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GAS CONCENCENTRATIONS AND EMISSIONS IN MILK-FED CALF BUILDINGS

Martin Belzile, ing. jr., B.Sc., Research Assistant

Research and Development Institute for the Agri-Environment (IRDA), Deschambault, Québec, Canada

Stephane P. Lemay, ing., P.Eng., Ph.D., Research Scientist in Engineering

IRDA, Deschambault, Québec, Canada

Stephane Godbout, ing., P.Eng., agr., Ph.D., Research Scientist in Engineering

IRDA, Deschambault, Québec, Canada

Caroline Côté, Ph.D., Research Scientist

IRDA, St-Hyacinthe, Québec, Canada

Jacques Lavoie, Research Scientist

Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal, Québec, Canada

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Abstract

In livestock production, the air quality inside the buildings is known to have an impact on health and life quality of workers as well as on the animal performance. Milk-fed calf producers are concerned about this, especially during the winter period when the ventilation is reduced. This study was carried out to evaluate the air quality inside milk-fed calf buildings during three periods (winter, spring and summer) to quantify the risk for workers related to air quality. Three farms having different ventilation systems typically found in Québec (pre-heated hallways, lateral air inlets and chimney fans) were studied. Data measurements included ammonia (NH_3), hydrogen sulphide (H_2S), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) concentrations, as well as the ambient conditions like temperature, relative humidity and atmospheric pressure. Gas samples were drawn from inside the building to a mobile instrumentation trailer via Teflon tubing. Sample were analysed using a flame ionisation detector (NH_3), an electrochemical H_2S sensor and a gas chromatograph (CH_4, N_2O and CO_2). Flow rates from the ventilation system were also measured in order to calculate gas emissions. Results show that there is no important problem of air quality inside milk-fed calf building. The average indoor temperature was properly controlled while the relative humidity was higher than recommendations. The ammoniac was the only gas reaching a concentration close to the maximum time-weighted average recommended for human health. A better control of the minimum ventilation rate should rectify both the relative humidity level and the ammonia concentrations.

INTRODUCTION

Air quality in buildings where animal are raised is known to possibly have a negative impact on the health of the workers (Achutan et al. 2001, Godbout et al. 2000). Knowing the impact of indoor air quality in other productions, milk-fed calf producers question themselves about the effect it may have during the winter period when the ventilation rates are reduced. They want to know if gases, detectable in buildings, can have a toxic impact on their health and the health of their animals. Only limited literature exists on this subject and no data concerning this type of production in Québec is currently available.

INFORMATION REVIEW

In Québec, worker exposure to gases is regulated by the “Commission de santé et sécurité au travail” (CSST, 2004). Exposure limits are generally calculated using three different parameters. The first one is the time-weighted average (TWA) concentration for an eight hours work exposure and on a 40 hours per week basis. The second one is the short-term exposure limit (STEL) and is averaged on a period of 10 or 15 min. This concentration should never be exceeded during a working day even if the value of the average gas concentration is respected. Finally, there is a value for the maximum exposure at any time and this concentration should not be exceeded at any time.

The ammonia (NH_3) production is a consequence of the bacterial activity implying the nitrogen organic substrates. The conversion of the urea and the ureic acid into NH_4^+ and NH_3 is the main source of ammonia (Arogo et al., 2001). At ambient temperature, ammonia is a colourless and flammable gas that has a bitter, penetrating and strongly irritating odour. As the ammonia is very toxic and corrosive, the inhalation of this gas can cause serious wounds with the lungs and even be fatal. According to the CSST (2004), the TWA value for ammonia concentration should not exceed 25 ppm whereas the STEL is 35 ppm.

Hydrogen sulphide (H_2S) is a colourless, very toxic and very flammable gas. As for the ammonia, hydrogen sulphide is created by the degradation of animal excreta (Nordstrom et McQuitty, 1976). Hydrogen sulphide is heavier than air and it can accumulate close to the ground and presents a risk of toxicity, fire or explosions, especially in enclosed areas. This gas can be detected even at very low concentrations (0.0094 ppm) because of its rotten eggs odour (CCOHS, 2005). However, H_2S decreases the sense of smell at a concentration of approximately 50 ppm and quickly paralyses it with concentrations of 100 ppm or more. The TWA for workers should not exceed 10 ppm whereas the STEL must remained below 15 ppm (CSST, 2004).

Carbon dioxide (CO_2) is colourless and odourless. It is one of the main components of the air expelled by animals. Carbon dioxide is also heavier than air and can accumulate on the ground, move oxygen and cause asphyxiation. The inhalation of strong carbon dioxide concentration can cause hyperventilation and lead to a loss of conscience and death. The TWA should not exceed 5,000 ppm and the STEL must stay below 30,000 ppm.

Methane (CH_4) is a colourless and odourless gas extremely flammable and can form an explosive mixture when in contact with the air. Methane comes from the animal respiration and from manure decomposition. As methane is denser than air, it tends to accumulate on the ground where it moves oxygen and can present a risk of asphyxiation. Québec does not have an exposure limit for this chemical compound, but it must not exceed the limit concentration for the risk of explosion.

Nitrous oxide (N_2O) is a colourless and flammable gas. However, it is not very detrimental for health considering the lungs do not absorb it. The TWA should not exceed 50 ppm.

According to Wheeler et al. (2000), indoor temperatures in calf buildings should range between 10 and 21°C. In general, temperature should be at 21°C at the beginning of the cycle and should decrease by 0.6°C each week in order to reach 10°C by the end of the cycle. Moreover, according to the Recommended Code of Practices for Care and Handling of Farm Animals (CARC, 1998), relative humidity should be maintained between 40 and 60%. Below 60%, the survival of pathogens is reduced, but below 40%, the dust level increases.

PROJECT OBJECTIVES

General goal

The overall goal of this project is to measure indoor air quality in milk-fed calf buildings and define its potential risk on human health and animal well-being and recommend controlling measures if needed.

Specific objectives

The specific objectives of the project were:

- To carry out a literature review on airborne contaminants found in bovine livestock buildings and their impact on human health;
- To measure indoor gas concentrations (NH_3, H_2S, CO_2, CH_4, and N_2O) in milk-fed calf buildings in winter and summer conditions;
- To measure emissions of those same gases from milk-fed calf rooms;
- To evaluate other aspects of indoor air quality (dust, micro-organism, endotoxine, bacterial and mould concentrations);
- To characterise the risk for the worker related to the air quality in those buildings and to propose to the stockbreeders corrective measures that are easy to implement.

This paper focuses on the gas concentrations and emissions section of the project.

MATERIEL AND METHODS

Experimental site

The selection of the experimental sites being part of this project had to take into account specific characteristics of existing milk-fed calf buildings in Québec. A portrait of the buildings found in Québec was carried out by the professionals of IRDA and the "Fédération des Producteurs de Bovins du Québec (FPBQ)" and considered characteristics such as the ventilation and heating systems, room configuration and manure management. Following this portrait, three buildings with different heating and ventilation systems were selected. One room in each building was chosen to complete the trial. The principal parameters of each site are found in Table 1.

Description of production cycles

The milk-fed calves were fed using milk food for a period of approximately four months. The weight of the animals ranged from 41 to 52 kg up to 204 to 218 kg. Most of the animals were housed in individual wood stalls and the slatted floor was made of wood and plastic. On site 3, some calves were also kept in pens of 6 to 8 animals.

Milk-fed calf buildings are usually run in an all-in/all out way, meaning that calves are being grouped at a sorting plant and brought to the farm in an empty and clean room. Many of the producers are raising these animals on behalf of a larger corporation.

Experimental setup

Sampling on each site was done over a period of approximately 10 continuous days. The total duration of each sampling cycle, including all three sites analysed, was 30 days. The first sampling cycle took place in January 2005 in order to collect data under winter conditions. The two following cycles were completed in spring (April) and in summer (July) of 2005, for a total of 90 days of sampling.

Air temperature, relative humidity and ventilation rate

Temperature and the relative humidity of the air were measured using electronic probes throughout the experiment. Those probes were located at two points of measurement, one in the air inlet of the building and the other one in the centre of the room.

Fan airflow rates were evaluated using a standardised ventilation conduit (Fig. 1). This conduit was developed using the standard ANSI/ASHRAE 41.2-1987 (RA 92)

(ASHRAE, 1992). The static pressure difference between the interior of the room and the outside of the building as well as the fan rotation speed of each ventilation stage were continuously measured during the trials. The standardised conduit was then transferred to each site and the conditions (three levels of static pressure and four rotation speeds of each stage of ventilation) met along each trial were recreated. Collected data made it possible to calculate regression equations for each fan predicting air flow rate based on room static pressure and fan rotation speed. The fan airflow on experimental site 3 could not be evaluated in the same way considering its ventilation system included chimneys. Regression equations were calculated from the supplier information.

Calve weight and number

In order to establish the mass of calves in each experimental room, the number of calves at the beginning and the end of the period was recorded. Also, using the calf initial weight at their arrival to the building, their final weight prior to leave for the slaughterhouse as well as the number of growing days, a regression equation could be made to determine the calf weight at the beginning and the end of each sampling period.

Gas concentrations

Gas concentration measurements were performed using the MESANGES^{MC} mobile laboratory developed at IRDA. This mobile unit allows continuous measurement of various gases. The gases measured in this experimentation were NH_3, H_2S, CO_2, CH_4 and N_2O. The samples were sequentially taken from several sampling points and were pumped to the analysing system. Ammonia was analysed with an analyser using non-dispersive infrared spectroscopy (NDIR) and H_2S was measured using an electrochemical sensor. Carbon dioxide, methane and nitrous oxide were analysed with a gas chromatograph.

Gas emissions

Gas emissions coming from the building were also calculated to know the environmental impact of gases present in the milk-fed calf buildings. The calculation of gas emissions was done using Eq. 1:

$$E = \frac{(C_{outlet} - C_{inlet}) * Q * \frac{P_{atm} - P_v}{287 * T} * \frac{M_{gas}}{M_{air}}}{m_{calf}} \qquad \text{(Eq. 1)}$$

Where E is the gas emission (mg h^{-1} kg_{calf}^{-1}), C_{outlet} is the concentration of gas on the outlet side of the building, C_{inlet} is the gas concentration at the building air inlet of gas to the air intake of the building, Q is the airflow of the ventilation system (m^3 h^{-1}), P_{atm} is the atmospheric pressure (Pa), P_v is the vapour pressure (pa), T is the temperature (K), M_{gas} is the molar mass of gas, M_{air} is the molar mass of the air and m_{calf} is the mass of calves present in the building (kg).

RESULTS

Temperature and relative humidity conditions

The indoor temperature for the winter period on site #3 varied between 14.6 and 16.7°C whereas the outdoor temperature was between -19.9 and 3.2°C (Fig. 2A). Since the indoor temperature was quite stable despite the great variation in the outdoor temperature, it appears that the heating and ventilation systems performed well. The airflow rate is in the same order of magnitude from one site to the others (0.23 to 0.40 m^3 h^{-1} kg_{calf}^{-1}) and it is rather stable throughout the experimentation. The results indicate that indoor relative humidity ranged from 63 to 85%. Therefore, the relative humidity ended up being slightly higher than literature recommendations (40 to 60%). Figure 2 constitutes also a good description of what was observed on sites 1 and 2 as temperature and relative humidity patterns were very similar from one site to the other.

Indoor temperature during the summer period on site # 3 varied from 14.3 to 28.1°C (Fig. 2B). This large variation in temperature is primarily due to a variation of the outdoor temperature. Indeed, during that same period, the outdoor temperature went from 7.3 to 28.8°C. The peaks of interior temperature correspond with those of the outside temperature. It appears that the ventilation system was well designed on each site because it kept the indoor temperature less than 3°C above the outdoor temperature (generally accepted design practices). The relative humidity inside building #3 ranged between 50 and 89%. The relative humidity was again relatively high considering the fact that it should have been reduced further with the high summer airflow and the high indoor temperature (from a psychrometric perspective). The ventilation rates were about 0.71 to 0.88 m^3 h^{-1} kg_{calf}^{-1} and followed the same profile than the indoor temperature.

As shown in Table 2, the average outdoor temperature of each season was representative of winter, spring and summer conditions in Québec. Moreover, even if sampling periods were realised one after the other with the same mobile laboratory, the resulting outdoor temperature of the three sites was very similar. For example, during the winter sampling period, average outdoor temperature of sites 1 to 3 varied from –2.8 to –9.3°C, while for the summer period, the corresponding mean temperatures went from 19.3 to 22.9°C.

Gas concentrations

Ammonia concentration inside the room of site #3 was on average 19.0 ppm during the winter period (Table 3). This concentration is rather high but it is always under the limit acceptable for worker health. Moreover, it does not seem to have a daily pattern of NH_3 concentration associated to different tasks inside the room. The hydrogen sulphide concentrations are relatively low for all sites under winter conditions. The concentration inside site #3 is always below 1 ppm (average of 0.1 ppm), so there is no risk for the worker's health. The CO_2 concentration on site #3 reaches an average of 2310 ppm. This value is normal for a breeding building under winter conditions. The average concentrations of CH_4 and N_2O were respectively 8.4 and of 0.4 ppm. Those values do not indicate that there could be a problem with those gases for human health. Finally, the mixture of the air in the room is good since the concentrations of all gases in the middle of the rooms are similar to those found near the air exhaust. The NH_3 concentration profile during winter is shown on Fig. 3 and all the gases concentration are presented in Table 3.

During summer trials, all gas concentrations were weaker than in winter trials because of the higher ventilation. Indeed, the NH_3 concentration in the site #3 reaches an average of 8.9 ppm during this period (Table 4). Moreover, the concentration is affected by the airflow rate more than by the tasks performed inside the building. The higher is the flow, the lower are the NH_3 concentrations in the room. The NH_3 concentration reaches its maximum in the middle of the nights and its minimum in the middle of the day. The H_2S, CO_2, CH_4 and N_2O concentrations follow the same pattern. Average concentrations are 0.2 ppm, 846 ppm, 4.3 ppm and 0.4 ppm, respectively. As for the winter period, the gas concentrations in the middle of the rooms are similar to those found near the air exhaust. The air mixture in the room is thus correct. All data are being presented in Table 4.

Gases Emissions

Ammonia emissions on site #3 ranged from 0.1 to 6.9 mg h^{-1} kg^{-1} in the winter period and from 0.7 to 11.2 mg h^{-1} kg^{-1} in the summer period. The CO_2 emissions in the winter went from 19 to 2,126 mg h^{-1} kg^{-1} while the ones in the summer period varied from 8 to 1,235 mg h^{-1} kg^{-1}.

The emissions of NH_3 and CO_2 appear to be higher in winter than in summer (Table 5). The emissions of both NH_3 and CO_2, because those are related to the indoor temperature, should increase as the temperature is increasing. The airflow measurement may be a source of error in the calculation of the emissions from the three sites. Further experimentation with the standardized conduit has to be done. The results for all the different gas emissions are presented in Table 5.

RECOMMENDATIONS

The main recommendation resulting from this analysis is related to the minimum airflow during the winter period. The airflow rates should be adjusted in order to allow maintaining the relative humidity between 40 and 60% throughout the year. This increase in the airflow rate should also have a beneficial impact on the NH_3 concentration present in the building, which should decrease. If the building was properly designed, the heating system should be powerful enough to maintain the room temperature at a proper set point. The barn owner will simply have to pay more attention to the control of indoor temperature during very cold periods. If the heating system is under design, a compromise between a slightly reduced room temperature and slightly higher relative humidity will have to be achieved.

CONCLUSION

The air quality in milk-fed calf buildings has been analyzed. The literature review helped to know the maximum level and the impact of gas contamination. The characterization the air quality inside milk-fed calf buildings was measured during winter, spring and summer conditions in order to specify the risk for the worker related to the air quality in those buildings.

Based on the results, there is no important problem of air quality inside milk-fed calf building. The average indoor temperature was properly controlled while the relative humidity was higher than recommendations. Moreover, ammonia was the only gas reaching a concentration close to the maximum TWA recommended for human health.

The others gases were well controlled. As the gas concentrations were similar from one site to the others, there was no difference associated with the ventilation system configuration. A better control of the minimum ventilation rate should rectify both the relative humidity level and the ammonia concentrations.

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Table 1. Description of the main parameters specific to each site.

Parameter		Parameter description		
		Site		
		1	2	3
Ventilation system	Air inlet	Slotted Air inlet on one side	Slotted Air inlet on one side	Slotted Air inlet on two sides
	Heating	Preheated hallway	In the room	In the room
	Air exit	Wall fans on one side	Wall fans on one side	Centralised chimney fans
Housing capacity (calf)		134	124	124
Manure management		Animals on slatted floor and scraper	Animals on slatted floor and scraper	Animals on slatted floor and scraper

Table 2. Average temperature and relative humidity conditions during each cycle of the trial.

Season	Site	Outdoor temperature (°C)		Indoor temperature (°C)		Relative humidity (%)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Winter	1	-2.8	6.2	14.3	0.4	67.4	4.2
	2	-9.3	6.3	14.9	0.7	74.2	3.4
	3	-5.1	5.5	15.3	0.5	76.7	5
Spring	1	8.2	4.3	15.5	0.8	60	8.6
	2	12.4	5.6	17.9	2.5	61.2	9.6
	3	12.5	3.7	18.1	1.4	71.8	4.5
Summer	1	21.2	4.9	23.5	3.7	69.3	10.9
	2	22.9	4.7	25	2.6	71.4	12.5
	3	19.3	4.5	22.6	2.4	75.4	9.0

Table 3. Gas concentrations during the winter period.

Site	Point	Gas concentration (ppm)									
		NH_3		H_2S		CO_2		CH_4		N_2O	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	Inlet	2.5	0.8	0.20	0.09	396	22	2.0	0.1	0.39	0.01
	Room	21.1	4.8	0.26	0.07	1679	314	4.8	1.0	0.39	0.01
	Outlet	19.9	5.2	0.25	0.08	1574	432	4.7	1.3	0.40	0.02
2	Inlet	0.3	0.3	0.12	0.03	381	12	2.0	0.1	0.40	0.01
	Room	16.0	1.8	0.39	0.25	2325	286	7.8	1.7	0.42	0.01
	Outlet	18.8	2.6	0.40	0.31	2340	272	8.3	2.0	0.43	0.01
3	Inlet	0.4	0.2	0.11	0.07	381	28	2.0	0.3	0.42	0.02
	Room	19.0	1.7	0.26	0.13	2311	253	8.4	1.6	0.43	0.02
	Outlet	18.0	1.9	0.26	0.09	2175	246	8.3	1.7	0.43	0.02

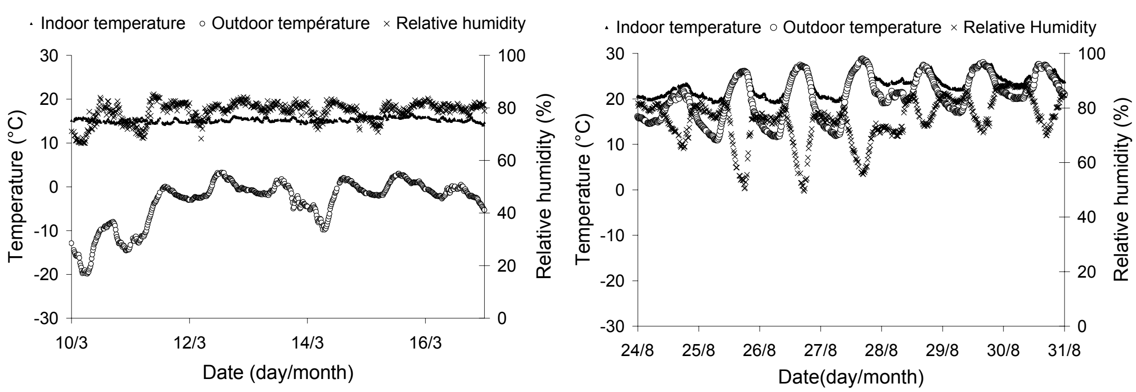
Table 4. Gas concentrations during the summer period.

Site	Point	Gas concentration (ppm)									
		NH_3		H_2S		CO_2		CH_4		N_2O	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	Inlet	1.3	0.7	0.17	0.05	399	73	2.0	0.2	0.49	1.73
	Room	3.6	1.1	0.19	0.06	584	99	2.5	0.3	0.38	0.02
	Outlet	4.8	1.8	0.20	0.06	696	112	2.8	0.5	0.38	0.02
2	Inlet	0.8	0.4	0.14	0.05	400	91	2.1	0.3	0.38	0.02
	Room	2.6	2.8	0.18	0.08	585	226	2.9	1.3	0.38	0.02
	Outlet	2.5	2.6	0.17	0.07	561	210	2.7	1.0	0.38	0.03
3	Inlet	0.3	0.2	0.13	0.03	401	69	2.6	0.7	0.38	0.02
	Room	8.9	3.7	0.21	0.05	846	186	4.3	1.0	0.39	0.01
	Outlet	8.5	4.2	0.22	0.06	807	187	4.2	1.0	0.39	0.02

Table 5. Gas emissions for each season and site during the trial.

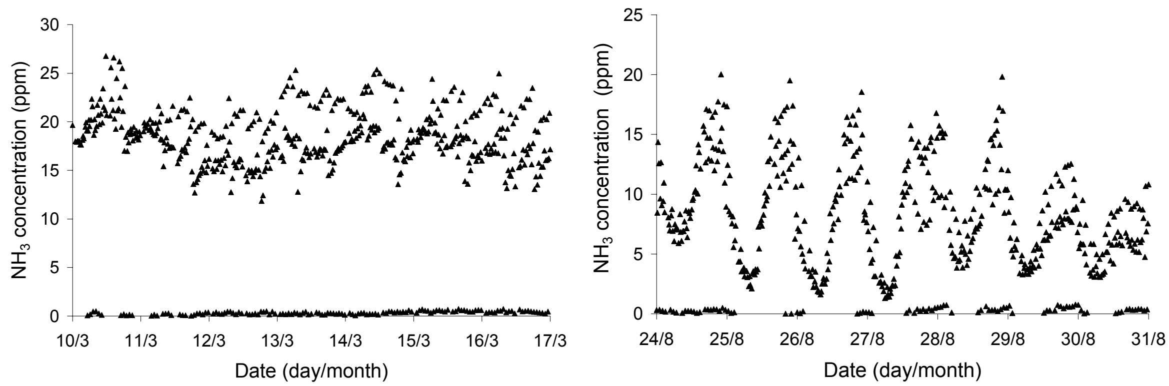
Season	Site	Gas emissions (mg h^{-1} kg^{-1})									
		NH_3		H_2S		CO_2		CH_4		N_2O	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Winter	1	2.6	0.5	0.03	0.05	487	107	0.4	0.2	0.01	0.04
	2	4.2	0.6	0.12	0.14	1138	178	1.4	0.4	0.02	0.04
	3	5.1	0.9	0.11	0.07	1342	284	1.7	0.6	0.02	0.04
Spring	1	1.8	0.6	0.09	0.07	473	98	0.4	0.2	0.01	0.01
	2	1.0	0.4	0.13	0.18	929	319	0.6	0.4	0.03	0.02
Summer	1	1.9	0.8	0.06	0.11	390	153	0.5	0.8	0.04	0.10
	3	3.6	2.6	0.07	0.05	429	276	0.6	0.4	0.02	0.02

Figure 1. Installation of the standardised conduit inside one room.



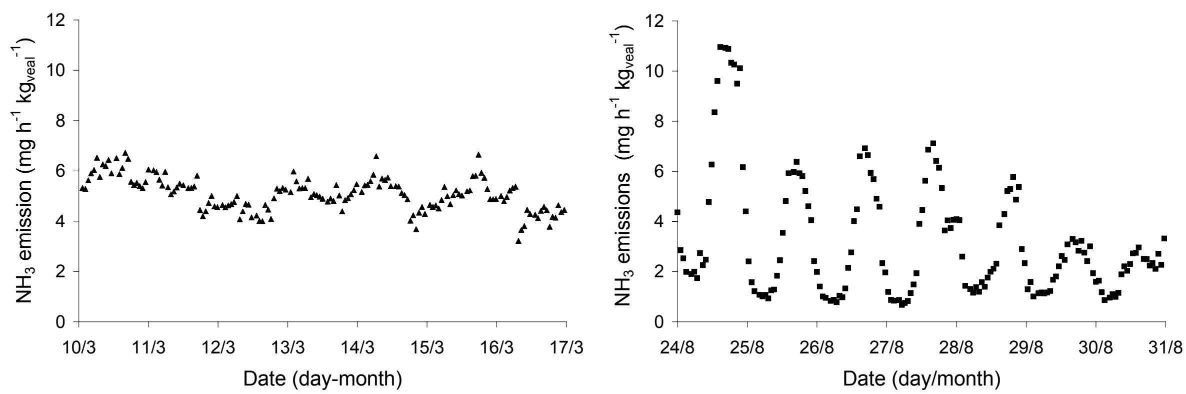
(A) (B)

Figure 2. Air temperature and relative humidity for the winter (A) and summer (B) periods on site #3.



(A) (B)

Figure 3.: NH$_3$ concentrations for the winter (A) and summer (B) periods on site #3.



(A) (B)

Figure 4.: NH$_3$ concentrations for the winter (A) and summer (B) periods on site #3.