pen was measured 3 times a day (8:00, 12:00, and 16:00).

Data analysis

The initial data were synchronised and recalculated to 1 h averages and these data were used for final calculations.

Multilinear model – relationship between ammonia production (dependent variable) and pig behaviour (independent variable). Independent variables are the following life activities: Feeding and drinking (FD), moving (MO), and lying (LY). In addition, basic characteristics of the stable microclimate (temperature $t_{(i)}$ and relative humidity $rh_{(i)}$) were included among the independent variables.

Correlations – degree of relation between NH_3 emission and different life activities or microclimate characteristics.

Table 1. Conditions in different experiments and at the time of emission measurements

Experiment	Technological system	Values for	Stable microclimate					
			$t_{(i)}$ (°C)		$RV_{(i)}$ (%)		$v_{(i)}$ $m.s^{-1}$	
			$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
1	standard conditions	experiment	20.9	0.751	52.6	2.71		
		measur. time	20.62	0.372	51.0	2.22	0.21	0.03
2	increased level of ventilation	experiment	29.4	1.05	44.2	2.35		
		measur. time	28.47	0.602	45.1	2.00	0.89	0.09
3	air ionization	experiment	20.66	0.802	55.9	2.11		
		measur. time	20.48	0.440	56.1	2.05	0.26	0.05

Results and discussion

1. Ammonia emission

In Exp.1 the emission was 8.160 g per pig and day (i.e. 2.98 kg per year). In Exp.2 the emission was increased due to a higher air flow rate by 21.6 % ($P \leq 0.01$) to 9.924 g (=3.62 kg per year). Exp.3 was designed to reduce the emission by air ionization and, indeed, the emission was decreased to 5.808 g (=2.12 kg per year), i.e. by 28.8 % ($P \leq 0.001$). The results are given in Table 2.

2. Life activities of pigs

Changing the conditions in the stable (see Table 2) resulted in a different structure of animal life activities expressed not only as total daily values but also as values from different daily periods. Compared to the referential Exp.1, times of FD and MO were reduced in Exp.2 (indexes 0.809 and 0.744, respectively). By contrast, the time of LY increased (1.075). Somewhat lesser changes occurred in Exp.3. FD as well as MO times were reduced (indexes 0.905 and 0.926, respectively, while LY time increased (1.027). However, all changes in life activities lacked statistical significance. This was due to the fact that FD and MO were not observed in certain periods of the day and particularly at night. These irregularities of the daily schedule resulted in the coefficients of variation of these activities sometimes higher than 100 %. This was particularly the case of FD with its variation coefficients ranging from 112.1 to 146.7. The highest variation of life activities was found in Exp.3. The data are summarised in Table 3. The behaviour of pigs is demonstrated in Graph 1.

3. Multilinear model of the dependence of ammonia emission on pig behaviour and microclimate

The used multilinear regression model did not fully describe the relationship between pig behaviour and ammonia emission (see Table 4). This fact is evidenced by the coefficients of determination (r^2) of the used regression model explaining ammonia emission by animal behaviour and stable microclimate, which were 66, 36, and 60 % for Exp.1, Exp.2, and Exp3, respectively. It is evident that including other parameters into the model did not result in a higher proportion of the explained variation. The coefficients of determination for the same regression model used in the study focused on changes of sow feeding times ranged from 0.48 to 0.66 (Groenstein et al., 2003). In our study, of all the linear terms of the regression equation, only the p-value of FD was close to the level of 0.05 ($p = 0.055$) in Exp.1. The p value for MO and LY was > 0.1 and for microclimatic characteristics even > 0.03. The coefficient of determination 0.6620 was highest of all the experiments. Entirely opposite relations to ammonia emission were revealed from Exp.2 when the level of ventilation was increased. The p-values of all variables were > 0.38. This was also demonstrated by the coefficient of determination r^2 (0.3615). Only the temperature was significant ($p = 0.012$). Pig behaviour and stable microclimate characteristics influenced ammonia emission more intensively in Exp. 3 when air ionization was used in spite of the fact that the coefficient of determination (0.5963) was lower than in the model for Exp.1. The p-values of all terms included in the model were close to 0.05 ($p < 0.058$). The p-values of $t_{(i)}$ and $rh_{(i)}$ were 0.044 and 0.049, respectively. Based on F-test the model could be used for standard stable conditions (Exp.1) and for the system with air ionization (Exp.3). In both cases the p-value of the model was < 0.01. It is not appropriate to use the model when the ventilation in the stable is increased (Exp.2).

4. Correlations between ammonia emission and the characteristics of pig behaviour and microclimate

The correlation between ammonia emission and pig behaviour was highest in Exp.1 but it was only lowly correlated with microclimatic conditions. The production of ammonia was directly influenced by life activities and was highly correlated with FD and MO (+0.777 and +0.733, respectively. These activities are associated with alimentary actions and are characterised by the fact that at this time of the day the animals urinate and defecate more frequently. Primary gases are emitted from the digestion tract and faeces to the stable environment and due to the almost stable air exchange the concentration of ammonia increases. After the produced gases are removed, the concentration of NH_3 and other gases are reduced. At the same time the microbiological activity continues and it results in a partially increased NH_3 concentration even before the following feeding. Then the activities FD and MO are slowly ceasing and the proportion of LY increases. As expected, the quiet in the stable indicated by the "lying" activity is negatively correlated with NH_3 emission (-0.768).

A similar development of NH_3 emission was also experienced in Exp.3 when air ionization was used. Compared to Exp.1, the duration of FD and LY was increased (indexes 1.031 and 1.027, respectively). On the contrary, the time of MO was decreased (index 0.844). As a result of air ionization the emission of NH_3 was reduced (index 0.712). The correlations between NH_3 emission and other variables slightly decreased.

Quite different relationships between individual variables were observed in Exp.2 when the level of ventilation was increased. Although the activities of FD and MO were decreased (indexes 0.809 and 0.729, respectively) while the time of LY increased (index 1.075), the emission of NH_3 was considerably higher (index 1.216) due to a high indoor temperature and an increased air flow rate. In comparison to the experiments 1 and 2, the magnitude of the relationship between NH_3 emission and life activities was significantly lower. The correlations between NH_3 emission and FD, MO, and LY were rather low (-0.172, -0.142, and +0.161, respectively; Table 5).

Based on the results it can be concluded that the NH_3 emission is significantly increased by growing temperatures and air flow rate (Exp.2). On the other hand, the emission was reduced by air ionization (Exp.3). The relationship between NH_3 emission and pig behaviour is apparently strongly affected by the air flow rate in the stable. It appears that the limiting value of this parameter is 0.30 $m.s^{-1}$ (Dolejs et al., 2003). At the air flow rate of 0.34 $m.s^{-1}$ the correlations between NH_3 concentrations and the same life activities of pigs as those observed in the present study ranged from 0.17 to 0.22. We assume that NH_3 is emitted from the substrate (complex of faeces, urine, and litter) to the living zone of animals and then to the discharge ventilator through the transfer air layer located directly above the substrate. Ammonia is released to higher sections of the stable by the movement of animals.

Only a limited amount of NH_3 is emitted to the upper part of the stable when the pigs are lying (20:00 – 04:00). If the air flow rate directly in the pen is increased, NH_3 is released from the transfer layer to the living zone of animals and then to the discharge site (ventilator). The amplitude of NH_3 concentration becomes smaller and the emission of ammonia from the stable is almost constant. The development of NH_3 emission and life activities during the day in different experiments are demonstrated in Graph 2.

The correlations between the microclimatic parameters (temperature and relative humidity) measured during the day in different experiments and NH_3 emissions were low to moderate. This fact also results from the values of these parameters in given experiments (Table 1). The effect of temperature was evidenced by the difference in NH_3 emissions between Exp.1 and Exp.2.

Table 2. NH_3 emission and life activities per 24 h

Experi-ment	NH_3 emission		Life activities per 24 h (minutes per 24 h)					
	$g.pig^{-1}.day^{-1}$	index	FD	index	MO	index	LY	index
1	8.160	1.000	139.18	1.000	214.16	1.000	1086.66	1.000
2	9.924	1.216**	116.60	0.809	155.64	0.727	1167.72	1.075
3	5.808	0.712***	143.50	1.031	180.71	0.844	1115.79	1.027

** $P \leq 0.01$, *** $P \leq 0.001$

Table 3. NH_3 emission and life activities per 1 h

Experiment		NH_3 emission	Life activities per 1 h – (minutes per 1 h)		
		$mg.pig^{-1}.h^{-1}$	FD	MO	LY
1	average	340.02	5.80	8.92	45.28
	SD	89.369	6.865	7.790	14.115
	V (%)	26.3	118.4	87.3	31.2
2	average	413.48	4.86	6.49	48.66
	SD	50.240	5.450	6.062	11.186
	V (%)	12.2	112.1	93.5	23.0
3	average	241.99	5.98	7.53	46.49
	SD	63.605	8.770	7.690	15.072
	V (%)	26.3	146.7	102.1	32.4

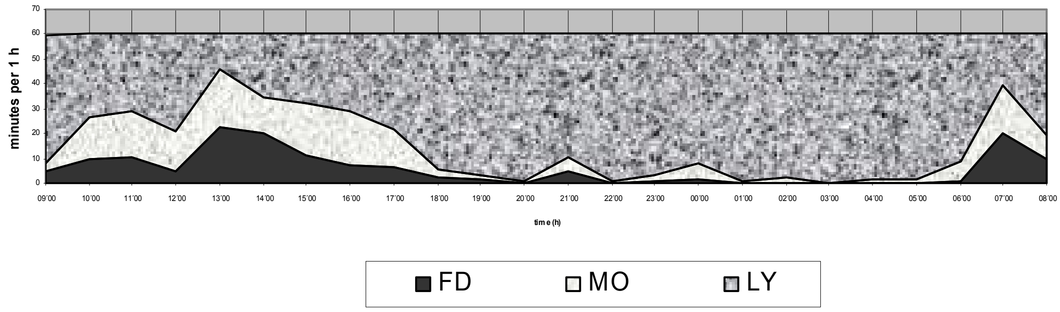
Table 4. Multilinear regression model ($y = b_o + ax_1 + ax_2 + ax_3 + ax_{(4)} + ax_{(5)}$) and statistical significance of linear terms (p =)

Experiment	FD	MO	LY	$t_{(i)}$	$rh_{(i)}$	b_0	r^2	F-test
1	19.12	16.07	12.32	-30.29	-4.45	379.5	0,6620	0,01
2	-207.53	-210.66	-207.44	47.71	-2.75	11646.2	0,3615	NS
3	1028.1	1022.1	1023.2	96.80	19.99	-64271	0,5963	0,01
Statistical significance of linear terms								
1	0.055	0.101	0.142	0.344	0.340			
2	0.384	0.383	0.385	0.012	0.350			
3	0.057	0.058	0.058	0.049	0.049			

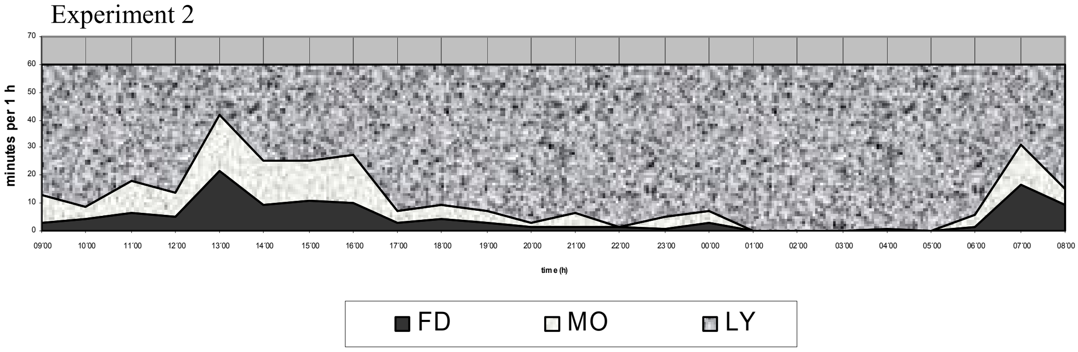
Graph 1.

Structure of life activities

Experiment 1



Experiment 2



Experiment 3

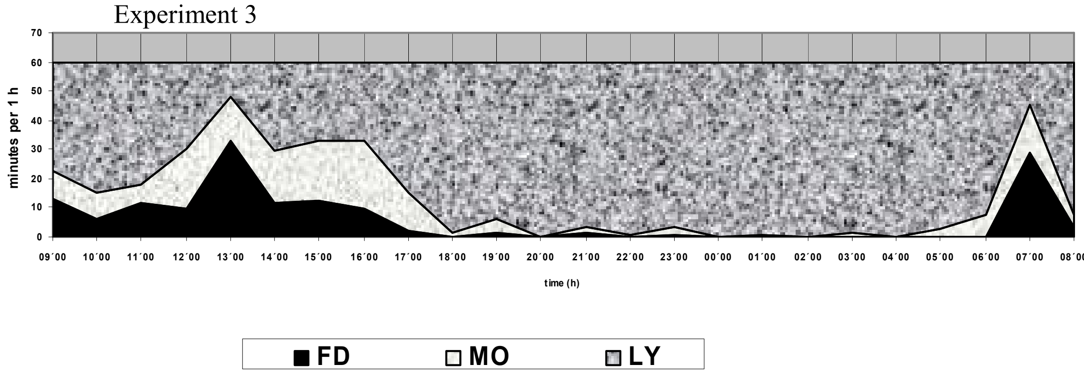
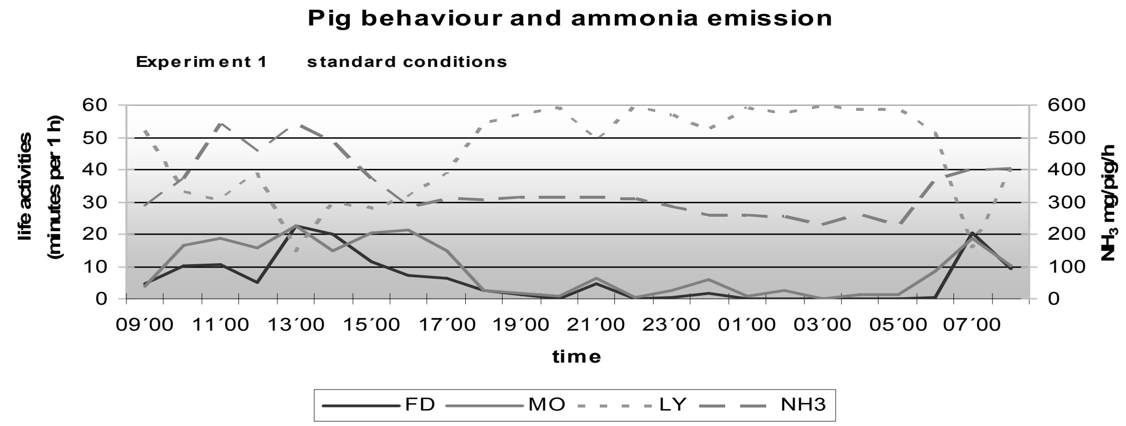
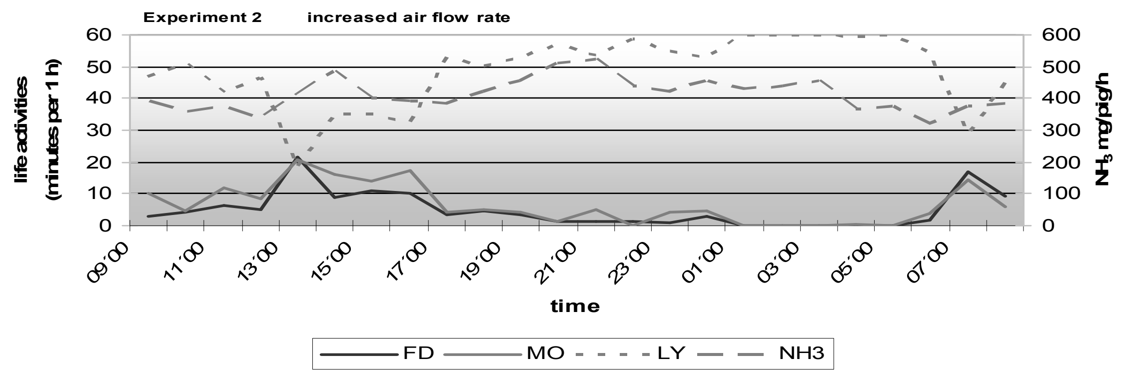


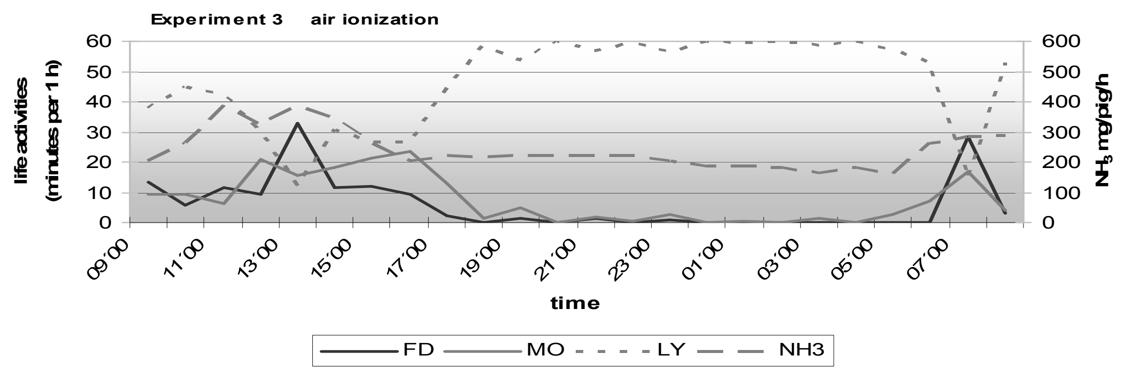
Table 5. Correlation between ammonia emission and life activities (r_{yx} =)

Experiment	FD	MO	LY	$t_{(i)}$	$rh_{(i)}$
1	0.777	0.733	-0.768	0.352	-0.299
2	-0.172	-0.142	0.161	0.501	-0.219
3	0.674	0.538	-0.666	0.100	0.176

Graph 2.







Conclusion

The daily emission of ammonia is not closely related to pig behaviour. Including temperature and relative humidity into the model did not result in an increased dependency as expected. A new parameter of the stable microclimate has appeared – air flow rate. It eliminated to a great extent the relationship between ammonia emission and pig behaviour. From the hitherto performed experiments it was revealed that the limiting value of this parameter is approximately 0.30 $m.s^{-1}$. Once exceeded, the relationships between ammonia emission and pig life activities become significantly weaker.

References

Berthiaume,P., Bigras-Poulin,M., Rousseau,A.N.(2005): Dynamic simulation model of nitrogen fluxes in pig. housing and outdoor storage facilities. Biosystems engineering. 92.(4)..453-467

Delcourt,M., Vandenheede,M., Desiron,A., Laitat,M., Capart,B., Nicks,B.(2001): Ammonia, nitrous oxide, methane, karbon dioxide and water vzpour emissions in fattening pig house on deep liter: levels of production and correlation with with pigs. Annales de medecine veterinaire. 145. (6).Suppl. 357-364

Dolejs,J., Toufar,O., Adamec,T., Knizek,J.,(2002): An ambient temperatures and life demonstartion of pig fattening.(in Czech) In:Proc.International Symposium, Nitra, Slovakia, Research Institute of Animal Prod. 545-549.

Dolejs,J., Toufar,O., Adamec,T.,(2003): Reduction of Ammonium emission in pig fattening. (in Czech). Agromagazin.4.(7).52-54

Groenestein,C.M., Hol,J.M.G., Vermeer,H.M., den Hartly,L.A., Metz,J.H.M., (2001): Ammonia emission from individual and group-housing systems for sows. Netherland Journal of Agricultural Science. 49. (4). 313-322

Groenestein,C.M., Hendriks,M.W.B., den Hartly,L.A., (2003): Effect of feeding schedule on ammonia emission from individual and group-housing systéme for sows. Biosystems engineering. 85. (1).79-85

Huynh,T.T.T., Aarnink,A.A., Ferrite, W.J.J., Heetkamp, M.J.H., Canh,T.T.,Spoolder,H.A.M.,

Kemp,B., Verstegen,M.W.A.,(2005): Thermal behaviour of growing pigs in response to high temperature and humidity. Applied Animal Behaviour Science. 91 (1-2). p.1-16)

Jeppsson,K.H., (2002): Diurnal variation in ammonia, carbon dioxide and water vapor emissions from an uninsulated, deep liter bilding for growing/finishing pigs. Biosystems engineering. 81. (2).213-223

Klement,S., Ross,A., Schwarz, H-P., (1995): Ammoniakmessungen in Mastschweinestallen. Landtechnik. 50. (3).162-163

Vranken,E., Clara,S., Hendriks,J., Darius,P., Berckmans,D.,(2004): Intermittent measurements to determine amonia emissions from livestock buildings. Biosystems engineering. 88. (3).351-358

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