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IMPACT OF THE MANURE REMOVAL FROM SLATTED FLOOR IN A DAIRY BARN ON THE AMMONIA EMISSION

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ABSTRACT Keeping dairy cattle in loose housing contributes to the total emission of ammonia up to 50% and has its main origin from soiled walking areas like slatted floors. The ammonia emissions from the barns have an impact on the environment, as does the soiled floor on the health of the claws. Aim of the investigations was to evaluate the impact of the manure removal from slatted floor on the ammonia emission in dairy barns. The cleaning system used is designed to combine the advantages of a wet and a mechanical cleaning-method. It features high-pressure water nozzles, mechanical star discharge rotors and a rubber-scraper. For the experiment, six exchangeable concrete slatted floor elements (55 cm x 62 cm x 20 cm) were cut out of the existing floor. This way the test elements could be separated from other sources of ammonia emission and moved into closed chambers (120 cm x 80 cm x 60 cm). Via membrane pumps the air carrying emitted ammonia from the slats was run through a solution of sulphuric acid (0,1n) and determined quantitatively in a lab using a photometer. Compared to untreated control slats, a reduction of the amount of manure weighted on the clean test elements up to 33.2% could be observed. However, no significant effect of the cleaning of the slats on the ammonia emission could be detected. Average ammonia concentrations measured directly after the cleaning (mean temperature in the barn: 21.1°C) were 13.2 mg NH_3 h^{-1} m^{-2} (clean) and 16.3 mg NH_3 h^{-1} m^{-2} (control), respectively.

Keywords: Ammonia emission, dairy barn, slatted floor cleaning

INTRODUCTION Ammonia emissions from animal husbandry highly contribute to environmental acidification and eutrophication as to odour nuisance. More than 50 % of the totally emitted ammonia has its origin from cattle husbandry (Misselbrook et al., 2000) and 60 % of the ammonia is emitted from the walking area (Ogink and Kroodsma, 1996). Next to the environmental factors, soiled surfaces in the barn have a negative impact on claw health and the skid resistance (Bergsten and Hultgren, 2002). In practical experi-

ence, slatted floor is known to have an insufficient self-cleaning effect. This raises the need of an adequate cleaning system for slatted floors in dairy barns (Braam et al., 1997).
In order to evaluate the cleaning effect of the devise and to measure the ammonia emissions from the barn, basically two different approaches have been carried out in the past. On the one hand, there are continuous measurements directly in the barn, calculating emission rates via the ammonia concentration in the air and the air flow rate, including side effects inside the barn like altering climate conditions and feed as well as the different sources of ammonia emission (Amon et al., 2001, Braam et al., 1997). On the other hand, there are studies on a laboratory base, excluding side effects from the barn and isolating the measurements either from the slurry pit, the cubicles or the walking areas (Anderson, 1994). However, real emissions from the stables can only be estimated (Phillips et al., 2000). In both cases, it is difficult to identify the individual emissions from the single parts of the barn. In this study, it was attempted to combine the advantages of both methods and to determine the amount of emitted ammonia only from the slatted floor without influences from the manure pit or the cubicles.
The objective of this study was to evaluate the effect of the manure removal from a slatted floor with a special cleaning device on the ammonia emission in naturally ventilated dairy barns.

MATERIALS AND METHODS

Experimental Site The experiment was carried out in 2009 in a naturally ventilated, organic dairy barn located in Labenz, Schleswig-Holstein, Germany. The experimental site of the barn consisted of two compartments with a manure storage pit under the slatted floor and straw beddings for 65 Holstein Friesian. 21 more cows were housed in another compartment of the barn, however also milked at the experimental part of the barn. From April to October the cows were grazed on a pasture next to the barn. For the whole period of this experiment the cows were on the pasture. Twice a day, the cows were fed with a total mixed ration. Per day and cow, the ratio included during the wintertime 38 kg of clover grass silage, 38 kg of barley whole crop silage, 4.5 kg shredded wheat and rye as well as 1 kg linseed. Hay was offered ad libitum. In summer, when the cows were grazed in the pasture additionally, the silage was reduced by 50 % and the concentrate by a third.
The temperature in the barn was measured by two data loggers (Onset, Model U12-012, Cape Cod, MA, USA) located above the cubicles. Mean values were calculated for the 24 hours before the slat elements were taken out of the barn. This was in order to describe the pre-effect of the storage in the barn before the measurement was performed under standardised conditions.

Cleaning of the slatted floor A special cleaning device was developed in order to remove manure from the slatted floor in dairy barns. The machine is a three-wheeled, fuel-powered truck (length: 2.9 m, width: 1.3 m, height: 2.0 m). In the front it features three different units to clean the floor (see Fig.2). In the first step, a rubber-scraper removes the manure from the top of the slatted floor. It moves the manure from the surface of the floor and pushes it into the gaps of the slats. As an individual cleaning procedure, this would smear the gaps and prevent falling through of further manure. However, mechanical star discharge rotors made from flexible rubber that are placed behind the scraper reach into the gaps and push the manure through the slots. The rotors are powered by the advance of the machine. Furthermore, high pressure nozzles are located behind the rotors. The water sprayed on the slats removes remaining urine and feces from the surface of the slatted floor.

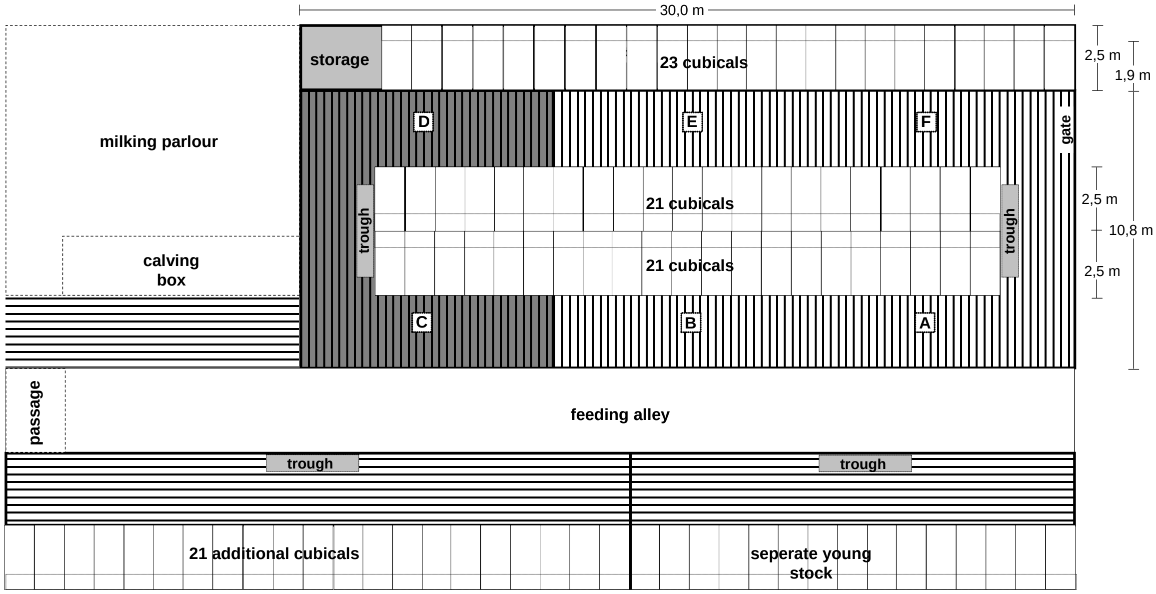

Figure 1. Floor plan of the barn. White vertical lining: cleaned experimental area. Grey vertical lining: control area in control treatment 2. Letters A-F: test elements. Horizontal lining: additional slatted floor, not included into the experiment.

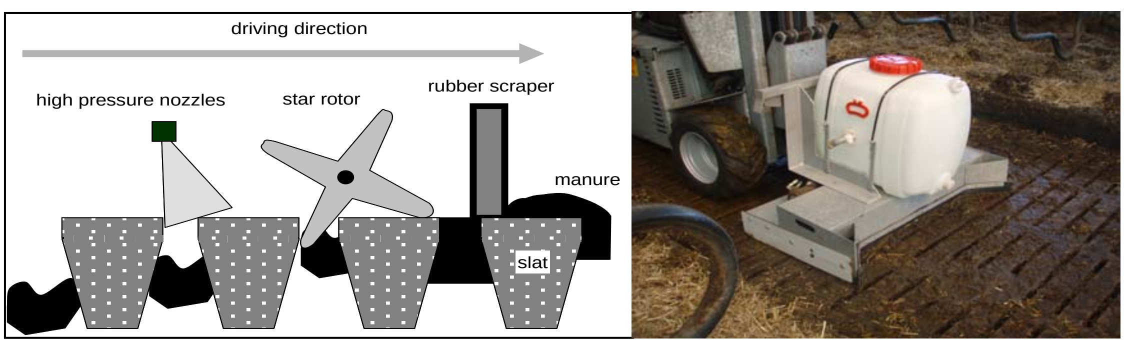

Figure 2. Plan of the different cleaning steps. Picture of the cleaning device with water tank

To be able to compare the cleaned slatted floor with untreated concrete elements, control-measurements were done in two different control treatments. In treatment 1, the whole barn was cleaned for two measurement sequences in a row (four days). After that the barn was not cleaned for two following days and a measurement of the control slat was done. This scheme was repeated to have four measurements of three cleaned slats respectively and two measurements of three control slats respectively. In treatment 2, only three quarters of the barn including four test elements (A, B, E, and F) was cleaned every day (Fig.1). The left out, non-cleaned quarter included the two slat elements C and D and was used as the control part of the barn.

For the experiment, three cleaning sequences were performed. The first included the control treatment 1 and measurements zero hours after the cleaning. In the second sequence, the slat elements were taken out of the barn two hours after the cleaning (control treatment 1). The third sequence included control treatment 2 and measurements of the ammonia emissions from the floor elements straight after the cleaning.

Removing of the floor elements from the barn In order to measure the ammonia emissions exclusively from the slatted floor, six exchangeable concrete floor elements (55 cm x 62 cm x 20 cm) were cut out of the existing floor. To hold the cut pieces of the slatted floor at the same level as the remaining floor, a metal support was build and placed underneath each test slat. Thus, the single elements could be isolated from the rest of the barn to avoid influences from other sources of ammonia emissions like the slurry pit, the cubicles or the cows themselves during the measurements. A special hook was build in order to carry the slat elements with a small wheel loader out of the barn. For each measurement three slat elements were removed from the barn (alternating: combination A, C, E or combination B, D, F; see Fig.1) and weighted with a digital crane scale (Bosche, Model KHW003, Damme, Germany; resolution: 50 g). Before the weighing, the sides of the test slat that had been cut were cleaned manually with a metal scraper. This was done to avoid different amounts of manure clinging to the sides caused by differently sized gaps between the cut test element and the remaining concrete slat. The net weight of the scales was determined before the measurements after being cleaned with a high-pressure cleaner. The amount of manure left on the slats was determined by subtracting the net weight from the total weight of the concrete elements.

Measurement and analysis of ammonia emissions The measurements of the ammonia emissions were done in three different sequences, each with six measurements. Two sequences were done straight after the cleaning and one was performed two hours later. If the measurements were taken zero hours after the cleaning, the cleaning was carried out after the cows were taken to the pasture at 9:00 am. If the measurements were done two hours after the cleaning (9:30 am), the floor close to the feeding alley was cleaned before the milking in the morning (5:30 am). The floor opposite the latter was cleaned after the milking was finished (6:30 am). This way the disturbance of the animals and the daily routine was kept at a minimum.

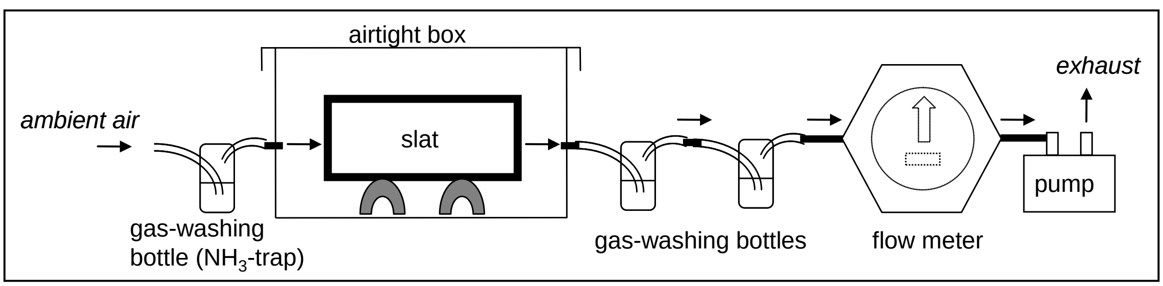

Figure 3. Set-up of one box and one slat element

After the weighing of the slat elements, they were stored in an air-conditioned 20 ft office container (room temperature: 20.1 °C ± 1.5) in four airtight PE-boxes (120 cm x 80 cm x 60 cm) with an acrylic glass lid. The lids were secured with a wooden frame and tension belts. During the measurement, three boxes contained one slat element respectively. One empty box (in rotating order) was used as a blank box. As illustrated in Fig.3 gas-washing bottles (500 ml) were installed at the air inlet and at the outlet of the boxes, connected with silicone "Tygon®"-tubes (Saint-Gobain Performance Plastics, Northboro, MA, USA; inner diameter: 8 mm, outer diameter: 16 mm). With the help of lab-scales (Sartorius, Göttingen, Germany) all bottles were filled with 250 mg of sulphuric acid (0.1n). The bottle at the inlet was used as an ammonia-trap to make sure no ammonia from the ambient air was sucked into the box where it would interfere with the measurement of the emitted ammonia. The two bottles at the air outlet of the boxes were connected in series to absorb the ammonia emitted from the slats. In order to catch all the ammonia, the second bottle featured a frit. This ensured smaller bubbles, hence a bigger connecting surface between liquid and air where all the ammonia can react with the sulphuric acid. For 24 hours, four membrane pumps (Iwaki, Model APN-085LVX1-E4, Tokyo, Japan) sucked the air out of the four boxes and through the gas-washing bottles. An air flow meter (Ritter, Model TG5, PVC, Bochum, Germany) at each box detected the volume of the air sucked through.

After 24 hours (Elzing and Monteny, 1997) the bottles with the sulphuric acid were weighed again in order to get the total amount of the acid that was left after partly evaporation. Thereafter, the acid was filled in 100 ml PE-bottles. The product of the reaction between ammonia and sulphuric acid is ammonium sulphate.

Via photometry and based on a modification of the "Berthelot-Reaction", the concentration of the ammonium sulphate was calculated with a segment flow analyzer (Skalar, Model San^{++}, Breda, The Netherlands). The ammonium reacts with sodium dichlorine isocyanurate and sodium salicylate into the blue colorant complex indophenol. At a wavelength of 660 nm the absorption of light can be measured. The absorption is proportional to the concentration of ammonia. At least every day before the analysis, the Analyzer was calibrated with a standard solution of ammonium chloride. This method is based on the VDI standard (VDI, 1974).

Calculation of the emission

$$m_{NH3;b1,2} = c_{NH4+} \times \frac{m_{H2SO4}}{\rho_{H2SO4}} \times \frac{M_{NH3}}{M_{NH4+}} \qquad \text{(Equation 1)}$$

$$m_{NH3;sl} = \frac{(m_{NH3;b1} + m_{NH3;b2})}{A_{sl} \times t} \qquad \text{(Equation 2)}$$

Where:

$m_{NH3;b1,2}$ = amount of NH_3 in bottle 1 and 2 (mg)

c_{NH4+} = concentration of NH_3 in the bottle (mg/l), as assayed by photometry

m_{H2SO4} = weight of H_2SO_4 (kg)

ρ_{H2SO4} = density of H_2SO_4 (kg/l)

M_{NH3}= molar mass of NH_3 (mol/l)

M_{NH4+} = molar mass of NH_4^+ (mol/l)

$m_{NH3;sl}$ = amount of NH_3 emitted from the slats (mg NH_3 h^{-1} m^{-2})

A_{sl}= surface of the slat element (m^2)

t = time (h)

The concentration of the ammonium sulphate in the bottles was calculated from the concentration of the ammonium sulphate, as assayed by photometry and the volume of the remaining sulphuric acid after 24 hours of measurement (Equation 1). The ammonia emission from the slats in mg NH_3 h^{-1} m^{-2} was obtained by division through the total surface area of the slat element and the time of the measurement in hours (Equation 2).

Statistical analysis The ammonia emissions of the single cleaning sequences were analysed separately as repeated measurements using the Glm procedure of a software package SAS 9.1 (SAS Institue Inc., Cary, NC, USA). The amount of the manure, the temperature of the barn and the position of the elements in the barn were included as fixed effects. The results show the adjusted mean values for the ammonia emission and the amount of manure on the test elements.

RESULTS

Temperatures in the barn Table 1 shows an overview over the three different measurement sequences with the different control treatments and the time of the measurement after the cleaning, respectively. The mean temperatures measured in the barn are also given for each sequence. There is a clear difference between the temperatures in summertime (21.5 °C) and fall (8.6 °C).

Table 1. Three different measurement sequences and mean inside air temperatures.

Sequence	Date	Measurement after cleaning (h)	Control treatment	Mean inside air temperature (°C)
1	21.08.-02.09.	0	vers. 1	21.1
2	04.09.-14.09.	2	vers. 1	17.4
3	13.10.-23.10.	0	vers. 2	8.6

Table 2. Adjusted mean values of the ammonia emission from the different cleaning sequences.

Sequence	Adjusted mean of NH_3 emission (mg NH_3 h^{-1} m^{-2})		Cleaning-effect on emission (%)
	Cleaned	Control	
1	13.3 ± 2.2 n.s.	16.3 ± 4.0 n.s.	- 18.9
2	13.7 ± 1.3 n.s.	11.2 ± 1.9 n.s.	+ 18.5
3	8.8 ± 2.1 n.s.	14.2 ± 3.4 n.s.	- 38.1

(n.s.: not significant)

Ammonia emission The adjusted mean values of the ammonia emission from the cleaned slats measured zero hours after the cleaning in the barn are 13.3 mg NH_3 h^{-1} m^{-2} in sequence 1 and 8.8 mg NH_3 h^{-1} m^{-2} in sequence 3 (Table 2). The untreated control slats show higher values of 16.3 mg NH_3 h^{-1} m^{-2} and 14.2 mg NH_3 h^{-1} m^{-2} respectively. However, there are no statistically significant differences between the cleaned slat elements and the control elements. In sequence 2, where the measurement was carried out two hours after the cleaning, the emissions from the cleaned slatted floor (13.7 mg NH_3 h^{-1} m^{-2}) elements are higher than the emissions from the control floor elements (11.2 mg NH_3 h^{-1} m^{-2}). However, no statistically significant differences can be detected again. The effect of the cleaning on the ammonia emission from the floor is expressed in the percentaged difference between the emission of the cleaned and the control slats. Even though the values are not significantly different from each other, there is a difference between the measurement straight after the cleaning and two hours later. In sequence 1 and 3, there is a reduction in the emission of -18.9 % and -38.1 %, respectively. In opposite, there is an increase of 18.5 % in the ammonia emission in sequence 2.

Amount of manure The amount of manure on the slat elements are presented in Table 3. In every sequence, the weight of the manure on the control slat elements is higher than on the cleaned slats. However, only in sequence 1 and 3, where the measurements were done straight after the removal of the manure on the slatted floor, there is a statistically significant difference between the control and the cleaned elements. Two hours after the cleaning, this significance can not be detected anymore.
The percentaged difference between the treated and non-treated slat elements also differs between the measurements zero hours and two hours after the cleaning. In sequence 1 and 3, the effect of the removal of the manure on the weight is -29.6 % and -33.2 %, respectively. In sequence 2 the effect is still negative but smaller (-2.4 %).

Table 3. Adjusted mean values of the amount of manure from the different cleaning sequences.

Sequence	Adjusted mean amount of manure (kg)		Cleaning-effect on removal (%)
	Cleaned	Control	
1	2.2 ± 0.1 *	3.2 ± 0.1 *	- 29.6
2	2.7 ± 0.2 n.s.	2.8 ± 0.3 n.s.	- 2.4
3	1.5 ± 0.1 *	2.2 ± 0.2 *	- 33.2

(n.s.: not significant, *: $p < 0.01$)

The effect of the temperature and the amount of manure on the emission was investigated statistically. However, no significant effect of the temperature in the barn or the amount of the manure on the slatted floor elements on the ammonia emission could be detected.

DISCUSSION Compared to the results of other authors, the values of emitted ammonia derived during the measurements (up to 16.3 mg NH_3 h^{-1} m^{-2}) appear to be rather low. Svennersted (1999) found values of ammonia emission from cow feces up to 200 mg NH_3 h^{-1} m^{-2}, while Kroodsma et al. (1993) even found values up to 400 mg NH_3 h^{-1} m^{-2}. However, these measurements were done inside the barn. In agreement with other studies (Moreira and Satter, 2006, Braam et al., 1997, Swierstra et al., 1995), the measurements of the slatted floor from the dairy barn showed only a small positive impact of the cleaning devise on the ammonia emissions. On a visual base, the surface of the slats in this experiment appeared to be cleaned efficiently, however, no significant effect of the cleaning could be observed. This leads to the assumption that a considerable fraction of the ammonia is emitted from the gaps between the bars of the concrete slats. Even though the manure from the walking area is removed thoroughly, a considerable amount of manure is left on the sides of the slats showing an insufficient cleaning effect of the water nozzles. Instead of a mechanical removal, the slats are only wetted with the water.

The reduction of the amount of manure from the slats straight after the cleaning is statistically significant. Consequently, this shows that the total amount of manure is not the only driving factor of the emission. Furthermore the cleaning of the floor causes a more thorough mixing of the feces with the urine than only the walking of the cows over the floor. This mixing causes higher emissions of ammonia because of the enhanced action of urease (Muck, 1982). This effect increases two hours after the cleaning when fresh manure is added to the wetted floor again.

A severe influence on the ammonia emission from the slat elements are the effects of the pre-treatment in the barn before their measurement in the office container under standardised conditions. The difference in temperature and air humidity as well as feed ration and the alterable ventilation of the barn can affect the nitrogen content of the manure on the slats and therefore the ammonia emission. Especially the variability of the allocation of the feces and urea and the time of the soiling through the cows cause a high variance of the emissions from the individual slat elements under practical circumstances (Kroodsma et al., 1993). However, the fact that the actual measurements of the emissions in this study were done in the office container under standardised climatic conditions provides the possibility to perform accurate measurements isolated from the side factors in the barn.

Even though other authors found significant differences between emission values derived at different temperatures in the barn (Powel et al., 2008 Moreira and Satter, 2006, Muck and Richards, 1983), in this study only a small and not significant tendency of reduction of the ammonia emission could be detected at lower temperatures in autumn.

Another factor influencing the statistical significance of the cleaning procedure is the insufficient amount of data. This will be improved in ongoing studies. Straight after the cleaning the percentaged difference between the cleaned and the control slat element tend towards a reduction of the emission of ammonia. Further optimisations of the cleaning machine and especially the angle of the water nozzles might lead to a more efficient cleaning of the slatted floor.

CONCLUSION the removal of the manure from the slatted floor did not show a significant effect on the emission of ammonia yet. However, the method of isolating the floor elements from the remaining naturally ventilated dairy barn presents a possibility to quantify the different sources of ammonia emission individually. This might be a progress compared to current calculations and estimates of the single values. Even though the ammonia emissions could not be reduced, the clean surface of the slatted floor might depict a possibility to increase claw health of the cows and to reduce slippery of the walking area.

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