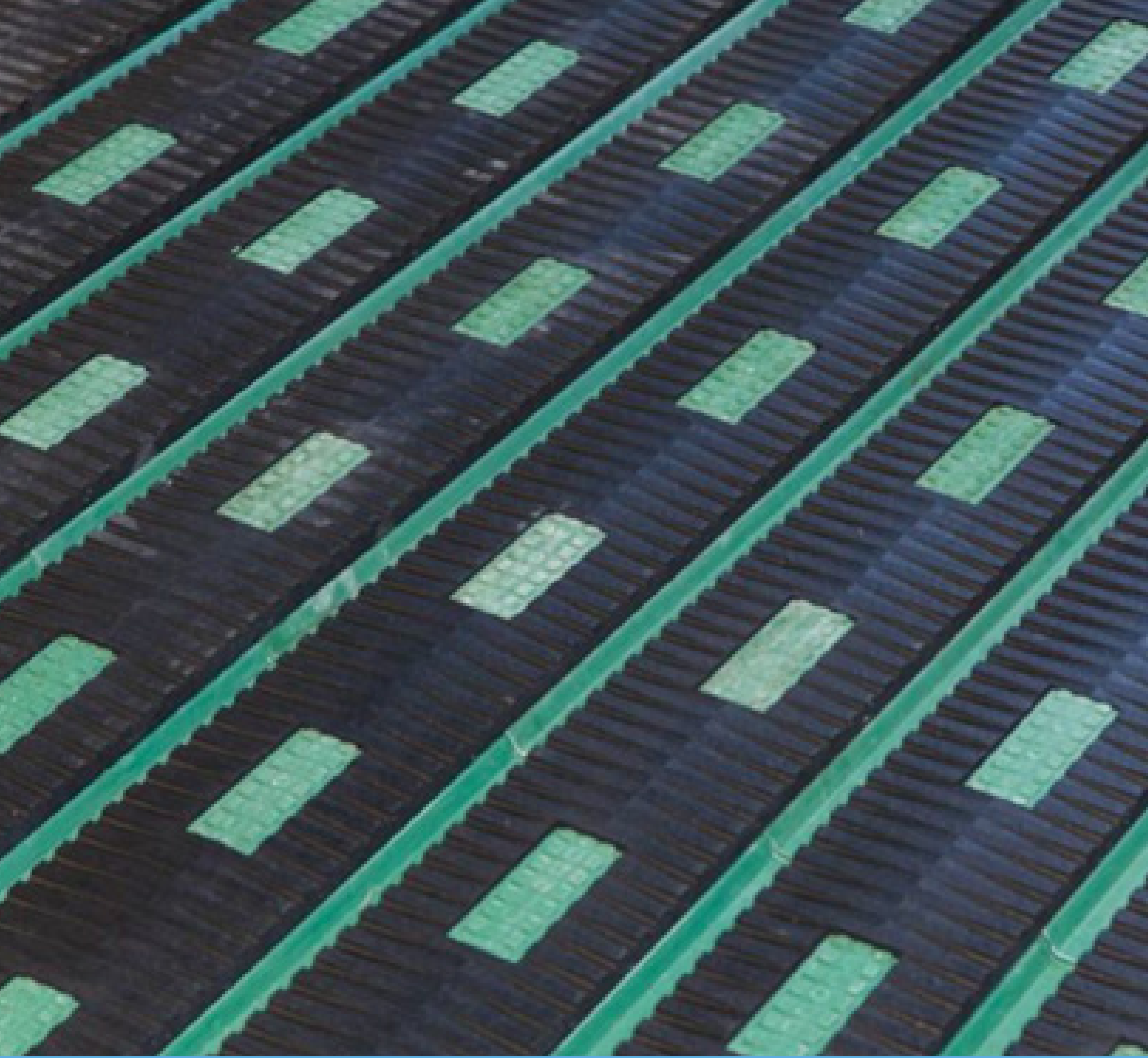


Ammonia emission of the MeadowFloor CL for dairy barns

A case-control study in the Environmental Research Barn of Dairy Campus

A. Winkel, S. Bokma, J.M.G. Hol, K. Blanken

Report 1275

WAGENINGEN
UNIVERSITY & RESEARCH

Ammonia emission of the MeadowFloor CL for dairy barns

A case-control study in the Environmental Research Barn of Dairy Campus

A. Winkel, S. Bokma, J.M.G. Hol, K. Blanken

Wageningen Livestock Research

This research was carried out by Wageningen Livestock Research, commissioned by the companies Proflex Betonproducten (Mill, the Netherlands) and JOZ (Westwoud, the Netherlands). The project has been co-funded by the Dairy Campus Innovation Fund. Via this fund this project has been financed by the Northern Netherlands Alliance (SNN), Spatial Economical Programme.

Wageningen Livestock Research
Wageningen, October 2020

Report 1275

Winkel, A., Bokma, S., Hol, J.M.G., Blanken, K., 2019. *Ammonia emission of the MeadowFloor CL for dairy barns. A case-control study in the Environmental Research Barn of Dairy Campus.* Wageningen Livestock Research, Report 1275.

In this study, measurements of ammonia emission have been carried out in a cubicle room of the environmental research barn of Dairy Campus equipped with the MeadowFloor CL of the company Proflex and a slurry scraper of the company JOZ. An identical room, equipped with a conventional concrete slatted floor, served as control. This study shows that the MeadowFloor CL yields a 35% reduction of ammonia emission.

In deze studie zijn emissiemetingen van ammoniak uitgevoerd aan een ligboxenafdeling in de Milieustal van Dairy Campus uitgerust met de MeadowFloor CL van de firma Proflex en een mestschuif van de firma JOZ. Een identieke afdeling uitgerust met een conventionele betonroostervloer zonder schuif diende als referentie. Uit deze studie blijkt dat de MeadowFloor CL een 35% reductie van de emissie van ammoniak bewerkstelligt.

This report can be downloaded for free at DOI: https://doi.org/10.18174/531749 or at www.wur.nl/livestock-research (under Wageningen Livestock Research publications).

Wageningen Livestock Research Report 1275

Table of contents

Foreword

This study has been commissioned by the companies Proflex Betonproducten (Mill, the Netherlands) and JOZ (Westwoud, the Netherlands) and was co-financed by the Innovation Fund of Dairy Campus. It has been carried out in a team of researchers, research technicians and animal caretakers at the Environmental Research Barn of Dairy Campus (Leeuwarden, the Netherlands). A special thanks goes to Jos Tuinier and Auke Geert Ybema for taking care of the animals and the research facility. Finally, I would like to thank everyone involved for the pleasant and fruitful cooperation.

Dr.ir. A. (Albert) Winkel
Project leader

Summary

Introduction

The MeadowFloor CL (Proflex Betonproducten, Mill, the Netherlands) is a recently developed closed floor for dairy barns (both for new construction and renovation projects) which aims to combine animal comfort with low ammonia emission. The floor is thought to reduce ammonia emission by shutting off the headspace of the slurry pit and by quickly draining urine from the floor to the manure pit or manure storage by means of urine gutters. The floor is cleaned by a slurry scraper with fingers tailored to the surface profile of the floor. The MeadowFloor CL has been added as a low-emission floor to Appendix 1 of the Rav legislation under Rav code A 1.34 and BWL number 2015.07 with a provisionary ammonia emission factor of 9.0 kg/animal place per year.

Objective

The objective of this project was to empirically determine the ammonia emission reduction of the MeadowFloor CL on a semi-practical scale using the “case-control” approach as described in the measurement protocol for determination of ammonia emission from housing systems in livestock production (Ogink et al., 2017). Subsequently, this project aimed to provide a basis for obtaining a definitive ammonia emission factor in the Dutch Rav legislation.

Methodology

In this project, the MeadowFloor CL was installed inside a case room of the Environmental Research Barn of Dairy Campus whereas an identical room equipped with standard concrete slats (no scraping) served as control. All other factors next to the floor type, such as meteorological conditions, indoor climate, number of cows, feeding, milk production, ventilation rate, et cetera, were kept identical (i.e., following the “ceteris paribus principle”). Rooms were climate separated and were ventilated mechanically at 1000 m^3/h per animal via side wall inlets and two ventilation shafts mounted from the roof of each room. Each room housed 16 cows of the Holstein Frisian breed in cubicle housing and were milked twice daily. Ventilation rates were determined using fan wheel anemometers in the ventilation shafts. Concentrations of ammonia in the shafts were determined using ammonia to nitric oxide converters followed by a NO_x analyser. Between May 16th, 2017 and February 9th, 2018, a total of 6 measurement periods were carried out, spread over the calender year in intervals of 6 to 9 weeks (mean 7.6 weeks). Each measurement period lasted for 96 hours but the milking periods (two times two hours daily) were excluded from the analyses.

Results and conclusions

The statistical analyses showed no significant differences between case and control for indoor temperature, milk urea content, and ventilation rate, indicating a valid basis of comparison. The concentration and emission of ammonia was 34.7% lower in the case room (P=0.002) as compared to the control room with concrete slats (Rav code: A 1.100; 13 kg/year per animal place). This reduction is equivalent with a proportional emission rate of 0.653. Multiplied with the emission factor of the reference floor in the control room of 13 kg/animal place per year, the ammonia emission rate of the MeadowFloor CL amounts 8.5 kg/animal place per year. It must be noted, that results from a second case-control approach, or results from emission measurements at another two barns with the housing system of interest, are needed to obtain an official emission factor for the Rav legislation.

1 Introduction

1.1 Problem definition and context

Ammonia (NH_3) is a nitrogen containing gas which - in dairy barns - originates from the urine puddles on the floor and from the slurry (i.e., a mixture of urine and faeces) in the manure pits. To reduce detrimental effects on the ecosystem in terms of eutrophication, acidification and loss of biodiversity, the emission of ammonia from dairy barns is restricted in the Netherlands and solutions are needed to reduce emissions. One such solution is the use of low-emission floors to be installed in the walking aisles for the cows.

In past decades, development of such floors has focussed on closed concrete floors which shut off the headspace of manure pits and quickly drain urine from the floor to the manure pit under the building or manure storage outside the barn. Disadvantages of closed concrete floors are that they are difficult to clean and provide minimal comfort to the cows. The MeadowFloor CL has been designed such that the aforementioned emission reducing principles are combined with comfort and grip for the cows using a rubber top mat. The floor is cleaned by a slurry scraper tailored to the mat profile. The MeadowFloor CL has been added as a low-emission floor to Appendix 1 of the Rav legislation under Rav code A 1.34 and BWL number 2018.07 (see Appendix 1 to this report) with a provisionary ammonia emission factor of 9.0 kg/animal place per year (Kingdom of the Netherlands, 2018). Before the MeadowFloor CL can be marketed to dairy farmers who want to build a new barn or renovate an existing barn, the floor must obtain an official ammonia emission factor in the Dutch Rav legislation. At present, the true reduction of ammonia emission by the floor is unknown.

1.2 Objective

The objective of this project was to empirically determine the ammonia emission reduction of the MeadowFloor CL on a semi-practical scale using the “case-control” approach as described in the measurement protocol for determination of ammonia emission from housing systems in livestock production (Ogink et al., 2017). Subsequently, this project aims to provide a basis for obtaining a definitive ammonia emission factor in the Dutch Rav legislation.

1.3 This report

This report has been set up as a measurement report, following the criteria laid down in the protocol for determination of ammonia emission from housing systems in livestock production (Ogink et al., 2017). Chapter two describes the floor of interest as well as the methodology of the study. Chapter three presents the results of the measurements. The report ends with the conclusions and a list of references.

2 Material and methods

2.1 The MeadowFloor CL

The MeadowFloor CL is a new type of the existing MeadowFloor of the company Proflex Betonproducten in Mill, the Netherlands. The CL stands for "closed", i.e., it is a closed floor based on the MeadowFloor characteristics. The original MeadowFloor is shown in Figure 2.1.

Figure 2.1 *Image of the original MeadowFloor.*

The MeadowFloor is a slatted floor which can be used for new built barns as well as renovation of existing barns where the old concrete slats remain. It consists of a 2 cm thick profiled rubber mat which provides a comfortable walking surface for the cows due to the depressible material absorbing the impact of the hoof and providing grip during movement. The mat contains composite blocks intended for wearing down the hoof of the cows in a natural way. When cows urinate, urine puddles are drained to the slurry pit via sloped urine groves (slope: 6%) in the rubber mat (perpendicular to the longitudinal direction of the floor) and via the slat openings. The slat openings are equipped with plastic valves which reduce air flow from the headspace of the slurry pit to the barn. Both the quick drainage of urine (i.e., separation of urine and faeces) and the air barrier in the valve openings are the ammonia-reducing principles of the floor. The floor must be cleaned by a slurry scraper (once every 90 minutes) or slurry robot (once every two hours). The MeadowFloor has been added as a low-emission floor to Appendix 1 of the Rav legislation under Rav code A 1.28 and BWL number 2015.05.v1 and has been assigned a definitive ammonia emission factor of 6.0 kg/animal place per year (Infomil, 2019a).

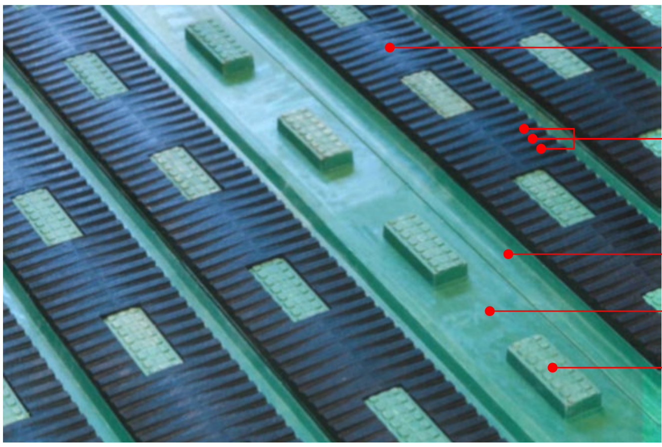


Figure 2.2 *Image of the MeadowFloor CL.*

The MeadowFloor CL is shown in Figure 2.2. The MeadowFloor CL is a closed floor which can be used for newly built barns (including barns without slurry pits) as well as renovations of existing barns where the old concrete slats and slurry pits remain. In the latter case, the composite layer (Figure 2.2) is installed onto the old concrete slats closing off the floor entirely. In contrast to the MeadowFloor, the rubber mats and urine gutters run parallel to the longitudinal axis of the building which makes it possible for a slurry scraper to push the slurry towards the end of the building where disposal openings can be built (either to an outside slurry storage or to the slurry pit under the floor). Instead of slat openings, the MeadowFloor CL contains urine gutters which drain off the urine to the slurry disposal openings of the slurry scraper. A slurry scraper must be used to clean the floor. The rubber mat, the sloped urine grooves, and the composite blocks are identical to the original MeadowFloor. The MeadowFloor CL has been added as a low-emission floor to Appendix 1 of the Rav legislation under Rav code A 1.34 and BWL number 2018.07 (see Appendix 1 to this report) with a provisionary ammonia emission factor of 9.0 kg/animal place per year (Infomil, 2019b).

2.2 Test location

2.2.1 Description of the case-control barn

The project has been carried out in the Environmental Research Barn of the Dairy Campus in Leeuwarden, the Netherlands. Figure 2.3 shows the location of the Environmental Research Barn in the Netherlands and on the Dairy Campus terrain.

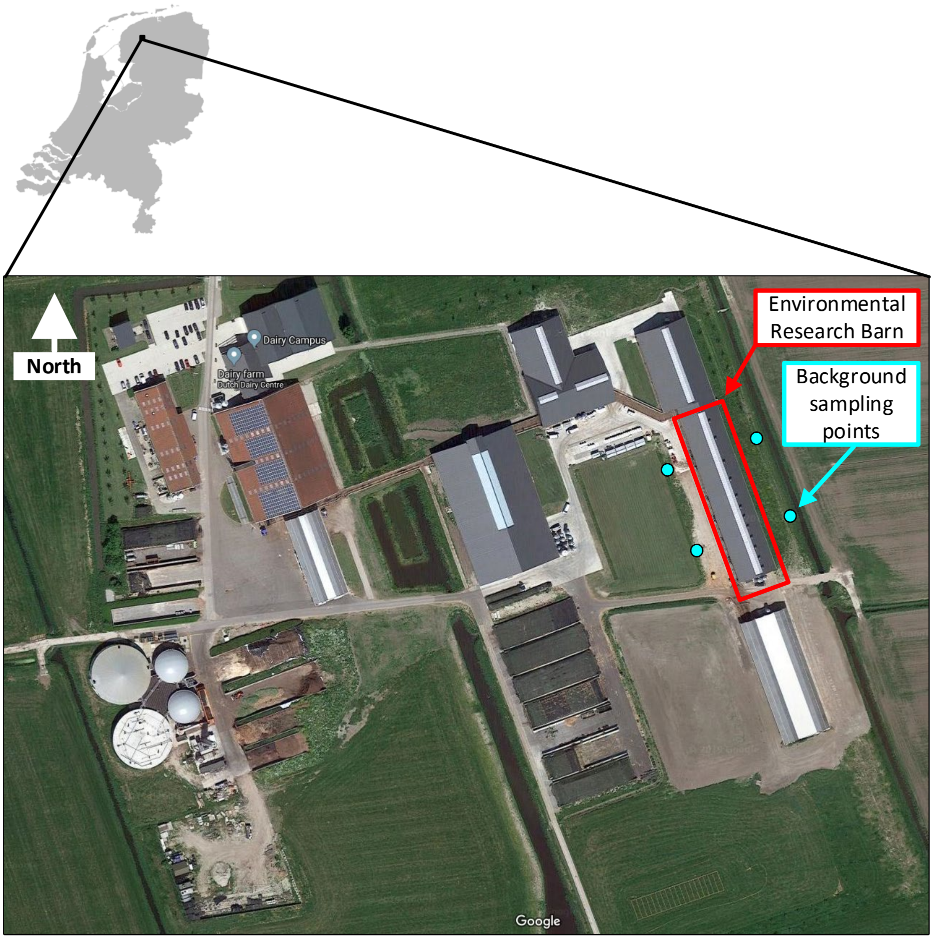


Figure 2.3 *Location of the Environmental Research Barn in the Netherlands and on the Dairy Campus terrain.*

Figure 2.4 shows the general lay-out of the Environmental Research Barn. In this barn, the MeadowFloor CL was installed in room 73 (“case”) whereas room 72 (with concrete slats without slurry scraper) served as the control. The main characteristics of these rooms are summarised in Table 1.

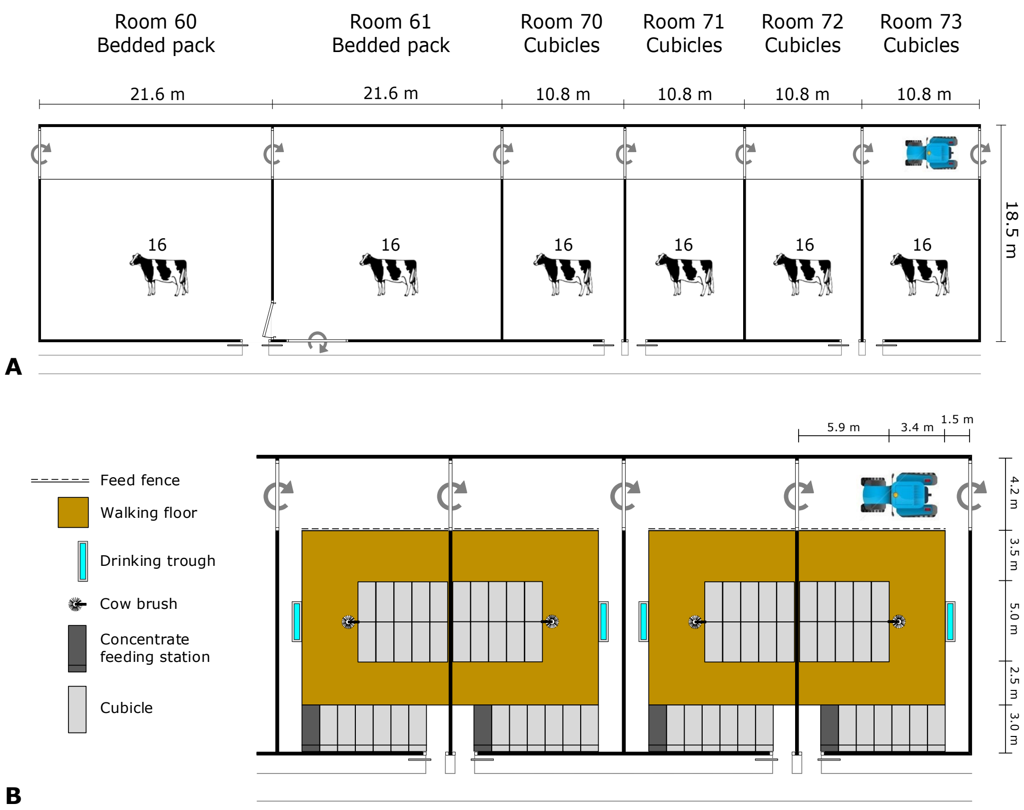


Figure 2.4 *Lay-out of the Environmental Research Barn at Dairy Campus. **A**: Overview of the two experimental rooms for “bedded pack” housing systems and the four experimental rooms for “cubicle” housing. **B**: Detailed lay-out of the four cubicle rooms. Note that the MeadowFloor CL was installed in room 73 (case) whereas room 72 (with concrete slats and no slurry scraper) served as the control.*

Table 1 *Main characteristics of the case and control room in the Environmental Research Barn.*

Parameter	Unit	Room 73 MeadowFloor CL	Room 72 Control
Rooms and dimensions			
Length × width	[m]	10.8 × 18.5	Idem
Height gutter / ridge	[m]	4.5 / 8.2	Idem
Total surface area	[m^2]	201	Idem
Total volume (excluding manure pits)	[m^3]	1278	Idem
Roof shape	-	Gable roof	Idem
Orientation building	-	NNW-SSE	Idem
Ventilation			
Principle	-	Mechanical	Idem
Ventilation capacity	[m^3/h]	42,000 at 0 Pa	Idem
Air inlet	-	Open side walls with bird netting and wind curtains	Idem
Air outlet	-	2 Ventilation shafts in the roof	Idem
Slurry pits			
Surface area of slurry in pits	[m^2]	126	Idem
Depth	[m]	1.6	Idem
Volume	[m^3]	201 (12.6 per cow)	Idem
Walking floor			
Floor type	-	MeadowFloor CL	Concrete slats
Slurry scraper	-	Yes	No
Surface area of walking floor	[m^2]	72.8 (4.6 per cow)	Idem
> elevated zone behind feed fence [1])	[m^2]	4.6 (0.3 per cow)	No
Soiled surface area [2])	[m^2]	68.2 (4.3 per cow)	72.8 (4.6 per cow)
Cubicles			
Number of cubicles	-	16	Idem
Width	[m]	1.15	Idem
Length	[m]	2.5 (10 cubicles) / 3.0 (6 cubicles)	Idem
Surface area of cubicles	[m^2]	49.5 (3.1 per cow)	Idem

[1]) “Voerstoep” in Dutch. [2]) “Mest besmeurd oppervlak” in Dutch.

Figure 2.5 *Combination of two photos of one of the cubicle rooms of the Environmental Research Barn. Note the two ventilation shafts mounted from the ceiling.*

The six rooms inside the Environmental Research Barn are climate separated. The barn is composed of concrete walls, steel rafters and insulated roof panels. Side walls are closed to a level of 1.5 m from the floor; the remaining distance to the gutter is open with bird netting and wind curtains which can be controlled automatically (based on a weather station) or manually. In this project, the wind curtains were always closed (which leaves a 10 cm wide gap for air inlet, to ensure no cross-ventilation could take place). The ridge is composed from transparent panels with switch-operated valves that can be opened in case natural ventilation is needed. The barn has slurry pits under the entire surface area behind the feed fence (i.e., except the area under the feed alley). Rooms are lit by 2 LED lights mounted from the ceiling. The feed fence has 12 feed places. Each room was equipped with a drinking trough, a cow brush, a concentrate feeding station and 16 cubicles.

2.2.2 Description of the MeadowFloor CL in the case room

The MeadowFloor CL was installed onto the existing concrete slats in room 73 (Figure 2.4 B). It was installed on the walking floor behind the feed fence (9.3 m long, 3.5 m wide; 33.3 m^2) and on the walking floor between the cubicle rows (9.3 m long, 2.5 m wide; 23.4 m^2). Both stretches of walking aisle had their own slurry scraper equipped with “fingers” that were tailored to the surface profile of the MeadowFloor CL. The scrapers were driven by a motor, metal chains and a control unit (JOZ, Westwoud, the Netherlands). The slurry scrapers deposited the slurry in openings at the outside end of the aisles (i.e., the end of the room where the water trough is located; Figure 2.4 B). The openings were shut off by a metal plate valve covered by rubber flaps (closing off any remaining gaps around the valve) which opened automatically when the slurry scraper reached the deposition opening. The control unit was programmed to operate the slurry scrapers once every 2 hours.

The “connecting aisle” between the two aisles with the MeadowFloor CL (i.e., the floor between the cow brush and the water trough; 3.4 m long, 5.0 m wide; 17 m^2) could not be equipped with the MeadowFloor CL since a slurry scraper could not access this part of the floor. Instead, this connecting aisle was equipped with a slightly sloped solid rubber floor which was cleaned manually twice per day when the cows had left the room for milking.

2.2.3 Management of animals and climate

Animals
Both the case and control room housed 16 lactating cows of the Holstein Frisian breed. The rooms did not house dry cows or (pregnant) young stock. The animal groups in all rooms of the Environmental Research Barn were composed and monitored such that they had similar mean milk productions (kg/cow per day, ± 10%; based on the milk production in the milking parlour) and similar mean urea milk contents (mg/100 g, ± 10%; based on the monthly individual milk quality analyses).

Feed and water
Cows were fed a ration primarily composed of grass silage (58%) and corn silage (18%). By-products in the ration where: wheat yeast concentrate (8%), wheat meal (7%), milled soy (6%), DairyFit (a mixture of acid buffers, vitamins and minerals; Agrifirm, Apeldoorn, the Netherlands) and a mineral powder (calcium, magnesium, sodium bicarbonate). The afore mentioned percentages represent the overall mean contribution in the ration based on the digital reports from the feed mixing wagon for the six measurement periods in this study. The crude protein content of the ration was >160 g/kg throughout the study. The aforementioned components were mixed and deposited along the feed fence using a feed mixing wagon. Feeding was done once a day during morning milking. During the afternoon milking and in the evening (around 22:00) the ration was pushed up towards the feed fence. Cows received portions of concentrate feed, when they visited the concentrate feeding box, spread over the day in total amounts of 2 to 10 kg, depending on their nutritional needs. Daily feed intake of roughage was registered per room, the intake of concentrate feed per individual. Water was provided ad libitum in the drinking troughs in the rooms (Figure 2.4 B).

Grazing
Cows did not graze outside in the pasture, they were kept inside continuously (apart from milking times).

Milking
Cows were milked in the morning and the afternoon in a separate building at the Dairy Campus terrain consisting of a waiting room and a 40-stands rotary milking system. Cows walked from the Environmental Research barn to the milking building and back again via an outside animal path (Figure 2.4 A). On their way back, selection gates (which read the identity of each animal via the responder around their neck) directed each animal into the right room again.

Animal welfare and veterinary care
The rooms of the Environmental Research Barn and the animal management were in agreement with regulations on animal welfare and health (e.g., as laid down in the "Wet Dieren" and "Besluit Houders van Dieren", chapter 2). General signs related to health and well-being were assessed by the animal caretakers when cows were collected from their rooms for milking. Cows received standard veterinary care. Cows in oestrus were separated after morning milking, inseminated and brought back to the right room at 10:00 AM the latest.

Ventilation
Rooms were ventilated mechanically by two ventilation shafts mounted from the ceiling (Fancom, Panningen, the Netherlands; Ø 80 cm; max. 21,000 m^3/h at 0 Pa; each having its own fan wheel anemometer and control valve, type: ATM), controlled by a climate computer (Fancom, Panningen, the Netherlands; type FC14). The ventilation rate was set at 50% of the capacity, which resulted in a ventilation rate of approximately 16,000 m^3/h (1000 m^3/h per cow). Wind curtains in the side walls were kept in the closed position. In the closed position, an opening of approximately 10 cm wide remained between the bottom of the curtain and the side wall along the length of the room for air inlet preventing possible cross-ventilation. Rooms were kept strictly climate separated. Only during milking the animal doors to the animal path were allowed to be open, as well as the sliding doors in the feed alley for feeding or pushing up feed (Figure 2.4). These two "open door periods" lasted for max. 2 h (max. 4 hours daily). The data from these periods were excluded from the analysis (for more information see par. 2.6).

Lighting
Rooms were lit by natural daylight via the transparent roof ridge and in winter by the 2 LED lights in the morning and evening hours (Figure 2.5). Cows received a natural (nocturnal) dark period of at least 6 hours.

Manure management
The level of slurry in the slurry pits was determined weekly. When slurry was mixed and removed (either because slurry was applied directly to the fields or pit levels became too high), wind curtains and sliding doors in the feed alley were fully opened to avoid dangerous concentrations of manure gasses. Such events were planned outside measurement periods.

2.3 Measurement strategy and sampling points

Since rooms were ventilated mechanically (with wind curtains in the closed position, a closed ridge and underpressure inside the rooms), the two ventilation shafts represented the emission points of the rooms where the measurement of ventilation rate and ammonia concentration took place. Furthermore, the background (ambient) concentration of ammonia was determined outside the barn at two opposite locations at 10 m distance from the barn (Figure 2.3). The mean of the concentrations of both locations was used as background concentration throughout this study.

This project used measurement strategy B as described in the ammonia measurement protocol (Ogink et al., 2017; chapter 2). The main criteria of this strategy were worked out as follows:

- *Measurements must be conducted at two different farm locations which are equipped with a room with the housing system of interest (case) and a room with a reference housing system with a known emission rate (case)*.
  This project has been carried out in one case-control farm. Results from a second case-control farm location, or results from emission measurements at another two barns with the housing system of interest, are needed to obtain an official emission factor for the Rav legislation;
- *A measurement period must have a duration of at least 24 h or a multitude of this*.
  In this project ventilation rates and ammonia concentrations were aggregated to hourly values. A measuring period (see par. 2.6 for more information) lasted for 96 hours and was carried out from Monday 19:00 until Friday 19:00. Due to the "open door periods" and the absence of cows during milking (see par. 2.2.2 section Ventilation), 2 hours of data in the morning and 2 hours of data in the afternoon, were excluded from the analyses. One measurement period therefore contained (96 minus 4 × 4=) 80 hourly values.
- *At each farm location, 6 measurement periods must be performed, spread over the calender year.*
- *Measurements in animals with a stable emission pattern must be carried out in consecutive time periods of two months in which a measurement period must be chosen randomly.*
  In this project the first measurement period was chosen randomly. Subsequently, each next measurement period was set at the first measurement period + 8, 16, 24, 32, and 40 weeks. When this target week could not be realised a week within an interval of 2 weeks earlier until 2 weeks later than the target week was selected. This way, measurement periods were always well away from previous and next measurement periods.

2.4 Measurements methods

2.4.1 Ventilation rate

The ventilation rate was measured by the fan wheel anemometer in the Fancom ATM measuring and control valve units under each ventilation shaft. The output signals (pulse frequency, Hz) of the units were stored in a data storage box (Campbell Scientific, Logan, USA; type CR1000). The frequencies were converted into ventilation rates using a calibration line. The fan wheel anemometers were calibrated by DLG prior to installation in the barn (DLG-Prüfungs-Nr.: 12-00892).

2.4.2 Ammonia concentration

For the determination of ammonia concentration air was sampled from the interior of the ventilation shafts and transported to the measuring room of the barn via polyethylene tubes. The air first passed a measurement point switch (produced by the central workshop of Wageningen University and Research) connecting only one room at a time to the following steps. The air was then heated in an ammonia converter (produced by the central workshop of Wageningen University and Research) to 775 °C. In the presence of a metal catalyst, ammonia is oxidised into nitric oxide (NO). The conversion efficiency of the ammonia converter was calibrated before and after the project. The temperature reading of the converters was checked daily. The switching time of the measurement point switch amounted 10 minutes. The averaging time for logging of the ammonia concentration was 1 minute. Of the total sampling duration of 10 minutes, the first 9 minute values were utilized to obtain a stable concentration pattern. These values were only used to ascertain a flattened-out concentration pattern but were excluded from further calculation of the ammonia emission. Only the tenth minute value was used as the ammonia concentration. The measurement point switch had 12 inlets available which were utilized for five rooms with two fan shafts each, and 2 background sampling locations. This means that each of the three locations (case room 73, control room 72, and the background locations) was sampled once every hour.

The concentration of NO was measured by a NO_x-analyser (Teledyne Advanced Pollution Instrumentation, Inc., San Diego, USA; type T200). The analyser uses the chemiluminescence detection principle. The NO present in the sample air reacts with O_3 (ozone; produced by the analyser) to produce nitrogen dioxide (NO_2) and oxygen (O_2). Through the collision between NO and O_3 molecules the NO_2 molecules produced shortly reside in an exited energy state when one of the electrons of the NO_2 molecule has a higher energy state than normal, denoted by an asterisk in the following equation: $NO + O_3 \rightarrow NO_2^* + O_2$. Because the laws of thermodynamics require that systems seek the lowest stable energy state available, the excited NO_2^* molecules quickly return to their ground state, releasing the excess energy. This release takes the form of light with wavelengths between 600 and 3000 nm, with a peak at about 1200 nm (infrared light). The overall reaction can now be described as: $NO + O_3 \rightarrow NO_2 + O_2 + \text{photons}_{1200\ nm}$. Since the pressure (vacuum) and the temperature (50 °C) in the reaction cell are kept constant, and ozone is excessively present, the amount of photons detected by an infrared sensor is a linear measure for the amount of NO_2 present in the reaction cell and thus the amount of NO in the sampling flow. The NOx-analyser was calibrated, and if needed adjusted, every 4 weeks using a gas cylinder with 40 ppm NO. Concentrations obtained from the NOx-analyser were corrected for the conversion efficiency of the ammonia converter. Data from the NO_x-analyser were stored in the aforementioned data storage box (Campbell Scientific, Logan, USA; type CR1000).

2.4.3 Air temperature and humidity

Air temperature and relative humidity in the rooms were measured using sensors (Rotronic; ROTRONIC Instrument Corp., Huntington, USA) with a precision of ± 1.0 °C en ± 2% respectively. The data were stored in the aforementioned data storage box (Campbell Scientific, Logan, USA; type CR1000).

2.4.4 Animal performance

The milk production (kg/cow) was recorded during each milking and automatically logged in a central database. The milk quality of each cow was determined during the monthly individual milk quality assessments (MPR, Milk Production Registration) and included fat content (%), protein content (%), and urea content (mg/100 g). These data were also stored in the central database.

2.5 Data storage

The data on ventilation rate, ammonia concentration, temperature and relative humidity stored in the aforementioned data storage box were send to the servers of Wageningen University and Research. Back-ups of these servers are made twice per day.

2.6 Estimation of ammonia emission and reduction

The absolute ammonia emission (kg/year per animal place) during hour *i* (1, 2, …, 80) of measuring period *j* (1, 2, …, 6) in room *k* (1=case, 2=control) was calculated by the following equation:

$$E_{ij} = Q_{ijk} * \left(Cout_{ijk} - Cin_{ijk}\right) * 24 * 365$$

where:

- E_{ij} = the emission of ammonia (kg/year per animal place) during hour *i* in measuring period *j* in room *k*
- Q_{ijk} = the ventilation rate (m^3/h per animal place) during hour *i* in measuring period *j* in room *k*
- $Cout_{ijk}$ = the concentration of ammonia (mg/m^3) in the outgoing air during hour *i* in measuring period *j* in room *k*
- Cin_{ijk} = the concentration of ammonia (mg/m^3) in the incoming air during hour *i* in measuring period *j* in room *k*

Subsequently, the proportional emission reductions P_j of the "case" room to the "control" room were calculated following the equation:

$$P_j = \frac{E_{j1}}{E_{j2}}$$

Subsequently, the mean proportional emission reduction *P* was calculated as the arithmetic mean of the P_j values:

$$P = \overline{P_j}$$

According to the ammonia measurement protocol (Ogink et al., 2017), the emission factor of the housing system in the case room is obtained by multiplying *P* with the emission factor of the housing system applied in the control room (i.e., 13 kg/year per animal place). This final step in the calculation procedure has been performed too and results are presented in the Results and discussion chapter.

In the case control approach, results are not standardized for air temperature, milk urea content, and soiled surface area.

2.7 Statistical analysis

Paired sample t-tests were performed to determine statistically significant differences between the case room and the control room for the following variables:

Conditions during the project, related to the ammonia emission process:

- Temperature of the inside air (°C);
- Milk urea concentration (mg/100 ml);

Direct emission variables:

- Ventilation rate (m^3/h)
- Ammonia concentration (mg/m^3)
- Ammonia emission rate (kg/animal place per year)

The input for the t-tests were the mean values for each measurement period (n=6 per room). These values were assumed to be independent observations (i.e., not auto-correlated in time). A statistical significant difference was declared at P-values ≤ 0.05. Variables that were expected to be identical between the rooms (temperature of the inside air, milk urea concentration, and ventilation rate) were tested with two-sided t-tests, whereas those that were expected to be different (ammonia concentration and ammonia emission rate) were tested with one-sided t-tests. The tests were performed with the GenStat software (VSN International Ltd, 2018).

3 Results and discussion

3.1 Conditions during the project

The MeadowFloor CL was installed in room 73 of the Environmental Research Barn in the summer of 2016. The period for the official measurements started in May 2017. At that moment, the floor had been in use well over 3 months. Table 2 shows the conditions during the period of the official measurements.

Table 2 *Conditions during the project.*

Variable	Measurement period						
	1	2	3	4	5	6	Mean
Measurement period							
Week number in calender year	20	28	37	43	52	6	31
Interval between periods (weeks)	-	8	9	6	9	6	7.6
Start date of measurement period	16-05-17	11-07-17	12-09-17	24-10-17	26-12-17	6-02-18	-
Day number in calender year	136	192	255	297	360	37	213
End date of measurement period	19-05-17	14-07-17	15-09-17	27-10-17	29-12-17	9-02-18	-
Time since last manure removal (days)	11	13	12	54	117	159	61
Climate conditions							
Temperature ambient air (°C)	16.9	15.5	13.2	13.0	4.0	-0.9	10.3
Relative humidity ambient air (%)	78	80	82	89	86	82	83
Temperature inside air (°C)							
- Case room	19.9	19.2	15.7	15.6	7.3	3.5	13.5
- Control room	20.0	19.6	16.1	16.0	6.7	2.8	13.5
Relative humidity (%)							
- Case room	80	80	97	98	n.d.	84	88
- Control room	91	85	94	97	99	86	92
Animal performance							
Milk production (kg/animal per day)							
- Case room	28.0	29.9	31.8	27.3	30.0	29.8	29.5
- Control room	29.2	29.7	27.9	25.0	29.9	29.4	28.5
Milk fat content (%)							
- Case room	4.29	4.25	4.14	4.23	4.54	4.24	4.28
- Control room	4.25	4.32	4.61	4.66	4.59	4.13	4.43
Milk protein content (%)							
- Case room	3.57	3.32	3.37	3.67	3.58	3.62	3.52
- Control room	3.59	3.36	3.48	3.77	3.70	3.65	3.59
FPCM (kg/animal per day)							
- Case room	29.4	30.8	32.4	28.6	32.3	31.2	30.8
- Control room	30.5	30.9	30.1	27.5	32.6	30.4	30.4
Milk urea concentration (mg/100 g)							
- Case room	22.0	25.0	23.7	17.6	20.8	23.6	22.1
- Control room	22.0	26.1	26.1	19.4	18.8	23.7	22.7

n.d.: no data

The measurements were conducted between May 16th, 2017 and February 9th, 2018. The 6 measurement periods were spread over the calender year in intervals of 6 to 9 weeks (mean 7.6 weeks). The first three measurement periods fell in the growing season of the meadows during which manure was removed from the slurry pits frequently to be applied to the fields. The last three measurement periods fell in the winter period when slurry accumulated in the pits for longer periods.

The mean ambient temperature (10.3 °C) and relative humidity (83%) are in close agreement with the long-term average values for the Netherlands (i.e., 10.6 °C and 81%; Royal Netherlands Meteorological Institute, based on measuring station De Bilt, 2007-2016). On average, the temperature in the case and control room were 3.2 °C above the ambient temperature, most likely due to the heat production of the cows, the insulated roof and the ventilation regime with closed wind curtains and mechanical ventilation. Table 2 furthermore shows that the temperature in the case and control room were very similar (differences less than 10%). The statistical analysis showed that temperature was not statistically different (P=1.000) between the rooms.

Another variable related to the emission of ammonia, the milk urea concentration, also differed less than 10% between the case and control throughout the study. The statistical analysis showed that the milk urea content was not statistically different (P=0.417) between the rooms.

The ammonia measurement protocol (Ogink et al., 2017) lists a number of conditions on various pages that must be met during the study. They were met in this work as follows:

- ✓ each measurement period lasted for a multitude of 24 hours, namely: 4 days = 96 hours (bullet 1 at page 4 of the protocol);
- ✓ six measurement periods were carried out (bullet 3 at page 4 of the protocol);
- ✓ after a randomly chosen first measurement period, the next measurement periods were set at the first measurement period + 8, 16, 24, 32, and 40 weeks. When this target week could not be used, a week within an interval of 2 weeks earlier until 2 weeks later than the target week was selected. This way, measurement periods were always well away from previous and next measurement periods (bullet 4 at page 4 of the protocol);
- ✓ during measurement periods all animals were kept inside the rooms (i.e., no grazing; bullet 8 at page 5 of the protocol);
- ✓ more than 4 of 6 measurement periods (namely 6 out of 6) are available for calculation of the emission factor (bullet 8 at page 9 of the protocol);
- ✓ more than 80% of the measurements yielded usable data (namely 80 out of 96 hourly values per measurement period; bullet 8 at page 9 of the protocol);
- ✓ the number of dry cows per room was less (i.e., zero) than 25% of the total number of cows (page 17 of the protocol);
- ✓ the number of pregnant young stock was less (i.e., zero) than 30% of the total number of cows (page 17 of the protocol);
- ✓ the occupation during measurement periods was within 90 and 110% (i.e., 100%) of the number of cubicles (page 17 of the protocol);
- ✓ in the eight weeks prior to the measurement periods, the animals were kept inside the rooms for more than 12 hours per day (i.e., continuously except for milking times; page 17 of the protocol);
- ✓ the concentration of carbon dioxide was not determined continuously since rooms were ventilated mechanically. Incidental measurements of carbon dioxide showed that concentrations were always well below 3000 ppm (page 17 of the protocol);
- ✓ the fraction of roughage in the ration was well over 50% (page 17 of the protocol);
- ✓ the crude protein (CP) content of the ration was well over 160 g/kg (page 17 of the protocol);
- ✓ the urea content of the milk produced by the cows was always well over 15 mg/100 g (page 17 of the protocol);
- ✓ the mean milk production was always well over 25 kg FPCM per animal per day (page 17 of the protocol);
- ✓ the cows received standard veterinary care. No irregular events occurred with regard to animal welfare or health during the study;
- ✓ the number of cows per case or control room amounted more than 15 (i.e., 16; page 17 of the protocol).

3.2 Ventilation rate, concentration, emission and reduction

Table 3 shows the variables directly related to the ammonia emission process. The statistical analysis showed that the ventilation rate was not significantly different between the case and control rooms (*P*=0.952). The concentration of ammonia however, did differ significantly between the rooms (1.10 versus 1.53 mg/m^3; *P*=0.002). As a result, also the emission rate of ammonia (being the product of the ventilation rate multiplied with the ammonia concentration) differed significantly between the rooms (6.79 versus 10.32 kg/animal place per year; *P*=0.002). The relative reduction of the ammonia emission varied within a narrow range between 27.5% and 48.0% and was therefore well reproducible between measurement periods.

According to the ammonia measurement protocol (Ogink et al., 2017), the emission factor of the housing system in the case room is obtained by multiplying the proportional emission reduction (0.653; Table 2) with the emission factor of the housing system applied in the control room (i.e., 13 kg NH_3/year per animal place). This procedure results in an absolute emission factor of (0.653 × 13 =) **8.5** kg NH_3/animal place per year. It must be noted however, that results from a second case-control approach, or results from emission measurements at another two barns with the housing system of interest, are needed to obtain an official emission factor for the Rav legislation.

Table 3 *Ventilation rates, concentrations, emissions and emission reductions.*

Variable	Measurement period						
	1	2	3	4	5	6	Mean
Ventilation rate (m^3/h)							
- Case room	11,568	16,755	16,816	15,937	15,454	14,982	15,252
- Control room	11,522	16,333	17,068	15,942	15,499	15,185	15,258
Ammonia concentration (mg/m^3)							
- Background	0.33	0.34	0.20	0.20	0.28	0.27	0.27
- Case room	1.69	1.38	1.18	0.94	0.74	0.65	1.10
- Control room	2.23	2.17	1.55	1.24	0.98	0.99	1.53
Ammonia emission rate (kg/apl per year)							
- Case room	8.67	9.55	9.05	6.45	3.90	3.14	6.79
- Control room	11.96	16.40	12.57	9.01	5.97	6.03	10.32
Emission reduction							
- Absolute (kg/apl per year)	3.29	6.85	3.53	2.56	2.07	2.89	3.53
- Relative (%)	27.5	41.8	28.0	28.4	34.7	48.0	**34.7**
- Proportional	0.725	0.582	0.720	0.716	0.653	0.520	0.653

apl: animal place.

3.3 Comparison of results to the literature

It is difficult to compare the results from this work with values from scientific journal articles or research reports since little emission values are available specifically on solid floors with urine gutters (or "sleufvloer" in Dutch). The most valid comparison can be made by looking at the sleufvloer system in the Rav legislation which has an ammonia emission factor of 11.8 kg/animal place per year (A 1.5, loopstal met sleufvloer en mestschuif, BWL 2010.24.V6). The 8.5 kg/animal place per year found in this work is 28% lower than the 11.8 of the original sleufvloer.

3.4 Reliability and plausibility of the results

This study followed the "case-control strategy" as laid down in the ammonia measurement protocol (Ogink et al., 2017) and was carried out in the Environmental Research Barn of Dairy Campus. The advantage of this approach is the sound basis of comparison. The Material and methods chapter and the results in Table 2 illustrate that all other factors except the floor type (e.g., meteorological conditions, indoor climate, number of cows, feeding, milk production, milk urea content, ventilation rate, et cetera) could be kept very similar, which is the “ceteris paribus” concept behind this strategy. Furthermore, all conditions and criteria listed throughout the ammonia emission protocol were met. This means that the 34.7% lower ammonia emission in the case room has most likely been caused by the test floor: i.e., causality can be appointed in this strategy.

To further increase the causality between the lower ammonia emission and the test floor, the test floor could have been changed between the rooms periodically. This could have averaged out any room effects that might have been present. However, this would demand drastic building activities during the project and high costs. For these reasons, floors were not changed between rooms.

The “case-control strategy” yields a relative reduction of the ammonia emission by the test floor as compared to the control room. The emission rate of the case room amounted 6.79 kg/animal place per year against an emission rate of 10.32 kg/animal place per year for the control room. The mean proportional ammonia emission of the case room therefore amounted 0.653 (equivalent with a reduction of 34.7%). To obtain the emission factor of the test floor, the proportional emission must be applied to the emission factor of the control room (13 kg/animal place per room; A 1.100), yielding 8.5 kg/animal place per year as end result. The mean emission rate of the control room however was 10.32 kg/animal place per year which is 2.68 kg/animal place per year or 21% lower than the emission factor of 13. The latter emission factor is based on the study of Mosquera et al. (2014). This report states that the true emission factor lies within a 95% confidence interval of ± 15%, i.e., between 11 and 15 kg/animal place per year. If the emission rate of the control room would have been closer to 13 due to factors such as a higher milk urea content, a higher air velocity/ventilation rate, a higher air temperature, et cetera, these factors would have been likewise in the case room. If no interaction effects between aforementioned factors and floor type are present, the reduction of the ammonia emission by the floor type will remain proportional. However, given the fact that this study was performed under representative factors in terms of milk urea content and ambient/indoor temperature, the 34.7% reduction can be regarded as a reliable estimate of the true ammonia reduction of the MeadowFloor CL.

4 Conclusions

The reduction of the ammonia emission rate by the MeadowFloor CL, as compared to a reference floor with concrete slats (Rav code: A 1.100) amounts 34.7%.

This reduction is equivalent with a proportional emission rate of 0.653. Multiplied with the emission factor of the control room of 13 kg/animal place per year, the ammonia emission rate of the MeadowFloor CL amounts 8.5 kg/animal place per year.

It must be noted however, that results from a second case-control approach, or results from emission measurements at another two barns with the housing system of interest, are needed to obtain an official emission factor for the Rav legislation.

References

Infomil, 2019a. A 1.28: Ligboxenstal met roostervloer, voorzien van rubber matten en composiet nokken met een hellend profiel, kunststofcassettes met kleppen in de roosterspleten en met mestschuif (BWL 2015.05.V1). Website: https://www.infomil.nl/onderwerpen/landbouw/stalsystemen/emissiefactoren-per/map-staltypen/hoofdcategorie/. Geraadpleegd: 28 mei 2019.

Infomil, 2019b. A 1.34: Ligboxenstal met dichte gegroefde vloer met rubber matten met een hellend profiel, aangebrachte composietnokken met een mestschuif met vingers (BWL 2018.07). Website: https://www.infomil.nl/onderwerpen/landbouw/stalsystemen/emissiefactoren-per/map-staltypen/hoofdcategorie/. Geraadpleegd: 28 mei 2019.

Ogink, N.W.M., Groenestein, C.M. & Mosquera J., 2014. Actualisering ammoniakemissiefactoren rundvee: advies voor aanpassing in de Regeling ammoniak en veehouderij (Update of ammonia emission factors for cattle categories: advisory report for amendments in regulations on ammonia and livestock). Wageningen Livestock Research rapport; no. 744. Wageningen: Wageningen UR Livestock Research. 29 p.

Ogink, N.W.M., Mosquera, J. & Hol, J.M.G., 2017. Protocol voor meting van ammoniakemissie uit huisvestingssystemen in de veehouderij 2013a [Measurement protocol for ammonia emission from housing systems in livestock production 2013a]. Wageningen Livestock Research rapport; no. 1032. Wageningen: Wageningen UR Livestock Research. 39 p.

VSN International Ltd, 2018. Genstat Nineteenth Edition. Version 19.1.0.21390. http://www.vsni.co.uk.

Appendices

Appendix 1: system description BWL number 2018.07

Nummer systeem	**BWL 2018.07**
Naam systeem	**Ligboxenstal met dichte gegroefde vloer met rubber matten met een hellend profiel, aangebrachte composietnokken met een mestschuif met vingers**
Diercategorie	**Melk- en kalfkoeien ouder dan 2 jaar**
Rav- code	**A 1.34**
Systeembeschrijving van	**December 2018**
Werkingsprincipe	De ammoniakemissie wordt beperkt door de versnelde afvoer van urine vanaf de dichte vloer naar regelmatige groeven. De dichte vloer wordt voorzien van een rubber mat met sterk hellend profiel in de composietnokken. Daardoor wordt de urine geconcentreerd opgevangen en elke 2 uur afgevoerd met een getrokken mestschuif met vingers, die de groeven grondig reinigen. De mest (faeces en urine) wordt minimaal elke 2 uur afgeschoven naar een afsluitbare mestafstort. Mestopslag kan plaatsvinden onder de vloer of in een (afgesloten) buitenopslag.

DE TECHNISCHE UITVOERING VAN HET SYSTEEM

	Onderdeel	Uitvoeringseis
1a	Vloeruitvoering	Loopgedeelte worden uitgevoerd als gesloten betonnen vloerelementen (variabele lengte, breedte) of een gestorte betonnen vloer op zand.
1b		Op de vloer zijn geprofileerde nokken (‘pedicure profiel’) van composiet aangebracht. De nokken zijn ca. 2 cm hoog, 4,5 cm breed en 11 cm lang aangebracht. Het profiel ervan loopt met een helling van 6% af, vanaf het midden van de nokken naar de zijkanten.
1c		De vloer is bedekt met een ± 2 cm dikke rubber mat met uitsparingen. De uitsparingen in de rubber mat passen exact op de nokken op de vloer. De rubber matten zijn voorzien van een antislip profiel dat aansluit op het profiel van de composiet nokken Op deze manier ontstaat een aaneengesloten oppervlak bestaande uit een combinatie van geprofileerd composiet en rubber.
1d		De vloer is voorzien van sleuven (breedte 28 tot 50 mm, diepte ≥ 25 mm; onderlinge afstand hart op hart 160 tot 180 mm), die evenwijdig lopen aan de lengterichting van de loopgangen. Doordat de sleuven in de vloerelementen zijn aangebracht lijkt het alsof er banen/balken over de vloer lopen.
1e		Uitgezonderd van deze eisen zijn de doorsteken, de wachtruimte en de doorlopen; deze hoeven niet te worden voorzien van boven beschreven systeem. Deze ruimten moeten echter wel emissiearm worden uitgevoerd door gebruik te maken van een ander in de Rav opgenomen emissiearm systeem dan wel een dichte vloer. In deze ruimtes mag de breedte van de vloerplaten kleiner zijn dan voor het betreffende emissiearme systeem is vereist, mits dit de emissiereducerende werking niet nadelig beïnvloedt.
2	Rubber matten	De rubber matten moeten voldoen aan de volgende eisen: - de matten dienen deugdelijk te zijn bevestigd aan het betonnen gedeelte van de vloer, zodat het rubber niet kan gaan schuiven of opkrullen; - de maatvoering van de rubber matten is afgestemd op de maatvoering van de banen met composietnokken tussen de sleuven; - de maattolerantie van de rubber matten is +/- 1,5%; - de rubber matten moeten goed beloopbaar en slijtvast zijn. Dit kan

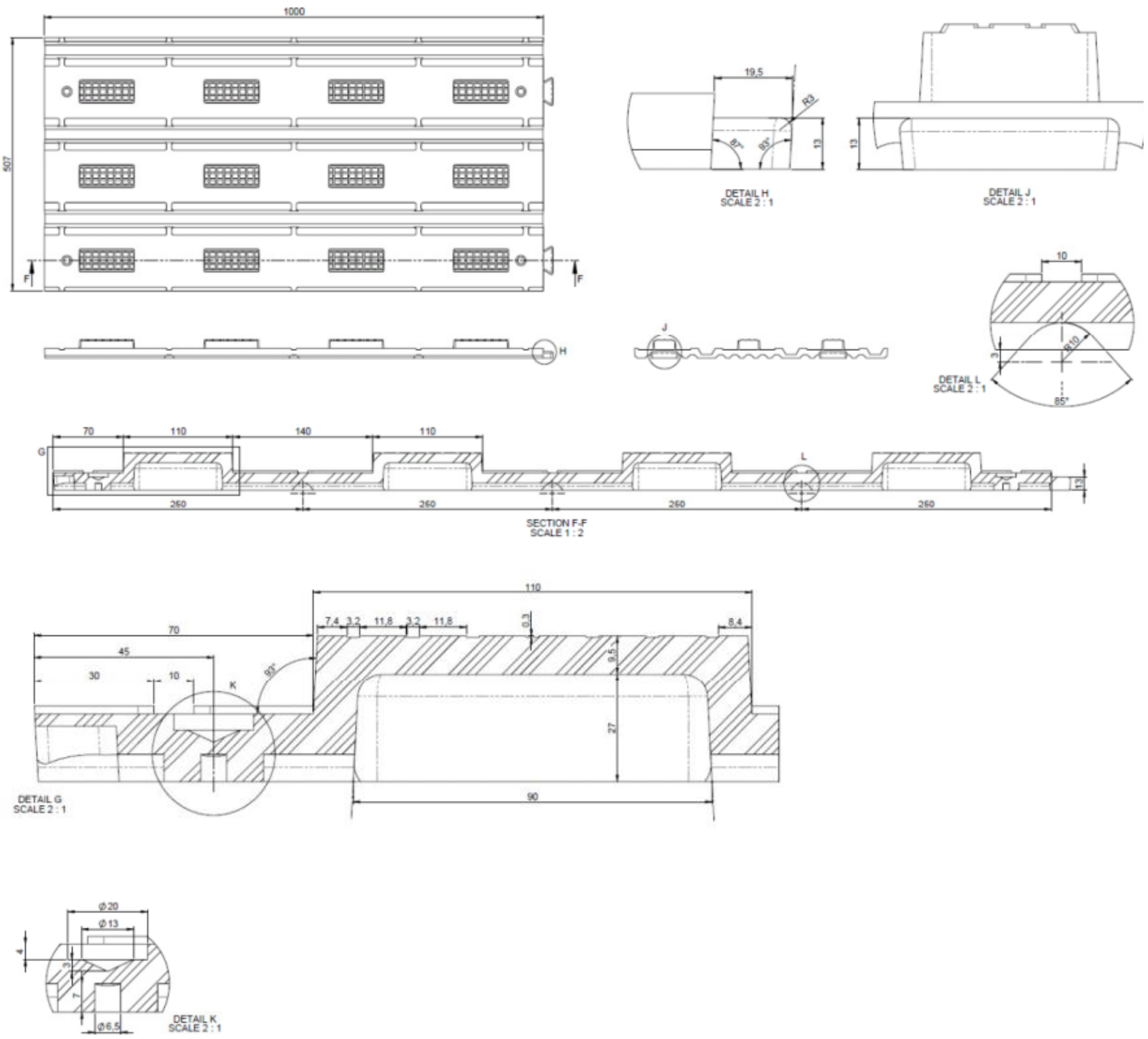
		inzichtelijk worden gemaakt door het overleggen van een DLG-certificaat voor beloopbaarheid en slijtvastheid.
3a	Mestkelder en mestafvoer	Onder de mestafstorten[1] en eventueel onder de vloer in de doorsteken, wachtruimte en doorlopen (dit is afhankelijk van de gekozen vloeruitvoering) is een mestkelder aanwezig.
3b		Indien in de doorsteken, de wachtruimte en de doorlopen een ander emissiearm systeem wordt toegepast en daardoor extra emissie vanuit de kelder daaronder kan optreden (schoorsteeneffect), dient bij elke overgang van vloersysteem in de mestkelder een stankafsluitende voorziening te worden aangebracht.
3c		Aan één of beide uitgangen van de loopgang is in de vloer een mestafstort gemaakt voor de afvoer van de mest. De afstorten zijn voorzien van een zogenaamde brievenbussluiting, rubberen flappen of een andere voorziening die emissie vanuit de mestkelder zoveel mogelijk voorkomt.
3d		Wanneer tussentijdse mestafstorten worden gebruikt, bijvoorbeeld indien de schuifuitvoering dat noodzakelijk maakt of wanneer deze als noodvoorziening wordt geïnstalleerd, moeten deze afstorten worden voorzien van een zogenaamde brievenbussluiting, rubberen flappen of andere voorziening die emissie vanuit de mestkelder zoveel mogelijk voorkomt. Bij een vaste mestschuif zal de mestafstort tenminste de lengte moeten hebben van de naar voren gerichte mestgeleiders.
4a	Mestschuif	Voor afvoer van de mest moet een mestschuif met vingers zijn aangebracht. Dit is een mechanische vaste opstelling van een mestschuif met vingers, voorzien van een aandrijfmechanisme (kabel, ketting) en tijdschakeling. De mestschuif dient zodanig te worden uitgevoerd dat het geprofileerde loopoppervlak en de groeven goed worden gereinigd.
5a	Emitterend oppervlakte	Het met mest besmeurd vloeroppervlak per dierplaats is maximaal 5,5 m^2. Dit oppervlak omvat de loopgangen, doorsteken, wachtruimte en doorlopen. Niet inbegrepen is het vloeroppervlak van de melkstal en de voerstoep (indien aanwezig).
5b		Voor de wachtruimte geldt dat deze niet meetelt bij het bepalen van het met mest besmeurd oppervlak, wanneer deze met een dichte vloer is uitgevoerd. Wanneer de wachtruimte op een andere wijze is uitgevoerd, telt het oppervlak wel mee bij het bepalen van het met mest besmeurd oppervlak per dierplaats.
6	Registratie-apparatuur	- Voor het registreren van het aantal schuifbewegingen dient een verzegelde bedrijfsurenteller aanwezig te zijn. - Voor de waarborging van de schuiffrequentie dient een tijdklok aanwezig te zijn. Deze tijdklok dient daartoe de aansturing van de mestschuif te verzorgen
HET GEBRUIK VAN HET SYSTEEM		
	Onderdeel	**Gebruikseis**
a1	Schuiffrequentie	De mest dient tenminste iedere twee uur van de vloer te worden verwijderd met de mestschuif.

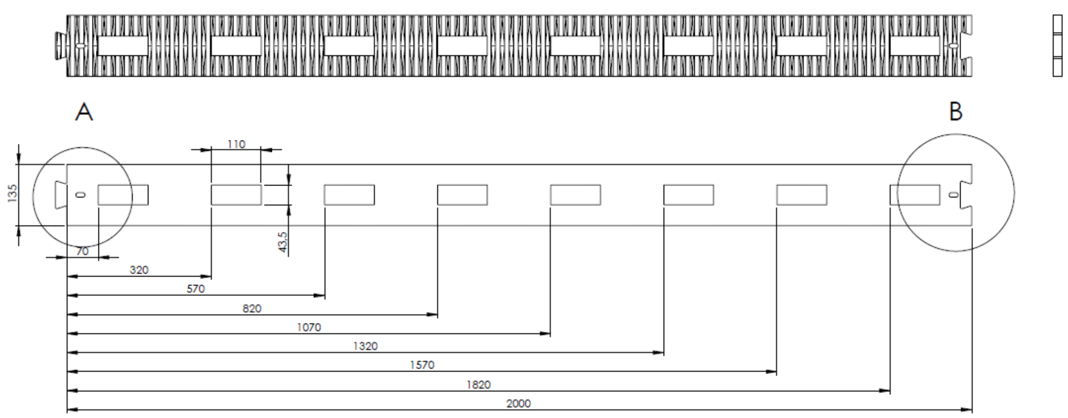
[1] Mestopslag kan plaatsvinden onder de vloer of in een (afgesloten) buitenopslag.

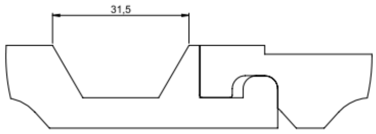
a2		Het met mest besmeurde vloeroppervlak waar de mestschuif niet kan komen, dient minimaal twee keer per dag handmatig te worden gereinigd.
b1	Wachtruimte	De gebruiksduur van de wachtruimte beperkt zich tot de melktijden. Buiten de melktijden worden in de wachtruimte geen dieren gehouden. Wanneer in de wachtruimte buiten de melktijden wel beschikbaar is voor de dieren maakt deze deel uit van de loopruimte. In dat geval moet de wachtruimte wel worden meegeteld als onderdeel van het mest besmeurd vloeroppervlak.
b2		Na elk gebruik moet de wachtruimte direct worden gereinigd waarbij alle mest en urineplassen worden afgevoerd naar de mestkelder.
c	Onderhoud	De mestschuif en de rubber matten dienen tenminste eenmaal per jaar te worden gecontroleerd en onderhouden. Aanbevolen wordt hiertoe een onderhoudscontract met de leverancier van de mestschuif of een andere deskundige partij af te sluiten.
d1	Controle en registratie	Om het gebruik van het systeem te controleren dient: - op de bedieningscomputer een terugleesoptie aanwezig te zijn waarmee de werking van het systeem gedurende de laatste drie maanden inzichtelijk kan worden gemaakt, of: - een verzegelde draaiurenteller te zijn geplaatst voor continue registratie van de bedrijfsuren van de aandrijfmotor van de mestschuif. De bedrijfsuren dienen maandelijks te worden afgelezen en geregistreerd zodat de schuiffrequentie terug te rekenen is
d2		Er moet een logboek worden bijgehouden waarin wordt aangetekend wanneer en door wie de controle en het onderhoud van de mestschuif en de rubber matten heeft plaatsgevonden

Emissiefactor	9,0 kg NH_3 per dierplaats per jaar
Verwijzing meetrapport	Deze emissiefactor is voorlopig vastgesteld en zal aan de hand van de meetresultaten worden herzien.

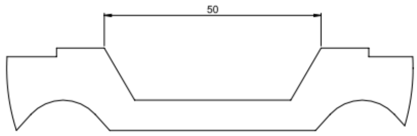
Detailtekeningen uitvoering vloer



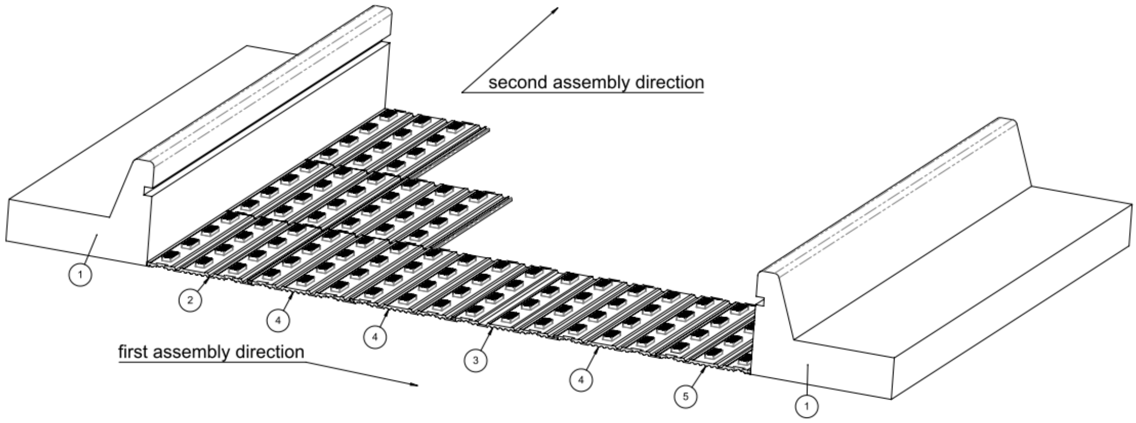


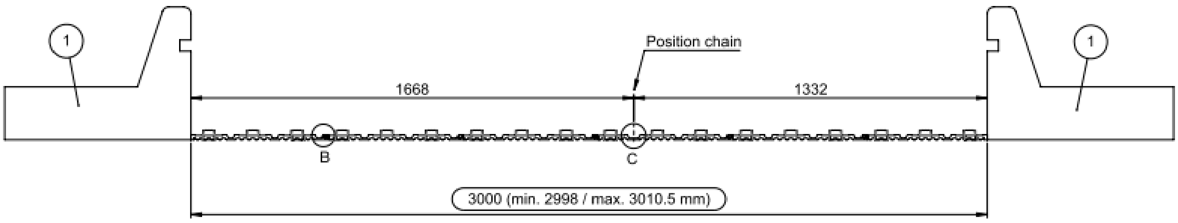


DETAIL B
SCALE 2 : 1

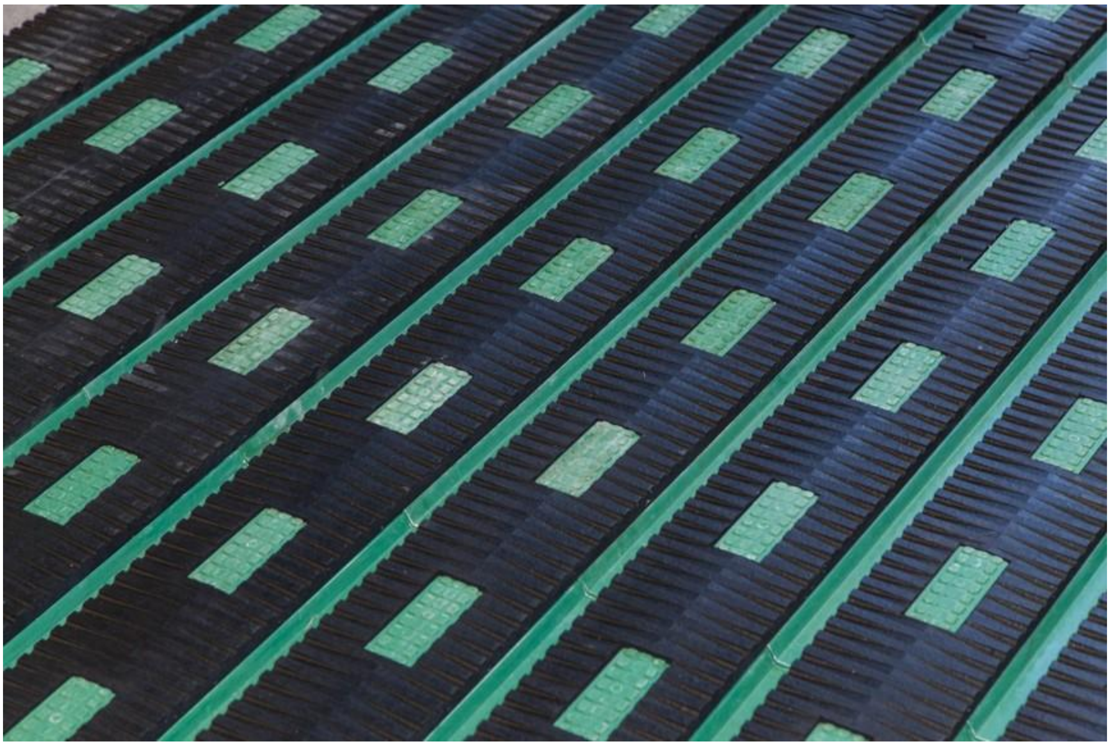


DETAIL C
SCALE 2 : 1





Foto



NAAM:	NUMMER:
Ligboxenstal met dichte gegroefde vloer met rubber matten met een hellend profiel, aangebrachte composietnokken met een mestschuif met vingers	BWL 2018.07
	SYSTEEMBESCHRIJVING:
	December 2018

To explore the potential of nature to improve the quality of life

Wageningen Livestock Research
P.O. Box 338
6700 AH Wageningen
The Netherlands
T +31 (0)317 48 39 53
E info.livestockresearch@wur.nl
www.wur.nl/livestock-research

Wageningen Livestock Research creates science based solutions for a sustainable and profitable livestock sector. Together with our clients, we integrate scientific knowledge and practical experience to develop livestock concepts for future generations.

Wageningen Livestock Research is part of Wageningen University & Research. Together we work on the mission: ‘To explore the potential of nature to improve the quality of life’. A staff of 6,500 and 10,000 students from over 100 countries are working worldwide in the domain of healthy food and living environment for governments and the business community-at-large. The strength of Wageningen University & Research lies in its ability to join the forces of specialised research institutes and the university. It also lies in the combined efforts of the various fields of natural and social sciences. This union of expertise leads to scientific breakthroughs that can quickly be put into practice and be incorporated into education. This is the Wageningen Approach.