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The Correlation between Ammonia Emissions and Bedding Materials in a Cow House

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ABSTRACT

Because ammonia from livestock production may substantially contribute to environmental pollution, emissions from all possible sources (housing systems, manure storage, manure application, outside grazing) should be reduced. The purpose of this study was to investigate the effect of different bedding materials on ammonia emissions in a cow house. By applying a combination of four treatment types: treatment 1-T_1 (sawdust (50%)+sawdust pellets (50%)), treatment 2-T_2 (sawdust (50%)+corn stalk pellets (50%)), treatment 3-T_3 (sawdust (100%)), and treatment 4-T_4 (sawdust (50%)+palm kernel meal pellets(50%)) as bedding materials in a cow house, the effects of such treatments on ammonia flux were assessed in approximately one month. The magnitude of ammonia emissions (mg m^{-2} min^{-1}) varied in the following order: T_1 (2.226), T_4 (2.052), T_2 (1.845), and T_3 (1.712). The patterns of pH had a decreasing trend for all bedding treatments during the experiment, and there was no significant relationship with ammonia flux. The results reveal that the most important factor influencing ammonia emissions is the physical structure of the bedding types.

Key words: Ammonia, Cow house, Emission, Flux, Bedding material, Greenhouse gas

1. INTRODUCTION

A major source of global atmospheric ammonia is agriculture ammonia emissions (Davidson and Mosier, 2004; van Aardenne *et al.*, 2001), of which animal waste and fertilizers are responsible for 90% or more of anthropogenic ammonia emissions (Battye *et al.*, 1994). In most Asian countries, fertilizers and livestock occupied nearly 77% of the total anthropogenic ammonia emissions, and the ammonia emissions from livestock alone occupied about 30% (Zhao and Wang, 1994). In the UK, approximately 42% of ammonia emissions are from houses in which cattle and pigs are bedded on straw (Misselbrook *et al.*, 2000). When ammonia is released into the atmosphere, it has a short lifespan (less than 5 days). Once transformed into ammonium (NH_4^+) aerosol, the lifespan of the species increases on the order of 10 days. Thus, NH_4^+ aerosol can travel and deposit at greater distances (Warneck, 2000). Atmospheric ammonia and its deposition lead to environmental consequences including eutrophication, soil acidification, and aerosol formation. Ammonia can affect ecosystems at relatively low concentrations (Genfa *et al.*, 1998). In addition, ammonia contributes to indirect emissions of N_2O which is one of the main greenhouse gases (IPCC, 2006). One alternative to reduce ammonia emissions could be to add bedding materials in the houses. Ammonia emissions can be reduced by the use of extra straw, resulting in reduced airflow across surface soiled by urine, and by the immobilization of ammonium-N (NH_4^+-N) by bacteria using a high C : N material as a substrate (Chantigny *et al.*, 2001; Dewes, 1996). Furthermore, ammonia emissions can be reduced from bedding materials in the cow house by adsorption of ammonium and ammonia and pH regulation of manure (Kirchmann and Witter, 1989). However, increased straw use can lead to increased temperature in the bedding and subsequently composting and ammonia loss (Maeda and Matsuda, 1997).

There have been a few studies on the effect of bedding materials used in cattle houses on ammonia emissions. Gilhespy *et al.* (2009) reported that an increase of 33% straw, spread over the entire floor reduced ammonia emission from cattle by 50%. Misselbrook and Powell (2005) studied the effect of 6 bedding materials (chopped wheat straw, sand, pine shavings, chopped newspaper, chopped corn stalks, and recycled manure solids) on ammonia emissions from dairy cattle excreta and reported that ammonia emissions were the lowest from sand and pine shavings. A report on the assessment of 4 different bedding types for young cattle (long straw, chopped straw with and without an additive, and chopped straw/peat mixture) showed that ammonia emission was the lowest from a chopped straw/peat mixture (Jeppsson, 1999). Andersson (1996) studied the effects of different bedding materials on ammonia emissions from pig manure and found that they were influenced by the C : N ratio, C availability, and the physical structure of the beddings used.

This paper describes a field study on ammonia emissions in a cow house with 8 different cells (A, B, C, D, E, F, G, and H) of 4 bedding materials. The objective of this study was to quantitatively investigate the effects of different bedding materials (sawdust, sawdust pellets, corn stalk pellets, and palm kernel meal pellets) with different application ratios of bedding material mixtures on ammonia emissions. In addition, the environmental conditions of bedding materials in the cow house affecting ammonia emissions were then evaluated.

2. MATERIALS AND METHODS

2. 1 Site Characteristics and Environmental Parameters

The ammonia fluxes were measured in a cow house for an approximate 1 month period (June 5 to July 3, 2007). The site is located in Yeongcheon city (35° 16′N, 128° 82′E,), Gyeongbuk province, South Korea (Fig. 1). Yeongcheon is located 350 km southeast of Seoul, Korea.

In this study, the ambient, manure, and DFC temperatures were measured by thermometer (model Tecpel 318, Tecpel, Taiwan). The manure pH was monitored by a pH probing system (model IQ 240, IQ Scientific instruments, USA). The thermometer and pH meter were calibrated in the laboratory prior to utilization in the field. The ambient, manure, and DFC temperatures averaged 26.9, 23.7, and 26.9°C, respectively.

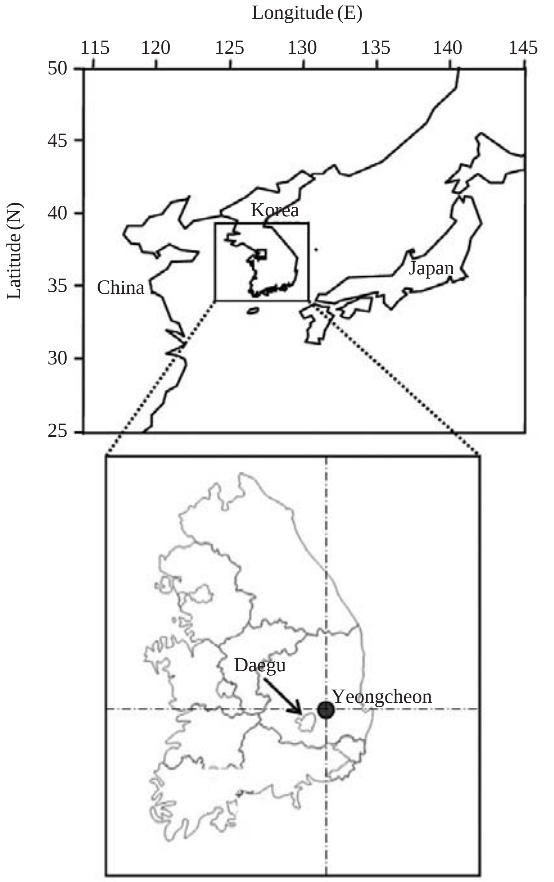

Fig. 1. Map of Yeongcheon city, Korea, experimental site of the present study.

Table 1. Bedding characteristics and mixtures of bedding materials applied in the experiment.

Cells	Short name	Bedding materials
A-B	T$_1$	Sawdust (50%)+Sawdust pellet (50%)
C-D	T$_2$	Sawdust (50%)+Corn stalk pellet (50%)
E-F	T$_3$	Sawdust (100%)
G-H	T$_4$	Sawdust (50%)+Palm kernel meal pellet (50%)

2. 2 Materials Applied to Cow House Floor

The cow house for the experiments was divided into eight cells including A, B, C, D, E, F, G, and H. Each cell had the area of 17.1 m^2, which penned two cows of 14 months old and weighing in an average of 350-400 kg each. Four bedding materials applied with the mixtures of different ratios were used for the cells at the rate of 25 kg m^{-2}. Mixtures of bedding materials applied by dry matter weight to cell A and B, cell C and D, cell E and F, and cell G and H were treatment 1-T$_1$ (sawdust (50%)+sawdust pellets (50%)), treatment 2-T$_2$ (sawdust (50%)+corn stalk pellets (50%)), treatment 3-T$_3$ (sawdust (100%)), and treatment 4-T$_4$ (sawdust (50%)+palm kernel meal pellets (50%)), respectively (Table 1). Two cells were each applied with samples of the same bedding material, which allowed two repetitions of a measurement for each treatment during the experiment period. Bedding materials were analysed for moisture (%), organic matter (% dry matter), NH$_3$-N (mg dL^{-1}), pH, and water absorption before applying as beds in the cow house (Table 2). The pH of a demineralised water/bedding mixture (2 : 1 ratio by weight) was measured using a calibrated portable pH meter (model IQ 240, IQ Scientific instruments, USA). Bedding materials had an average depth of around 10 cm. The starting and finishing dates of the bedding materials were May 30 and July 10, 2007, respectively.

2. 3 Measurement of Ammonia

The measurements of ammonia were made from each of the cells. A flow-through dynamic flux chamber (DFC) system was used to determine the ammonia (Blunden and Aneja, 2007; Roelle and Aneja, 2002; Roelle *et al.*, 2001). An impeller stirrer was installed inside the chamber to ideally mix the air inside, i.e., the composition of any elemental volume within the chamber is to be mixed homogeneously (Roelle and Aneja, 2002). Fig. 2 shows a schematic diagram of the DFC that was used. The chamber was cylindrical shaped (0.29 m ID × 0.3 m internal height to yield 20 L volume) and made up of fluorinated ethylene propylene (FEP) with a Teflon lining to minimize the sorptive loss of ammonia onto its inner walls (Roelle *et al.*, 2001). In order to initiate the flux measurement, the dynamic flux chamber (DFC) was placed to cover a small area from a specific cell (A, B, C, D, E, F, G, or H). Before the actual experiment, the chamber was flushed with ultra pure air for at least half an hour to attain steady state conditions. Compressed air (carrier gas) was supplied into the chamber at a constant flow rate (approximately 5 Lpm) via a flow meter (ball type) fixed on the top of the gas cylinder. The gas exiting the chamber was analyzed with the 17C Chemiluminescence analyzer (Thermo Environmental Corporation, Mountain View, CA), which measures ammonia concentrations. The standard concentration of ammonia gas (101.0 ppm, Rigas-Korea) was applied for the span check. A total of 5 readings were taken sequentially at an interval of 1 minute for each location after the equilibrium concentration was attained. The instrument had a lower detectable limit of 1 ppb for ammonia concentrations. The accuracy of the instrument varied with the concentration but was in the range of 3.7-10.5%. An average precision was found to be 0.7 % based on self-test made in the laboratory. A multipoint calibration of the instrument was done one day prior to the sampling campaign. Zero and span checks were made routinely each day as the basic QA procedure for the analysis.

Table 2. Initial properties and geometric particle size of sawdust (S), sawdust pellet (SP), corn stalk pellet (CSP) and palm kernel meal pellet (PKMP) used as bedding materials.

Item	S	SP	CSP	PKMP
Moisture (%)	36.1	7.8	11.7	10.8
Organic matter (%, DM)	99.6	97.2	97.2	97.2
NH_3-N (mg dL^{-1})	28.5	29.3	46.0	39.3
pH	5.9	4.5	7.6	5.1
Water absorption (%)	254	420	423	279
Screen openings (mm)				
11	0.7	0.3	60.8	16.1
3	8.1	99.0	38.2	74.9
2	13.1	0.2	0.4	4.4
1	39.0	0.2	0.3	2.6
< 1	39.0	0.1	0.1	1.9

Emission flux of ammonia was calculated according to the mass balance approach (Blunden and Aneja, 2007). If one assumes the mass balance of ammonia in the chamber;

$$dC/dt=(Q[C]_o/V+JA_P/V) -(LA_C[C]/V+Q[C]_f/V)-R \qquad (1)$$

where [C] is the NH_3 concentration in the chamber, A_P is the surface area of the plot covered by the chamber, A_C is the inner surface area of the chamber, Q is the flow rate of the carrier gas in the chamber, J is the

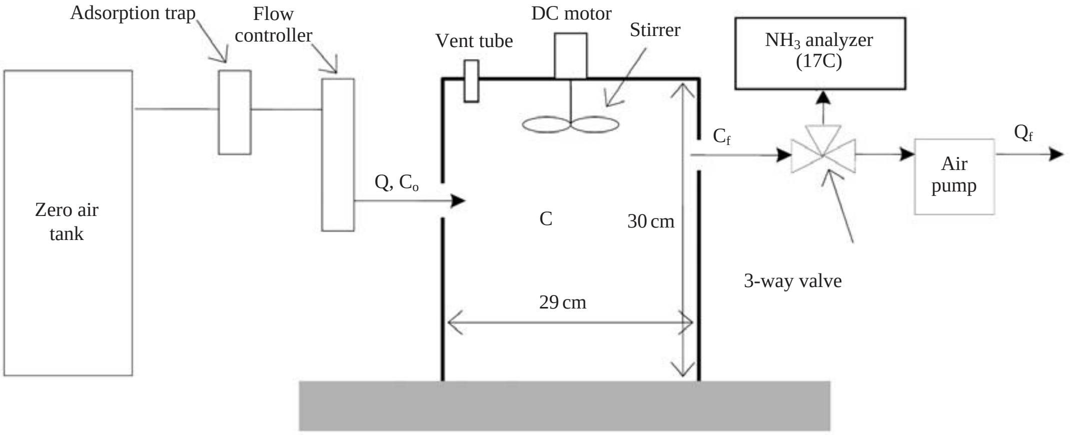

Fig. 2. Schematic diagram of dynamic flux chamber (DFC).

Table 3. Statistical summary of environmental parameters, ammonia fluxes and emission factors measured during the entire study period (Number of measurements-N, 9).

	Temperature (°C)			pH	Ammonia flux ($mg\ m^{-2}\ min^{-1}$)	EF $gN\ cow^{-1}\ d^{-1}$
	Ambient	Bedding	DFC			
Bedding material T_1						
Mean	27.4	23.8	27.4	7.9	2.226	22.57
(Min-Max)	(23.4-31.1)	(21.7-26.4)	(23.1-30.6)	(7.6-8.3)	(0.439-4.098)	(4.45-41.55)
Median	27.4	23.4	27.8	8.1	1.987	20.15
SD	2.18	1.54	2.22	0.27	1.259	12.77
Bedding material T_2						
Mean	27.4	24.0	27.4	7.9	1.845	18.70
(Min-Max)	(23.3-31.1)	(21.7-26.2)	(22.9-31.8)	(7.5-8.4)	(0.256-3.664)	(2.60-37.15)
Median	27.3	24.0	27.9	8.0	1.714	17.37
SD	2.14	1.38	2.55	0.27	1.070	10.83
Bedding material T_3						
Mean	27.4	24.0	27.5	7.9	1.712	17.36
(Min-Max)	(23.4-31.4)	(21.9-26.8)	(22.7-32.1)	(7.6-8.3)	(0.341-3.151)	(3.46-31.94)
Median	27.3	23.7	28.0	7.9	1.913	19.39
SD	2.24	1.71	2.78	0.23	0.973	9.87
Bedding material T_4						
Mean	27.2	23.9	27.5	7.9	2.052	20.80
(Min-Max)	(23.5-31.5)	(21.5-26.8)	(22.6-32.6)	(7.5-8.3)	(0.334-3.499)	(3.39-35.48)
Median	27.3	23.8	28.2	7.9	1.929	19.56
SD	2.33	1.70	2.94	0.31	1.148	11.64

emission flux of the respective gases (i.e., NH_3), V is the volume of the chamber, and $[C]_o$ and $[C]_f$ are the incoming and exiting concentrations of the chamber, respectively. In addition, L is the loss term by the chamber walls, whereas R is the chemical reaction rate inside the chamber.

Because compressed air is supplied to the inlet, there is no inlet concentration of NH_3; so $[C]_o=0$. When a steady state is reached in a well-mixed chamber, [C] may be assumed to be equal to $[C]_f$ in the chamber. The reaction term R can be ignored because reaction between the gases is unlikely to be significant due to their short residence times inside the chamber. When the steady state is attained, the above reaction can be reduced to

$$J=[C]_f(LA_C/V+Q/V)h \qquad (2)$$

In this new equation, h is the height of the cylinder above the bedding surface.

2.4 Data Analysis

In order to evaluate the effects of the bedding materials on ammonia emission from the cow house, comparisons of the means of the emission values were made using the SPSS statistical package (George and Mallery, 2008). Correlation analyses between the variables were conducted at the significance levels of $p<0.05$ and $p<0.01$.

3. RESULTS AND DISCUSSION

3.1 The General Patterns in NH_3 Emissions

The ammonia emissions from 8 cells of a cow house with 4 different bedding materials had been monitored for approximately one month (June 5 to July 3, 2007). All flux measurements were made with the mixtures of 4 different bedding materials in 8 cells. The mean concentrations of ammonia used for the computation of the flux values were above the detection limit, i.e., 1 ppb (the 17C analyzer), throughout the entire study period.

The emission patterns of ammonia with the application of 4 different bedding materials on 8 cells in a cow house are summarized in Table 3. A total of 46 flux values were recorded for ammonia. There were differences to be found between the four bedding materials in term of the daily mean gaseous ammonia flux. The means of gaseous ammonia flux were found to be 2.226, 1.845, 1.712, and 2.052 mg m^{-2} min^{-1} for T_1, T_2, T_3, and T_4, respectively (Table 3). T_3 had a lower ammonia flux compared with the other bedding alternatives. The difference in ammonia flux rate between T_3 and T_1 was significant; T_3, having the lowest ammonia flux, reduced the ammonia flux by 23% compared with T_1, having the highest ammonia flux among 4 bedding treatments. In general, during the one-month evaluation period the mean ammonia fluxes within the cells filled with T_2 and T_3 were lower than those of T_1 and T_4. In addition, the differences in the ammonia flux between T_2 and T_3, and T_1 and T_4 were not significant. The standard deviation (SD) shows a large variation within each treatment.

The results of our measurement showed that ammonia emissions from 4 bedding treatments appeared not to be related to the water absorption of the bedding materials. The average water absorption of the bedding materials of T_1, T_2, T_3, and T_4 were 337, 339, 254, and 267%, respectively, whereas the corresponding mean ammonia emissions were 2.226, 1.845, 1.712, and 2.052 mg m^{-2} min^{-1}, respectively. The results of this study suggest that the most important factor influencing ammonia emission is the structure of different bedding materials. The open structure of materials increased the surface area from which ammonia emissions could occur. In addition, a more compact structure in the beds with T_3 might have resulted in lower oxygen levels in the beds compared with T_1, T_2, and T_4. Composting activity might be low in the bed, which has low oxygen level, resulting in lower ammonia emission. Furthermore, oxygen transfer into the bed may decrease as the animals trample down the litter (Groenestein and Faassen, 1996). Besides the fact that the initial physical structure of the bed of T_3 was small, the animals trample down the litter, resulting in T_3 having a more compact structure in the litter compared with the beds in T_1, T_2, and T_4. This can explain why T_3 has the lowest ammonia emissions. Misselbrook and Powell (2005) found that ammonia emissions from small size bedding materials such as sand and pine shavings were lower than those of larger bedding such as chopped straw, newspaper, and corn stalks. Our results compare favorably with those of Jeppsson (1999). The author found that ammonia emissions from peat and chopped straw (60% peat+40% chopped straw) having the smallest size was the lowest in comparison with other bedding materials (long straw, chopped straw, and chopped straw with additive). Similarly, the results of treating pig manure by bedding materials such as straw, straw and peat, straw and Absorbera, straw and Purifi N, and straw and newspaper indicated that the structure of bedding material is important in controlling ammonia emissions from manure (Andersson, 1996). In another study on reducing ammonia emission from broiler manure by manipulating bedding materials, Tasistro *et al.* (2008) also found that bedding material with sawdust gave the lowest ammonia emissions compared with peanut hulls, shredded paper, wheat straw, and wood shaving.

Our study results showed that T_3 had the lowest mean ammonia emission factor (17.36 gN cow^{-1} d^{-1}), whereas the mean ammonia emission factor of T_1, T_2, and T_4 were 22.57, 18.70, and 20.80 gN cow^{-1} d^{-1}, respectively (Table 3). The mean emission factors of ammonia of 4 bedding treatments in this study (from 17.36 to 22.57 gN cow^{-1} d^{-1}) are higher than the estimate of Gilhespy *et al.* (2009) (13.8 g $beef^{-1}$ day^{-1}). The reason for this may be that the estimate of Gilhespy *et al.* (2009) was based on beeves with the mean weight of 214-342 kg, which is lower than the cow weight of our study (350-400 kg) even though those authors also used a combination of wheat and barley straw as bedding material, aiming to absorb the excrete and provide a dry bedded area for beeves. However, the mean emission factors of ammonia of our study can compare favorably with the emission factors found by Misselbrook *et al.* (2000) in the UK ammonia inventory (17.2 gN dairy cow^{-1} d^{-1}). Similarly, Powell *et al.* (2008) found that the ammonia emissions from manure solids, newspaper, pine shavings, and chopped straw as bedding materials were 20.0, 18.9, 15.2, and 18.9 gN $heifer^{-1}$ d^{-1}, respectively, which are fully identical to our emission factor results.

In our study, the mean ammonia fluxes from 4 different bedding materials were between 1.712 and 2.226 mg m^{-2} min^{-1} (i.e. between 102.72 and 133.56 mg m^{-2} h^{-1}), which were significantly lower than the results from an investigation of Jeppsson (1999) with a deep-litter housing system. Jeppsson (1999) found that the average ammonia emission rate was between 319 and 747 mg m^{-2} h^{-1} from bedding materials consisting of long straw, chopped straw, chopped straw with additive, and a mixture of peat and chopped straw. This can be explained by the fact that the area per cattle of our study (8.05 m^2 $animal^{-1}$) is greater than that of Jeppsson (1999) (4.25 m^2 $animal^{-1}$), even though in our study and Jeppsson's study the house penned cattle having the same body weight.

To discover the variation patterns of ammonia flux within each bedding material, mean ammonia flux values from two cells of each bedding material are compared (i.e. comparing between A and B, C and D, E and F, and G and H). As shown in Fig. 3, the highest variation of mean value of ammonia flux within the same bedding material was found in the case of T_1 (A was 0.372 mg m^{-2} min^{-1} higher than B), whereas the lowest variation of mean value of ammonia flux was in the case of T_3 (E was 0.069 mg m^{-2} min^{-1} higher than F). The variation of mean values of ammonia flux within the same bedding material in the case of T_2 C was 0.076 mg m^{-2} min^{-1} higher than D, and T_4 H was 0.179 mg m^{-2} min^{-1} higher than G (Fig. 3).

3. 2 Temporal Pattern in Ammonia Emissions

In order to evaluate the temporal variability of ammonia flux, all flux values for different bedding mate-

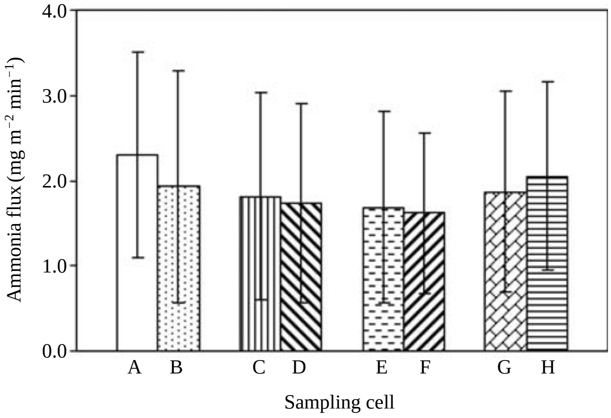

Fig. 3. Comparison of the total ammonia flux values of the same bedding material between cell A and B (T_1); C and D (T_2); E and F (T_3); and G and H (T_4).

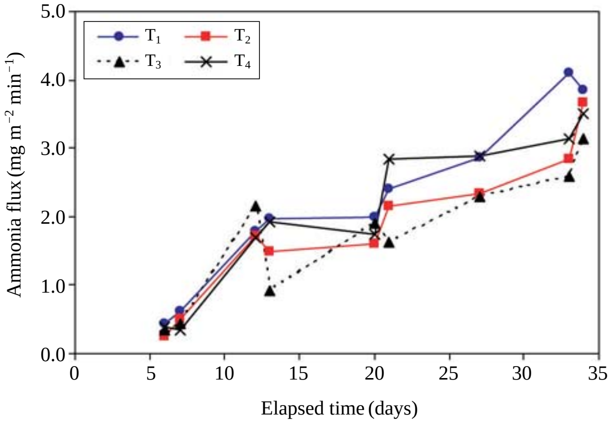

Fig. 4. Variation pattern of ammonia flux for different bedding materials.

rials were plotted as a function of time. Fig. 4 shows the daily average ammonia flux from 4 bedding alternatives. The ammonia flux varied during the measuring period and increased with time due to manure accumulation in the beds. The daily mean values of ammonia flux from T_3 were lower than the corresponding values of the other materials analysed. Some differences of the ammonia flux between the bedding materials were observed over a period of one month. The daily ammonia fluxes from the bed of T_3 varied between 0.341 and 3.151 mg m^{-2} min^{-1} while that of T_1 varied between 0.439 and 4.098 mg m^{-2} min^{-1} (Table 3). Similarly, Jeppsson (1999) investigated the application of bedding materials (long straw, chopped straw, chopped straw with additive, and a mixture of peat and chopped straw) on ammonia emission from bull pens, and found that the ammonia emission rate varied but had the increased trend during six month investigation. The increasing production of manure from the growing animals, the increased amount of manure in the litter, and the variation in ambient temperature due to the change in season could result in the variations of ammonia emission rate from the litter beds (Jeppsson, 1999). The concentration of gaseous ammonia in our study continuously increased from 4 bedding treatments during the experiment. In general, during the 1 month evaluation period the mean ammonia fluxes from bedding materials of T_2 and T_3 were lower than that of T_1 and T_4.

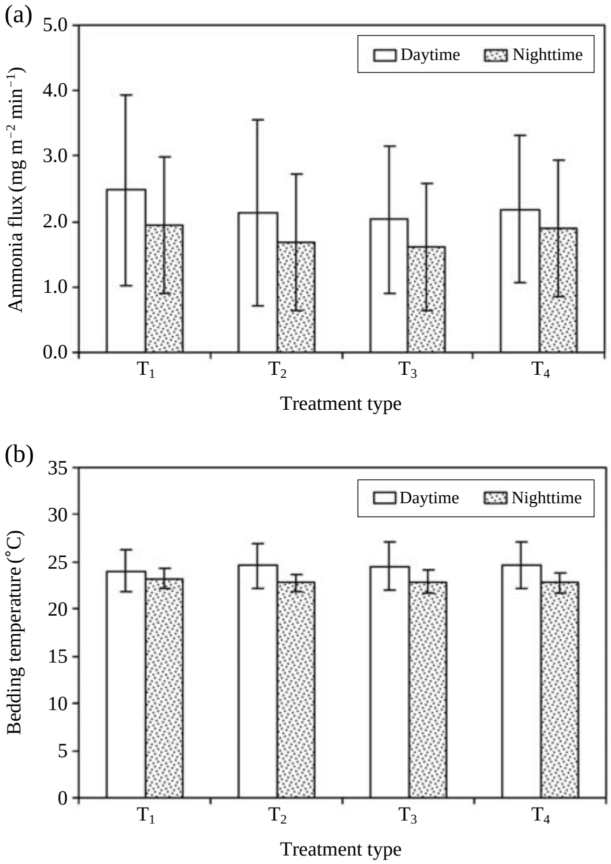

Fig. 5. Diurnal variation in (a) ammonia flux values; (b) bedding temperature values.

In Fig. 5a, the diurnal variation patterns are plotted for ammonia fluxes. When the ammonia fluxes are compared between day and nighttime, daytime fluxes for ammonia were much higher than the nighttime counterparts. The results indicated that maximum ammonia fluxes occurred during the daytime when both the bedding and ambient temperatures remained high (Fig. 5b).

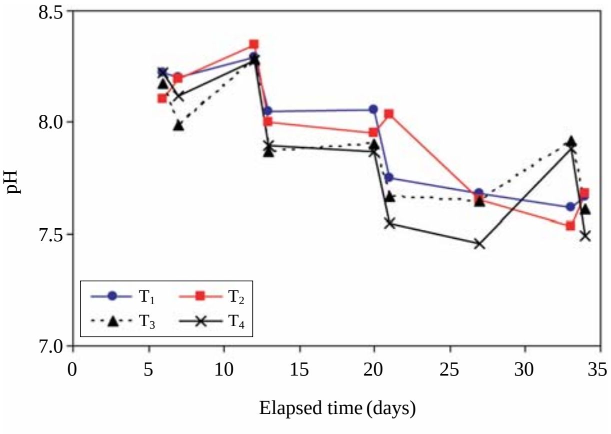

Fig. 6. pH temporal variation of bedding during the entire study period.

3.3 The Effect of pH on Ammonia Emissions

It is known that ammonia volatilization from soil or manure solution is sensitively affected by the equilibrium between NH_3 and NH_4^+ in the aqueous phase (Li, 2000; Warneck, 2000). Hence, more ammonia should be released with pH increases in soil or manure solution (OH^- increase).

$$NH_3 \leftrightarrow NH_4^+ + OH^- \quad (3)$$

Although the initial pH values of 4 bedding treatments were significantly different (Table 2), the pH values on the first day of measurement (day 6 after the starting date of bedding materials) were similar for 4 bedding treatments with the value of around 8.2. Fig. 6 presents the temporal variation of pH during the experiment. The results showed that the pH value of 4 bedding treatments decreased with time. However, the mean pH values of 4 bedding treatments after one month of the experiment were almost the same, with the value of 7.9, irrespective of the initial differences in the pH values of bedding materials. In the present study, ammonia flux was found to be inversely correlated ($p < 0.01$) with pH from treatment T_1 and T_4. No correlation between ammonia flux and pH was found for treatment T_2 ($p > 0.05$). Ammonia flux was found to be inversely correlated ($p < 0.05$) with pH from T_3 (Table 4). Similarly, Powell *et al.* (2008) used manure solids, chopped newspaper, pine shavings, and chopped wheat straw as bedding materials for dairy heifers, and the study results showed that ammonia emissions were affected by temperature but very little by the pH of manure. Misselbrook and Powell (2005) assessed on a laboratory scale the influence of 5 bedding materials (chopped wheat straw, sand, pine shavings, chopped newspaper, chopped corn stalks, and recycled manure solids) on ammonia emissions from cow urine. There was also no significant relationship between ammonia emission and initial bedding pH. Our study found that the pH of the beds from 4 treatments decreased during one month of experiment (Fig. 6). It seems to be that due to manure accumulation, anaerobic conditions are dominant during the manure biodegradation process, which results in organic acid formation (Mahimairaja *et al.*, 1994).

Table 4. Results of correlation analysis between ammonia flux values and different environmental parameters.

	NH_3 flux	Temperature		Bedding pH
		Ambient	Bedding	
T_1				
NH_3 flux	1.00			
Ambient temp.	0.17	1.00		
Bedding temp.	0.10	0.60	1.00	
pH	−0.54	0.21	0.06	1.00
T_2				
NH_3 flux	1.00			
Ambient temp.	0.16	1.00		
Bedding temp.	0.06	0.66	1.00	
pH	0.04	0.12	0.16	1.00
T_3				
NH_3 flux	1.00			
Ambient temp.	0.07	1.00		
Bedding temp.	−0.06	0.66	1.00	
pH	−0.34	0.50	0.27	1.00
T_4				
NH_3 flux	1.00			
Ambient temp.	0.05	1.00		
Bedding temp.	−0.14	0.62	1.00	
pH	−0.58	0.31	0.31	1.00

3.4 The Effect of Temperature on Ammonia Emissions

During the study period, the temperatures of ambient air varied between 19.3 and 33.3°C and the temperatures inside the chamber were from 19.4 to 36.5°C. On the other hand, the bedding temperatures at 3 cm depths varied between 18.3 and 28.8°C. The daily variation patterns of bedding temperatures of 4 bedding treatments are plotted as a function of time (Fig. 7a and b). The results from the statistical evaluation of bedding temperatures are presented in Table 3. The mean bedding temperatures of 4 bedding treatments are almost similar with the value of 23.8, 24.0, 24.0, and 23.9°C for T_1, T_2, T_3, and T_4, respectively. In the present study, no correlations ($p > 0.05$) were observed between ammonia flux and ambient temperature. Similarly, there were no correlations ($p > 0.05$) between ammonia flux and bedding temperature, as seen from ambient air (Table 4).

The volatilization of ammonia was affected by the

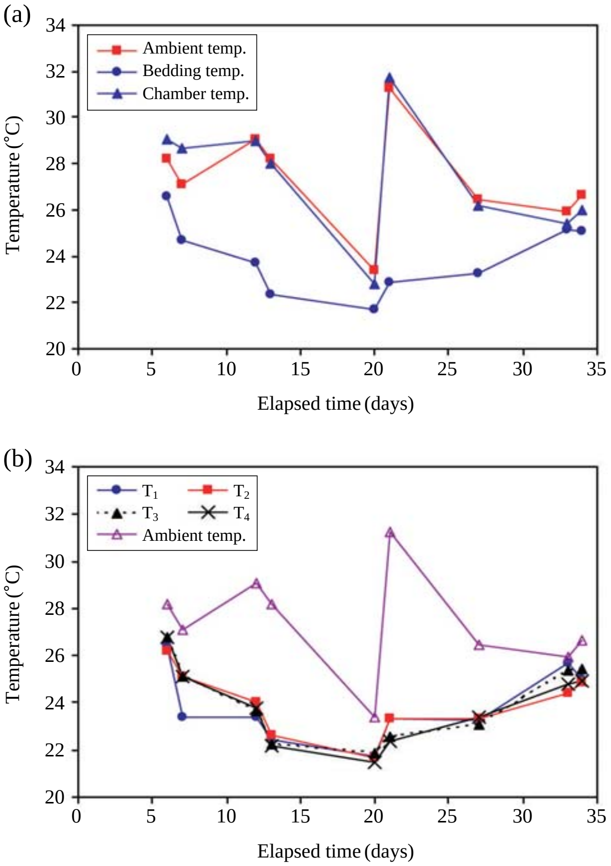

Fig. 7. Temporal variation of (a) ambient, bedding, and chamber temperatures; (b) ambient temperature and bedding temperature of 4 treatments during the entire study period.

manure temperature in several ways. A higher temperature stimulates a faster degradation of urea to ammonium and a faster mineralization of organic nitrogen (Aarnink *et al.*, 1993). The equilibrium between ammonium ions and ammonia in the manure solution is also affected by the temperature. A higher temperature results in an increase of ammonia. The de-adsorption rate is also affected by the temperature (Voorburg and Kroodsma, 1992). The results of this study indicated that maximum ammonia emissions occurred during the daytime when both bedding and ambient temperatures remained high. These show that there are correlation between daily ammonia emission and daily temperature. The ammonia emissions from 4 bedding treatments were high in the daytime, which corresponded with high bedding and ambient temperature. Conversely, ammonia emissions from 4 bedding treatments were low in the nighttime, which corresponded with low bedding and ambient temperature. However, for long term monitoring, our results showed that there was no correlation between ammonia emission and temperature. Jeppsson (1999) investigated the effect of different bedding materials on ammonia emissions with the application of 40 kg bedding materials per bull at the beginning and bedding materials were added to the pens at the rate of 2.7 kg $\mathrm{bull^{-1}}$ $\mathrm{day^{-1}}$. The author found that high temperature in the bed corresponded with a high ammonia emission rate. In our study, the lack of fresh bedding materials added to the cells and manure accumulation in the beds seem to be why the correlation between ammonia emission and temperature is not observed.

4. CONCLUSIONS

In this study, the ammonia emissions from 4 different bedding materials in a cow house were determined over nearly a 1 month period. The purpose of our study was to examine the variability of ammonia emissions in relation to the application of different bedding materials and to the change of the environmental conditions. The highest mean ammonia flux was found from T_1 (2.226 $\mathrm{mg\ m^{-2}\ min^{-1}}$) followed by T_4 (2.052 $\mathrm{mg\ m^{-2}\ min^{-1}}$), T_2 (1.845 $\mathrm{mg\ m^{-2}\ min^{-1}}$), and T_3 (1.712 $\mathrm{mg\ m^{-2}\ min^{-1}}$). T_3 reduced the ammonia flux by about 23 % compared with T_1. During the experiment, the ammonia fluxes from 4 bedding treatments were found to increase with time due to manure accumulation. A comparison of the diurnal variation patterns consistently showed a daytime dominance of ammonia fluxes for all bedding treatments.

In the present study, the pH patterns of the beds from 4 treatments had a decreasing trend for all bedding treatments. Manure accumulation and anaerobic conditions seemed to be dominant during the manure biodegradation process, resulting in organic acid formation and the pH decrease of the beds. Average temperatures in the beds were similar for the various bedding materials. Ammonia flux was found to be inversely correlated ($p < 0.01$) with pH from treatment T_1 and T_4. No correlation between ammonia flux and pH was found for treatment T_2 ($p > 0.05$). Ammonia flux was found to be inversely correlated ($p < 0.05$) with pH from T_3, whereas no correlations ($p > 0.05$) were observed between ammonia flux and ambient (and bedding) temperature.

Based on this study, the most important factor influencing ammonia emission was found to be the physical structure of the bedding types.

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