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Evaluation of different bedding materials for cubicles in dairy farm systems

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In modern dairy cow housing systems, the animals' cubicles are mostly scattered with organic materials, which have a positive effect on the lying behaviour of the cows and the hygiene in the cubicles. The objective of the present study was to investigate the economic and climate-relevant qualities of different bedding materials in the cubicles. The bedding materials showed differences in the acceptance among the animals as well as in the effort and expense involved. A further focus was on climatically relevant gases emitted by the bedding materials and their emission potential. Emissions in the cubicles were low compared to further emission sources in the barn (CH_4 from ruminal digestion and manure storage) or emissions (N_2O) generated during and after the spreading of slurry on the field. The measured emissions of the applied bedding materials are even negligibly low if the applied organic materials are scattered throughout the entire cubicles in the barn.

Keywords
Bedding material, nitrous oxide, methane, emission, lying behaviour

Dairy cows spend 10.8 to 13 hours each day in cubicles because essential activities such as rumination take place almost exclusively in a lying position (Willen 2004, Wierenga and Hopster 1990, Pelzer et al. 2012). Thus, deficits in the configuration of the cubicles can cause performance depression in dairy cows (Haidn et al. 2005). Choosing the right litter for a certain system is not easy, given the existing range of organic materials. The litter serves to form a stable and flexible surface which provides the best possible comfort for the animals (Pelzer et al. 2012). At the same time, the litter should offer a positive cost-benefit ratio because the cubicle area is one of the largest besides the walking and feeding area. From an ecological perspective, it must be taken into consideration that 7.3% of German agricultural emissions of greenhouse gases in 2014 were from the production of animal products and especially from cattle farming (UBA 2017). A quantification of greenhouse gases in modern open coverage type of dairy cow housing systems with cross-ventilation represents a bigger challenge than in dairy cow housing systems with forced ventilation (Amon et al. 2001). It is not possible to purify the exhaust air as it is in barns with forced-ventilation. Thus, an objective of this study was to investigate cubicles and litter material as possible source of different greenhouse gases in the barn area.

Very low climate-relevant concentrations of nitrous oxide (N_2O) were already measured in a barn (Schmithausen et al. 2016). The extent to which especially organic bedding materials in the animals' lying area emit climate-relevant greenhouse gases as N_2O, was not sufficiently investigated (Place et al. 2011). Thus, particularly the points of origin or sources of N_2O are of scientific interest.

It can be deduced that potential for the formation of N_2O emissions from the litter in the lying areas is higher through the combination of organic material and nitrogenous excretions as well as

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alternating dry and damp phases with aerobic and anaerobic conditions and temporary increases in temperatures.

This study is intended to show the advantages and disadvantages connected with the application of a special organic bedding material in deep litter cubicles in conventional dairy farming. For this purpose, the most commonly used bedding materials straw and sawdust (Jeppsson 1998, Robin et al. 1999, Nicks et al. 2004), miscanthus and separated fermentation substrate were considered in regard to ecological and economic aspects.

Material and Method

Experimental barn and experimental animals

The experiments were carried out in a naturally ventilated barn at the Experimental and Educational Centre for Agriculture Haus Riswick of the Chamber of Agriculture of North Rhine-Westphalia in Kleve, Germany. The free stall barn at the experimental farm is equipped with an eave-ridge ventilation system and additional ventilators that can be used in the summer months. The barn area which is relevant for the experimental period is equipped with 72 enlarged deep litter cubicles (15 cm upstand, approx. 2.75 m^{-2} $animal^{-1}$). Usually, when not in use for experiments, these cubicles are scattered with straw meal, as is customary practice. The passages are equipped with slatted floors and cleaned thirteen times daily by a slurry robot (JT200, company JOZ BV, KK Westwoud, Netherlands). During the experiment, 90 Holstein cows were in the barn. Further cubicles of the same construction type in an outbuilding were available to the cows at all times. Hence, there was an animal-cubicle ratio of 1:2.

Bedding materials

Six different bedding materials were compared over a period of 4 weeks (22.04.2016 to 21.05.2016). The following organic materials were scattered in 20 cubicles: separated fermentation substrate (A), straw meal (B), chopped miscanthus (8 mm chopped length) (C), miscanthus meal (D), sawdust (E), and lime-straw mixture (ratio 5:1, long straw, lime product: DESICAL® spezial, main ingredient: $CaMgO_2$) (F). A mixing of the materials among the experimental cubicles was precluded (Figure 1). All of the remaining cubicles in the barn were scattered with straw meal, in accordance with common practice (reference) and were not considered further in the course of the experiment. The position of the sampled cubicles in the barn was selected so as to minimise the influence of movements in the feeding corridor and a possible affect of weather conditions on the eave side of the barn (Figure 1). Before the experiment was started, the animals had an acclimatisation period of 14 days with the new bedding materials.

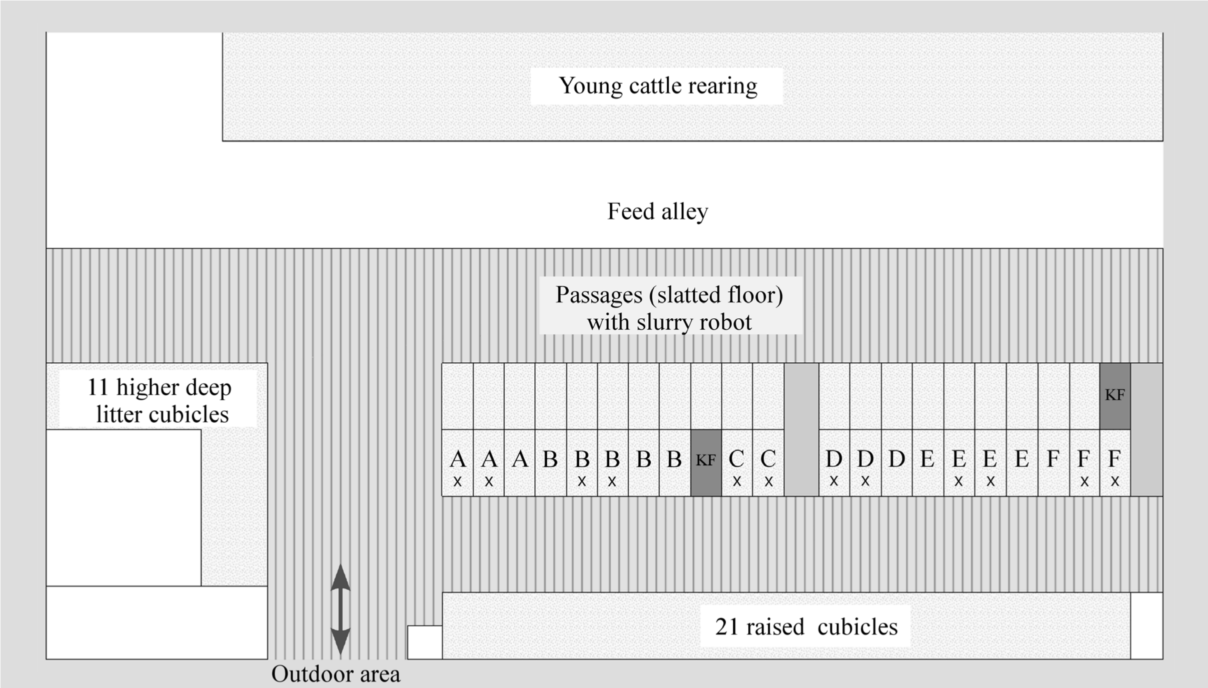


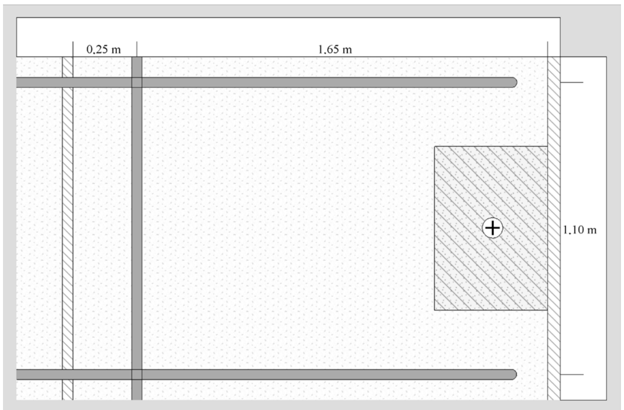
Figure 1: Sketch of experimental barn and the tested cubicles (A-F: cubicles with different organic bedding materials, x: positioning of chamber for gas measurement, KF: concentrate feeder).

Material consumption and animal behaviour

The cubicles were attended to be cleaned in the morning and evening before each milking session. According to good agricultural practice, the relevant materials were added regularly if necessary, as was also the case in the other barn areas. In the experimental period, a specific amount of each material was added to the cubicles every third day. The exact amounts scattered were recorded and compared arithmetically with current commodity prices. Due to seasonal effects, the total annual material requirements cannot be calculated on the basis of the data for the experimental period. The acceptance by the animals was recorded twice a day by counting the individual animals lying on each material three hours after milking sessions by direct observations (number of lying animals). An observed occupancy was defined as one “lying” animal in one cubicle. “Standing” animals in a cubicle were not taken into account. Altogether, 16 observations were carried out in parallel to the time when the gas samples were taken and another 2 observations 2 weeks after the experiment. The relative proportions of lying animals in the cubicles with the specific bedding materials were selected for analysis.

Methodology for the measurement of climate-relevant gases

The measurement of climate-relevant gases was conducted using the Closed Chamber Method by Hutchinson and Mosier (1981).Over a period of four consecutive days of measurement, two chambers were set up in each bedding material. The measurement times were at 6:00 am and at 5:00 pm. The chambers were positioned in the middle of the rear third of the cubicle (Figure 2). This position represents the potentially soiled area of a cubicle and is equivalent to practical conditions. Over a period of 30 minutes 4 samples were taken (at 0, 10, 20 and 30 minutes after placing the chamber on the soiled area) on the capture hood through a rubber septa of the evacuated Headspace Vials (20 ml) used. Through the increase in their concentration over the measurement period, the carbon dioxide (CO_2), methane (CH_4) und nitrous oxide (N_2O) gases can be calculated as the emission rate. Altogether n = 64 gas samples of each material were analysed. The analysis of the gas concentrations was carried out with a gas chromatograph in a laboratory. The experimental set-up for this measurement methodology was selected and carried out referring to De Klein and Harvey (2012).



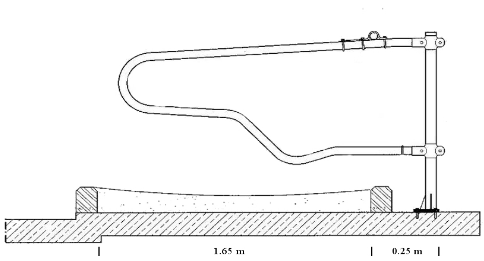


Figure 2: Schematic drawing of the chambers position in the cubicle (left); Lateral view of the cubicle (right, adapted from Sulzberger OHG)

Results and Discussion

Acceptance of the Bedding Materials by the Animals

Figure 3 shows the relative frequencies of lying cows in the respective cubicles scattered with different materials. If straw meal is selected as a reference, the animals tended to accept sawdust, lime-straw mixture and miscanthus meal in a slightly higher frequency.

Chopped miscanthus was seldomly favoured, which can possibly be ascribed to the coarser structure and hence the reduced lying comfort. Furthermore, an increased number of animals was observed standing in the cubicle and eating chopped miscanthus. Cubicles scattered with separated fermentation substrate were hardly occupied by the animals (Figure 3). The question as to whether the animals avoided the separated fermentation substrate because of the variety of materials selected and the subjective, distinctly perceptible odour development also remains to be answered. According to Hörning (2003), additional parameters such as the number of animals standing in the cubicles or the lying positions of those animals lying down should also be included.

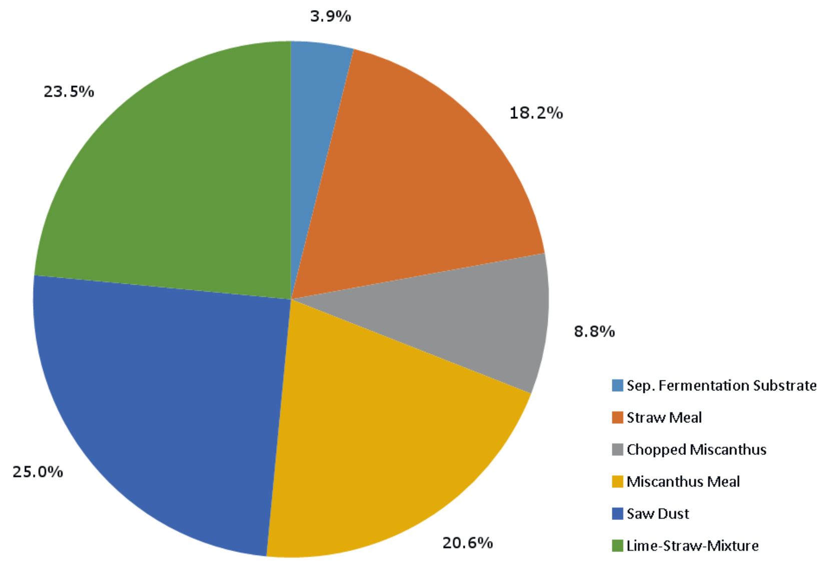


Figure 3: Presentation of relative occupancy frequency of cubicles with different bedding materials.

Effort and Expense

Table 1 displays the consumption of the bedding materials over the experimental period (28 days) and costs in € kg^{-1}. The amounts of organic materials used for the initial preparation of the cubicles amounted to approx. 210 litres per cubicle (bedding height approx. 10 cm). The listed supplementary amounts reflect the need-based expenditure over the experimental period.

Table 1: Costs and amount of bedding material for the first setup and daily amount

Material	Separated fermentation Substrate	Straw Meal	Chopped Miscanthus	Miscanthus Meal	Sawdust	Lime-Straw Mixture
Costs[1)] in € kg^{-1}	0.01	0.26	0.15	0.16	0.32	0.11
Amount for first setup in kg $cubicle^{-1}$	67	ca. 30	113	68	32	195
Additive amount in kg $cubicle^{-1}$ d^{-1}	4.8	1.6	2.1	3.2	1.3	6.5

[1)] Regional actual values, 04/2016.

When considering the material effort and the consequent expense, it becomes apparent that separated fermentation substrate shows lower commodity prices with an increased material effort compared to the other bedding materials. Both separated fermentation substrate and lime-straw mixture require an additional amount of work; hence, they need to be compressed for the initial preparation of a bedding surface. Furthermore, the application of separated fermentation substrate involves an additional technical effort in the form of a separator. This is, however, not considered in this calculation because investments in this type of technology are commonly made in collaboration with or by agricultural contractors. Thus, the material costs mainly consist of acquisition costs and the degree of utilisation of the separating system. Zähner et al. (2009) point out that the cost of this technology represents a high proportion of the total cost of this material. The other materials are scattered into the cubicle as loose material, and are therefore less work intensive and no further production costs were incurred.

The daily expenditure of materials for separated fermentation substrate was determined with 4.8 kg cubicle^{-1} d^{-1}. Even Hohenbrink (2011) found similar application rates with 5 kg cubicle^{-1} d^{-1}. However, Pelzer et al. (2012) found a significantly lower expenditure of material with 2.3 kg cubicle^{-1} d^{-1}. Heidenreich (2010) and Pelzer et al. (2012) determined a daily application rate of 1.1 to 1.4 kg cubicle^{-1} d^{-1}. In this experiment lime-straw mixture 6.5 kg cubicle^{-1} d^{-1} were added on average (Table 1). It was observed that the animals particularly scraped lime-straw mixture out of the cubicle, what could explain why this result differs considerably from the results of the experiments of Pelzer et al. (2012) and Heidenreich (2010). On closer consideration it was ascertained that, among other things due to the watering of lime-straw mixture for the initial setup, bedding material increasingly clung to the claws and was dragged onto the slatted floor. Kanswohl et al. (2006) observed a similar behaviour and concluded a considerable increase of material consumption. In this experiment, the lime-straw mixture that was scraped out caused additional effort as problems with the slurry robot made it necessary to solve the problem manually, which involved cleaning the slatted floor and repairing the technical equipment. Unlike finely structured bedding materials, lime-straw mixture could not fall through the slatted floor and clogged the slats. This situation was exacerbated by an exothermic climate (ø 19.8 °C) during the experimental period: the bedding material dragged out quickly formed a crust in conjunction with excrements on the slatted floor. As a result, the cleaning performance of the slurry robot deteriorated as soiling increased. Hohenbrink (2011) also reports dragged out bedding material (sawdust). However, in this experiment no increased dragging out of sawdust from the cubicle was detected.

Bedding materials that are filled into the cubicle as loose bulk material (straw meal, miscanthus meal, sawdust) entailed less work when the lying surface is initially installed than bedding materials that form a firm mattress (separated fermentation substrate, lime-straw mixture). The amount of time needed for daily cubicle care and the consumption of materials were lower for loose bulk material compared to bedding materials that form a mattress (Table 1), whereas the amounts for an initial installation varied for all materials.

Climate relevance

Table 2 displays the recorded emissions of CO_2, CH_4 and N_2O per square metre and hour over the experimental period. The different CO_2-equivalents (CO_2e) for these three greenhouse gases according to IPCC (2007) were taken into consideration (CO_2: 1 CO_2e; CH_4: 25 CO_2e; N_2O: 298 CO_2e).

Table 2: Average of emissions of greenhouse gases CH_4, CO_2 und N_2O emitted by the bedding materials of the experiment over the whole measurement period of four days in mg m^{-2} h^{-1}

		Separated Fermentation Substrate	Straw Meal	Chopped Miscanthus	Miscanthus Meal	Sawdust	Lime-Straw-Mixture
CO_2	Ø	410.40	1609.87	449.56	1877.48	1499.10	1745.02
	min.	-279.19	765.53	0.00	709.62	468.26	619.64
	max.	784.37	3027.97	1002.71	5307.80	2.903.93	2730.98
	σ	340.72	882.88	307.71	1306.09	853.72	958.44
CH_4	Ø	-0.18	0.38	0.01	0.02	0.35	0.12
	CO_2e	-4.50	9.50	0.15	0.50	8.75	3.00
	min.	-0.43	0.00	-0.25	-0.87	-0.09	-0.40
	max.	0.00	1.41	0.11	1.69	1.32	0.36
	Σ	0.19	0.59	0.12	0.45	0.45	0.33
N_2O	Ø	1.25	0.05	0.16	0.26	0.27	0.02
	CO_2e.	372.50	14.90	47.68	77.48	80.46	5.96
	min.	0.41	0.00	0.00	0.04	0.00	0.00
	max.	3.92	0.09	0.54	0.60	0.72	0.08
	σ	1.22	0.04	0.21	0.18	0.25	0.04

Ø: arithmetic mean.
Min.: lowest measured value.
Max.: highest measured value.
σ: standard deviation.

The emissions of CO_2 from the ruminants' surroundings are classified as climate neutral (Philippe and Nicks 2015) because the bedding materials are all plant-based raw materials, which sequestered carbon dioxide from atmosphere during growth. Low emissions of CO_2 for separated fermentation substrate could be traced back to the fact that in the separated fermentation substrate a large part of the easily biodegradable carbohydrates was already degraded in the production of biogas. Furthermore, the warmth of the lying animals could have supported the microbial degradation of the bedding materials. Thus, the low occupancy of cubicles with separated fermentation substrate could be another factor for low CO_2 emissions.

Additionally, pollution from the animals' excrements represent another source of CO_2. A higher occupancy is linked with subjectively determined higher levels of pollution, which could explain higher CO_2 emissions. For subsequent experiments, targeted bonitation for all cubicles would be interesting.

CH_4 emissions are very low in all bedding materials (Table 2). The highest CH_4 emissions originate from straw meal and sawdust. In a projection of the total bedding area in the barn, these bedding materials emit less than 0.03 g CH_4 d^{-1} $cubicle^{-1}$. In this context, it should be noted that the distribution of bedding material and the CH_4 emissions in a cubicle can be very heterogenic. In comparison to this, Grainger et al. (2007) report direct CH_4 emissions from a dairy cow (depending on feed and milk yield) in the amount of 322 g d^{-1} to 331 g d^{-1}. Jeppsson (2000) proved increased emissions in slurry in combination with sawdust as an organic bedding material in the barn. Thus, those results support the assumption that CH_4 emissions in cubicles do not originate from the organic bedding material itself, but mainly from the combination of bedding material and animal excrements. Philippe and Nicks (2015) describe lower CH_4 emissions from sawdust in comparison to those of straw meal, whereas sawdust shows increased N_2O emissions ($p < 0.05$). These statements were confirmed in the present experiment. The statement could not be confirmed for lime-straw mixture, which could be attributable to the addition of lime and a resulting alkaline environment (DLG-Prüfbericht 5814F, 2008). However, according to Philippe et al. (2010), pure straw increases emissions during the storage period of solid manure.

Our experiment showed that emission intensity varies at different measurement points in the same bedding material. This could be due to varying degrees of soiling. Hence, more heavily soiled areas tended to show higher emissions in this experiment. Determining the exact impact of soiling requires further experiments. These emissions of CH_4 und N_2O originate from processes such as methanogenesis, nitrification and denitrification, which are intensified in the polluted areas. Improved management with more frequent maintenance of the cubicles and higher amounts of bedding material could reduce emissions. Philippe et al. (2014) could not determine any effects on emissions by increasing the weekly amounts of bedding material from 50 to 100 kg. The question as to whether an increased amount of bedding material in the cubicles can reduce emissions requires further research projects.

The measured emissions of N_2O, with the exception of those from separated fermentation substrate, were very low in this experiment (Table 2). The N_2O emissions from separated fermentation substrate are comparatively higher than, for example, CH_4 emissions from the other bedding materials. Figure 4 illustrates the spread of N_2O emissions within the measurements of the individual bedding materials. Separated fermentation substrate shows significantly increased N_2O emissions compared to the remaining materials ($p < 0.05$). One possible cause for the increased N_2O emissions from this material could be the change between aerobic an anaerobic conditions within the compressed bedding material. In such conditions microbial processes of nitrification and denitrification increase the release of N_2O (Veeken et al. 2002). On comparison of the N_2O emissions from separated fermentation substrate with those of slurry application on the fields, the low relevance becomes apparent. A dairy cow (10,000 kg ECM) excretes an annual amount of approx. 143 kg nitrogen (Hiller et al. 2014). After the application of slurry, about 2% of the excreted nitrogen escapes in the form of N_2O emissions, i. e. approx. 2.9 kg a^{-1} (De Klein et al. 2006). A potential animal-cubicle ratio of 1:1 and N_2O emissions of 1.25 mg N_2O m^{-2} h^{-1} would only result in emissions of about 30 g N_2O $animal^{-1}$ a^{-1} directly from the cubicles. This analogy assumes that the application of slurry as well as the experimental period do not take place in winter months. For a detailed calculation of yearly emissions, further measurements are necessary.

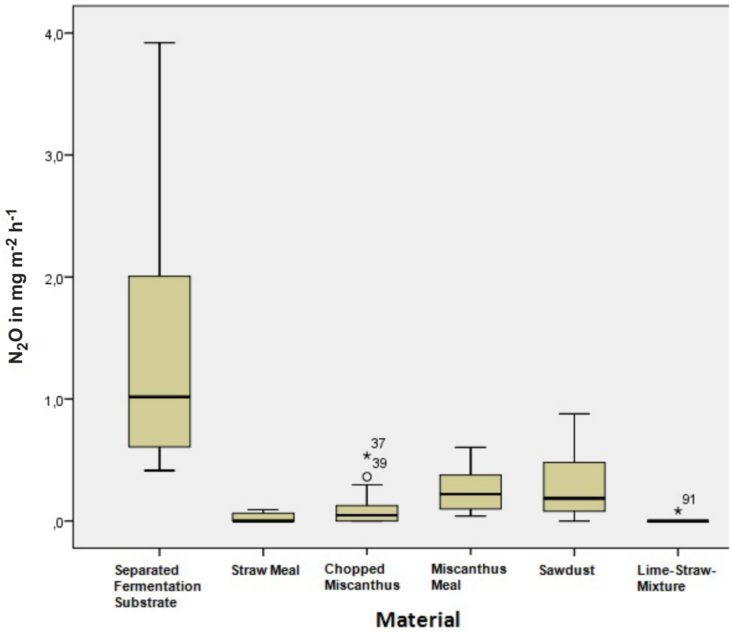


Figure 4: N_2O emissions in mg m^{-2} h^{-1} from different scattered cubicles (* ≙ extreme value; ° ≙ statistical outliers > 1.5 boxlength, bar inside boxplot ≙ average)

The climatic conditions throughout the entire test period were mild and dry (during the emission measurements in the barn: Ø 20 °C und 55% relative humidity). Further experiments should examine the effects of different climatic conditions on emissions with a stronger focus on to ensure a comprehensive and correct recording of the emissions. Referring to Sommer, (2001) and Hansen et al. (2006), mutual temperature influences can influence CH_4- and N_2O-emissions. However, lower emissions are expected in the cold season (Pereira et al. 2012).

Conclusions

In this experiment, it was established that not all of the tested bedding materials can be recommended for practical use, both with regard to the animals' acceptance as well as the economic and climate-relevant characteristics.

The acceptance of the various bedding materials was on a very similar level for most materials, but it became apparent that cubicles filled with separated fermentation substrate were occupied least often and the acceptance was much lower than for the remaining bedding materials. Whether this is associated with the odour-specific characteristics of the material must be examined more closely in further experiments. Direct observations of the animals and subjective odour perception provide first signs. In general, further experiments should include additional supportive parameters for the assessment of the animals' comfort, for example the lying position or the number of animals standing in the cubicles, lying time, further behaviours within the cubicle (e. g. feed intake, scraping etc.), soiling and injuries to feet and legs.

Effort and expense differ considerably for the various bedding materials. Bedding materials that needed to be compressed for the initial installation (lime-straw mixture and separated fermentation substrate) tend to require an increased technical effort and are more labour-intensive.

Regarding the emissions of greenhouse gases, slightly increased outgassing of CH_4 were determined for straw meal and sawdust as compared to the remaining bedding materials.

The analysis of greenhouse gas emissions from organic bedding materials showed that none of the bedding materials emit climate-relevant concentrations. Compared to the passages in a free stall barn, the cubicles scattered with organic material showed a theoretically higher emission potential (comparison with preliminary investigations). Emissions were probably significantly increased through soiling of the lying area with excrements. Thus, regular cubicle cleaning could be decisive for reducing emissions in the lying area.

In a comparative assessment, no organic bedding material achieved the best economic and ecological results in all trial areas in comparison to the reference material straw meal. Separated fermentation substrate proved to be unfavourable due to its lower acceptance by the animals and an increased effort for the initial installation of lying area in cubicles. The individual availability of the raw materials and the possibility of using them in the combination with the existing manure removal system need to be taken into account when deciding on a certain bedding material.

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