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Solid floors with grooves and with a slope: investigations of exercise areas' soiling and residual soiling mass on dairy farms

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Experiences of solid floors with grooves and with slope and their soiling was surveyed on 22 dairy farms. Slip resistance, dry floor surfaces, ammonia reduction and participation in subsidy programmes were cited as reasons for the choice of flooring. Wet faeces/urine mixture accounted for the largest percentage of exercise areas' soiling, affecting 70% of the grooved floors and 61% of floors with slope. The percentage of urine soiling – also relevant for ammonia formation – was significantly higher for grooved flooring (2.0%) than for sloped floors (0.2%). Soiling height was negatively correlated with dung-removal frequency. Investigations of residual soiling mass as an indicator of cleaning quality in farms with grooved floors revealed differences between as well as within grooved-floor types. The results of the survey as well as the floor-surface and residual soiling mass show a need to optimise the adjustment of the scraping tools to the floor surfaces and to increase dung-removal frequency.

Keywords
Floor surfaces, dairy cattle, residual soiling, process engineering, housing construction

In recent years, solid floors with a slope, combined with a urine-collection gutter in the middle (Zähner et al. 2017) or solid floors with longitudinal grooves have increasingly been installed in dairy housing. The purpose of these types of flooring is to divert urine away from the surface, collecting it in the urine-collection gutter or grooves, resulting in dry hooves and reduced ammonia (NH_3) emissions. In investigations at the pilot-plant scale, in model calculations and on commercial farms, Keck (1997), Monteny (2000) and Snoek et al. (2014, 2017), among others, showed that the amount of urine or the size of the urine puddles were relevant influencing factors on the formation and release of NH_3. Thus, in order to reduce NH_3 emissions from housing, the formation of urine puddles should be prevented. With emission measurements at practical scale in The Netherlands and Switzerland, solid flooring with a 3% transverse slope and a varying number or position of urine-collection gutter(s) showed a 20 to 50% NH_3 reduction compared to the respective reference variants of solid flooring without a slope and perforated flooring (Braam et al. 1997a; Braam et al. 1997b; Swierstra and Braam 1995; Zähner et al. 2017). A further approach is so-called grooved flooring in various designs. The underlying NH_3 reduction principle involves the reduction of the emission-active surface compared to solid-concrete floor surfaces without grooves or slope. This is meant to be achieved by the draining of the urine into the longitudinal grooves where it then collects and in some versions is also channelled away through holes in the grooves into the underlying slurry channel or flat channel (Swierstra et al. 2001). Dung is removed from the longitudinal grooves with a comb scraper, which hence also clears the grooves. Emission measurements in force-ventilated animal-housing compartments showed a 46% reduction

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in NH_3 in the case of one grooved-flooring type with urine-drainage holes and a 35% NH_3 reduction in a grooved-flooring variant without urine-drainage holes compared to the reference compartment with slatted flooring (Swierstra et al. 2001). A fairly recent grooved-flooring type consisting of rubber mat without urine-drainage holes was also investigated in force-ventilated compartments in experimental livestock housing in The Netherlands. NH_3 emissions in the housing compartment with grooved flooring were around 35% lower than in the reference section with slatted flooring. True, the grooved floor was cleaned every two hours with a comb scraper, whilst dung removal did not occur on the reference slatted floor (Winkel et al. 2019). Since 2023, grooved floors no longer qualify as an NH_3 reduction measure in The Netherlands. The reason for this is that NH_3 emissions on commercial farms were significantly higher than those on experimental farms, resulting in great uncertainty surrounding NH_3 reduction potential (Expertiseteam Stikstof en Natura 2000 van BIJ12, 2024). Emission measurements from different rubber grooved-flooring types on three dairy farms in Germany employing a before-and-after approach also failed to show any clear NH_3 reduction (Janke 2023).

Furthermore, different flooring variants with grooves are installed in dairy housing or on the market, some of which are advertised as NH_3 reduction measures. Process-engineering aspects, particularly as regards dung removal, urine on the floor surface or residual soiling mass as an indicator of cleaning quality, as well as farm managers' experiences, were heretofore not systematically recorded in practice.

The aims of this study were:

- to conduct a practical survey of process-engineering aspects and farm managers' experiences with grooved floors and, for purposes of comparison, with solid floors with a slope;
- to assess the exercise areas' soiling of grooved floors and of sloped floors on commercial farms according to type, percentage and height;
- to quantify the residual soiling mass as an indicator of the cleaning quality of selected types of grooved flooring.

Materials and Methods

Data were collected on the experiences of farm managers as well as on process-engineering aspects of grooved floors and sloped floors during visits to 22 dairy farms in southern Germany (14) and Switzerland (8). Exercise areas' soiling according to type, percentage and height was also assessed on these farms. In addition, the residual soiling mass on ten of the farms with grooved floors was investigated as an indicator of cleaning quality.

Farms visits with structured interview

Potential farms for farm visits with a structured interview were selected from reference addresses of companies manufacturing animal-housing fittings as well as from the European Innovation Partnership project (EIP-Rind e.V. 2025) website. Farm managers were usually interviewed in the housing itself by means of a questionnaire, which essentially encompassed the topics of (i) general information on the farm, (ii) flooring designs and reasons for their choice, and (iii) dung-removal aspects. In addition, photo documentation was carried out during the tour of the housing.

Assessment of exercise areas' soiling

Exercise areas' soiling was assessed on all farms participating in the survey immediately before dung removal using an established scoring scheme based on Schrade et al. (2010), Poteko et al. (2015) and Leinweber et al. (2019). The scaring was conducted by the same person on all farms. For this, the flooring was subdivided into a raster with fields of roughly the same size. The type of soiling and its relative percentage per raster field was visually assessed and documented in 10% increments. Soiling type was summarised in the following categories: "urine", "faeces/urine mixture, wet", "faeces, wet", "faeces, dry", "bedding/feed residuals", and "clean". A folding rule was used to determine soiling height in mm at a predefined point in each raster field.

Quantification of residual soiling mass

Residual soiling mass is defined as the degree of soiling remaining on the floor surface after the removal of dung from. It is thus an indicator of cleaning quality, or of the adaptation of the manure scraper to the floor surface (Poteko et al. 2018). Residual soiling mass was quantified on ten farms with the grooved-floor types:

- „Magellan® 25“ (Bioret agri, Nort-sur-Erdre, France; 4 farms)
- „Magellan® 16“ (Bioret agri, Nort-sur-Erdre, France; 1 farm)
- „profiDRAIN“ (Gummiwerk KRAIBURG Elastik GmbH & Co. KG, Tittmoning, Germany; 3 farms)
- „SG6“ (Grüter Handels AG, Buttisholz, Switzerland; 2 farms)

For this, the method developed by Poteko et al. (2018), which had been technically optimised with a view to easier handling on commercial farms, was used. Immediately after the dung-removal process, a 0.25 cm^2 experimental area was sealed off with a frame. With the SG6, the transverse slits to the slurry channel were also fitted with a sealing rubber. The residual soiling mass within the frame was diluted with a defined amount of water (250 ml). Then cleaned and vacuumed within a defined period of time (2 min 30 s) with a wet vacuum cleaner and hand brush, after which the frame was shifted and the process repeated. After four partial areas were vacuumed, the mass of the summed experimental area of 1 m^2 was weighed. The partial areas were chosen as visually representative of the residual soiling on the respective aisle. A total of six repetitions, each with a vacuumed experimental surface area of 1 m^2, took place per floor surface and farm.

Statistical analysis

The data were entered into Microsoft Excel and processed. The statistical analysis was performed, and graphs were created with Microsoft Excel and the statistics program R, version 4.4.1. Kruskal-Wallis tests were performed to compare individual soiling categories between the flooring types grooved floor and sloped floor. The correlation between soiling height and dung-removal frequency in grooved floors was investigated with a linear regression. A Kruskal-Wallis test was used to determine the residual soiling mass of the different groups of grooved-flooring types. In addition, a post-hoc test was used to make a pairwise comparison of the differences between the grooved-floor types. The significance level was established at 0.05%.

Results and Discussion

Farms, floor types and dung removal

Each of the surveyed farms kept between 30 and 250 dairy cows, and all but one were run as a primary source of income. Two farms formed part of research and teaching institutes. Table 1 presents an overview of the farms and their floor designs as well as their dung-removal systems with scraper tools and dung-removal frequency. Some of the farms had several different floor designs. Sloped solid floors (Figure 1) and grooved flooring (Figure 2) were installed on 11 and 18 farms, respectively. profiKURA 3D flooring (Gummiwerk Kraiburg Elastik GmbH & Co. KG, Tittmoning, Germany), with an integrated slope of 3% enabling its installation on flat floors, was the most common type of sloped flooring, installed on five farms. On one farm, the "V-TWIN" (Bioret agri, Nort-sur-Erdre, France) – rubber flooring with a 3% slope towards two urine-collection grooves (Figure 1a) – was installed. Seven farms had a concreted 3% slope (Figure 1b): of these, five had rubber mats, one had floor surfaces made of concrete with profiles and one farm had installed both rubber mats and concrete floors. With the grooved flooring, the Magellan 25 (Figure 2a) and the Magellan 16 were installed on seven and one farms, respectively. The Magellan 16 differs from the Magellan 25 solely in terms of the lower height of its surface and the lower depth and width of its grooves. Four farms had chosen the "RIMA2 grooved flooring (Gummiwerk Kraiburg Elastik GmbH & Co. KG, Tittmoning, Germany) (Figure 2b), whilst three had chosen the successor product profiDRAIN (Figure 2c). The grooved flooring "N26 ALLEY" (Huber Technik Vertriebs GmbH, Erding, Germany) was installed on one farm (Figure 2d). Two Swiss farms had the SG6 grooved flooring consisting of concrete elements with a grooved structure, each of which is set atop a slurry channel with a 30-mm-wide transverse slit (Figure 2e).

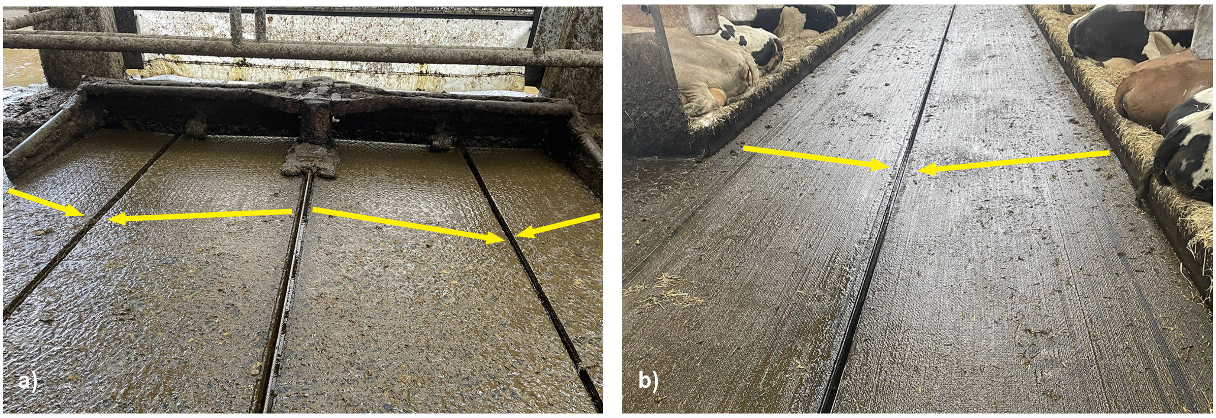

Figure 1: Sloped solid floors: a) V-Twin and b) profiKURA 3D (photos: Agroscope)

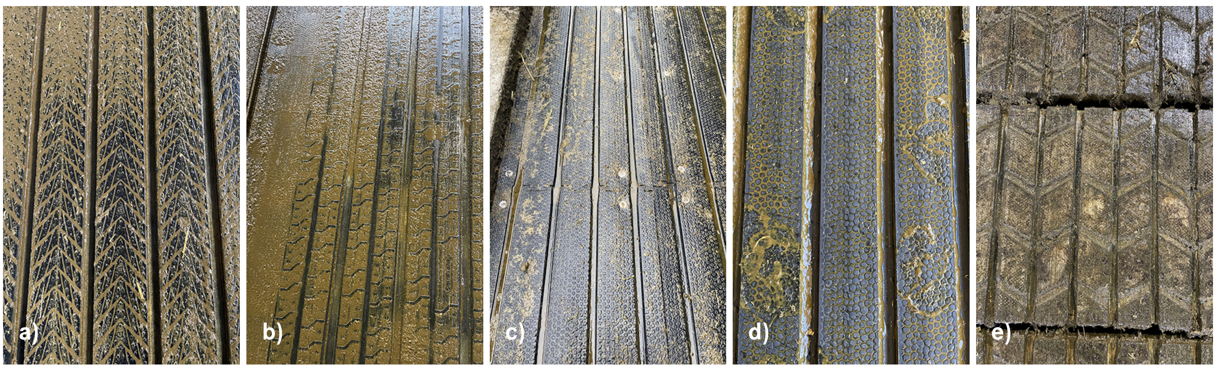

Figure 2: Grooved floors: a) Magellan 25, b) RIMA, c) profiDRAIN, d) N26 ALLEY and e) SG6 (photos: Agroscope)

Table 1: Overview of farms, floor types and dung removal (numbering corresponds to the order in which the farms were visited).

No. (Country)	Sloped floor: Floor design (position[1]); dung-removal system[2]	Grooved floor: Floor design (position[1]); dung-removal system[2] (scraping tool)	Dung-removal frequency (no. of times) per day)	New construction, conversion or renovation
1 (DE)		*Magellan 25 (2 x FA); SMS (comb scraper)	20	New construction
2 (CH)		*Magellan 25 (FA), SMS (comb scraper)	4-5	Renovation
3 (DE)		RIMA (FA, OEA); SMS (comb scraper)	12	New construction, renovation
4 (CH)		profiDRAIN (*FA, CCA); SMS (comb scraper)	3–4	Renovation
5 (DE)	V-Twin (CCA, OEA); SMS	Magellan 25 (2 x FA, CCA, OEA); SMS (comb scraper)	12	New construction
6 (DE)	profiKURA 3D (FA); SMS	Magellan 25 (FA, OEA); SMS (comb scraper)	15	New construction
7 (DE)	Concrete (FA, OEA), SMS	RIMA (FA, CCA, OEA); SMS (comb scraper)	24	New construction
8 (DE)	profiKURA P (2 x FA, OEA); SMS	RIMA (CCA); SMS (comb scraper)	12	New construction
9 (DE)	profiKURA 3D (CCA); SMS		20	Renovation
10 (DE)	Concrete (CCA, OEA), profiKURA P (FA, OEA); SMS		12	New construction
11 (DE)		profiDRAIN (*FA, OEA); SMS (comb scraper)	14	Conversion
12 (DE)		N26 ALLEY (FA, CCA, OEA); SMS (comb scraper)	24	New construction
13 (DE)	profiKURA P (FA, OEA); SMS	RIMA (CCA); SMS (comb scraper)	12	New construction
14 (DE)	profiKURA 3D (FA); SMS	Magellan 25 (FA); SMS (comb scraper)	12	Renovation
15 (CH)		*Magellan 25 (FA); SMS (comb scraper)	4–5	Renovation
16 (DE)	profiKURA 3D (FA, OEA); SMS	*profiDRAIN (CCA, OEA); SMS (comb scraper)	12	Conversion, renovation
17 (DE)		*Magellan 25 (2 x FA); SMS (comb scraper)	24	New construction
18 (CH)		SG6 (*FA); CR (brush)	6	New construction
19 (CH)	profiKURA P and KURA P (FA and CCA, respectively); SMS		10	Renovation
20 (CH)		SG6 (*FA, CCA, OEA); CR (no brush)	FA: 2, TA: 6, OEA: 1	New construction
21 (CH)	profiKURA 3D (CCA); SMS		12	Conversion
22 (CH)		Magellan 16 (*FA, CCA, OEA); CR (no brush)	12	New construction, conversion

* Floor surface on which quantification of residual soiling was carried out.

1) Position: FA = Feeding aisle; CCA = Cubicle access area; OEA = Outdoor exercise area.

2) Dung-removal system: SMS = Stationary manure scraper; SR = Scraping robot; CR = Collection robot.

The sloped solid floors were cleaned exclusively with stationary scrapers. Of the grooved floors, 15 used a stationary scraper with comb bar for dung removal, two a scraping robot and one a collecting robot. At 12 to 24 times a day, dung-removal frequency on the German farms was significantly higher than on the Swiss farms, where it was at three to twelve times per day. On floors with a 3% slope and a urine-collection gutter, an overflowing of the urine-collection gutter over time and/or during dung removal could sometimes be observed. This occurred if the urine-collection gutter was too small to completely absorb the accumulating urine. This can be countered either by adjusting the volume of the urine-collection gutter to the amount of excrements accumulating or by increasing the frequency of dung removal (Schrade et al., 2013).

Slip resistance (11), a dry floor surface (8), participation in the European Innovation Partnership project (EIP) (7) and the reduction in NH_3 emissions (7) were cited by the farm managers as the main reasons for installing the respective floor types(s). The interaction between scraping tool and floor surface is relevant in terms of the cleanliness of the floors. Of the farms with grooved flooring, eight had drawings sent from the flooring manufacturer to the scraper manufacturer, two had a consultation with no further details being provided in the interviews, and in the case of three farms the scraper or flooring manufacturer was on-site during installation. According to the farm managers, no consultations took place on three farms, and the consultations were unsuccessful on two farms. According to the farm managers' statements, in the case of sloped floors no consultations took place between the flooring and scraper manufacturers on most farms (7), two farms held consultations, and on two farms adaptations were made to the scraper.

One company selling grooved flooring advertises that the cows have cleaner hooves and legs because of reduced splashing of the faeces/urine mixture when they urinate. This does not square with the responses of the interviewed farm managers: whereas around 55% stated that soiling was less frequent than with non-sloped flooring without grooves, 45% could not confirm this. The impression that the splashing of the urine was actually intensified by the grooves was often reported.

Over 90% of respondents stated that they would choose the same floor (s) again. Of the remaining 9% of farm managers, the lack of slip resistance, the need to rectify the securing of the rubber flooring and the poorer cleaning of the outer grooves, from which the comb scraper does not remove the soiling completely, were mentioned as criticisms.

Exercise areas' soiling

The results of the scoring showed that across all farms, the wet faeces/urine mixture accounted for the largest relative percentage of exercise areas' soiling (Figure 3). Thus, the wet faeces/urine mixture averaged 70% (standard deviation SD: 9%) for grooved floors and 61% (SD: 13%) for sloped floors and was therefore significantly higher ($p<0.05$). In the "wet faeces" category, the averages for grooved and sloped floors did not differ significantly, at 15% (SD: 6%) and 17% (SD: 5%), respectively ($p = 0.15$). Averaging 18% (SD: 10%), the percentage of clean surface area of sloped flooring was significantly higher than the value of around 10% (SD: 7%) for grooved flooring ($p < 0.05$). For grooved floors, the average urine-soiling percentage of 2% (SD: 2.5%) was significantly higher than that of sloped floors, which stood at just 0.2% (SD: 0.4%) ($p > 0.05$). Hence, the average urine-soiling percentage of the grooved floors examined, although below the average for solid floors without a slope (5%), is still significantly higher than the 0.8% urine soiling of sloped floors examined over three seasons in the framework of emission measurements conducted in the experimental emissions housing in Tänikon at 12 dung-removal processes per day in each case (ZÄHNER et al. 2017). With grooved floors in the present study, urine puddles were mainly to be found where the subfloor was not concreted exactly evenly and therefore had hollows or depressions.

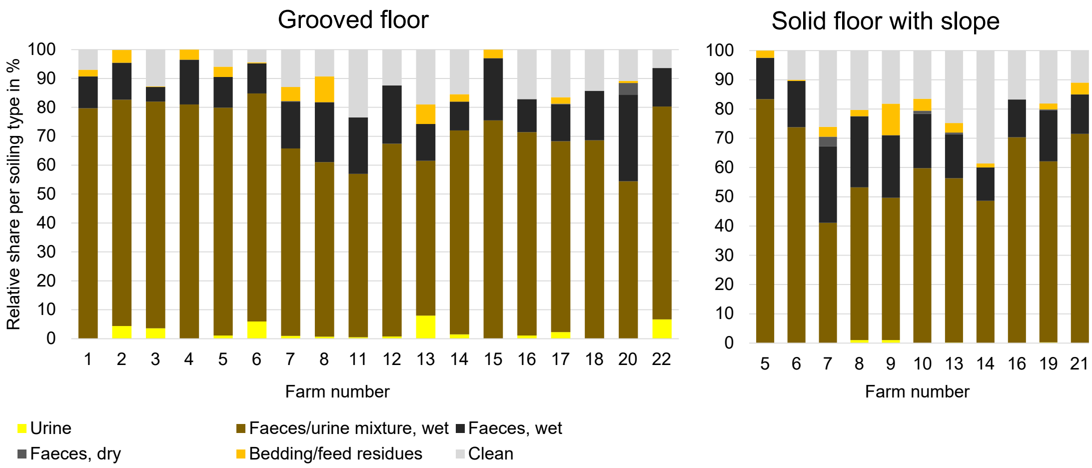

Figure 3: Relative percentage of exercise areas' soiling according to category in % of grooved floors (left) and sloped floors (right) of the participating farms

Averaging 3.8 mm (SD: 2.2 mm), the soiling height of the grooved floors (Figure 4) was slightly higher than that of the sloped floors, which stood at 2.5 mm (SD: 0.9 mm). Variation was quite high at times, both between farms and within individual farms. Soiling heights recorded using the same method averaged 1.8 and 2.8 mm for solid floors with and without a slope, respectively and with dung removal taking place 12 times daily (ZÄHNER et al. 2017), and between 1.6 and 1.9 mm for perforated floors undergoing frequent dung removal (LEINWEBER et al. 2019).

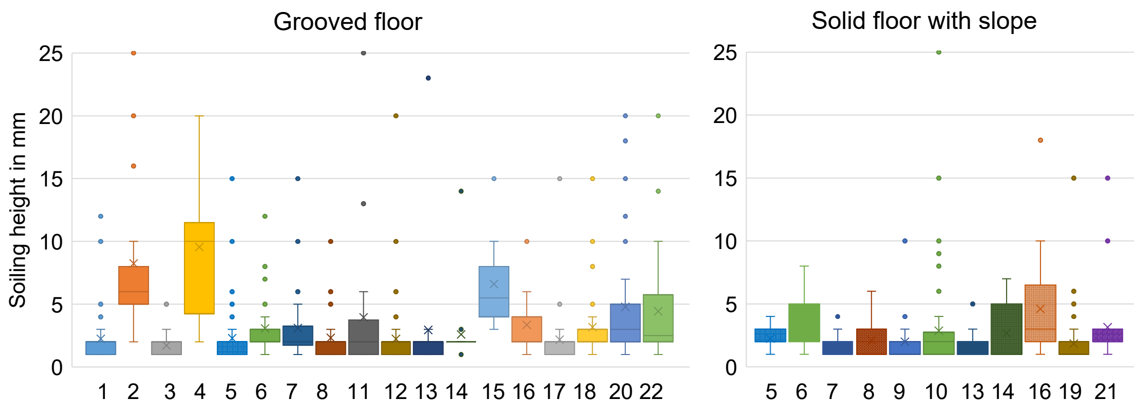

Figure 4: Soiling height in mm of grooved floors (left) and sloped floors (right) of the participating dairy farms

Figure 5 shows the clear correlation between soiling height in mm and dung-removal frequency per day for the grooved floors ($p < 0.001$). The data provide evidence that dung removal every two hours according to the recommendations of the Swiss Federal Offices for the Environment (Bundesamt für Umwelt BAFU) and Agriculture (Bundesamt für Landwirtschaft BLW) (BAFU AND BLW 2011), as opposed to fewer than six dung-removal procedures per day, significantly reduce the height, and hence also the mass, of the soiling.

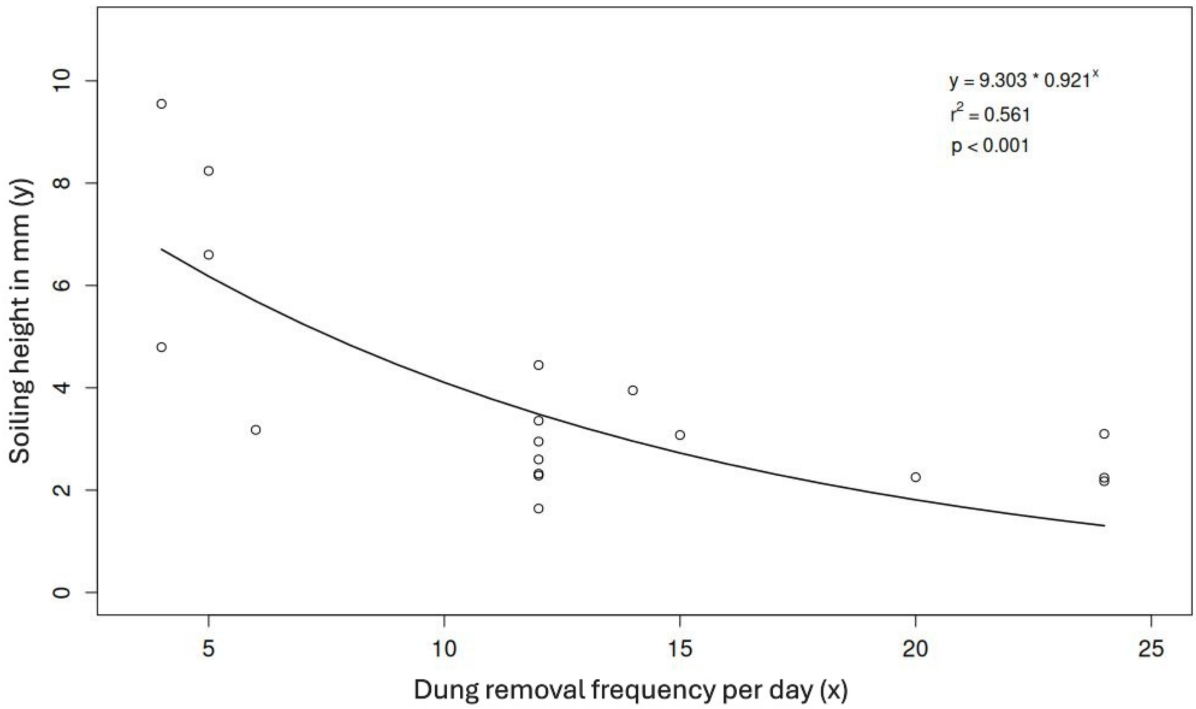

Figure 5: Correlation between soiling height in mm and dung-removal frequency per day of the grooved floors from the survey conducted on dairy farms with information on the regression equation, coefficient of determination (r^2) and p-value

Residual soiling mass

Figure 6 shows a comparison of the average residual soiling masses per grooved-floor type and farm. At 0.5 kg per m^2, the median of the profiDRAIN grooved floors had the lowest residual soiling mass, significantly differing in this factor from the Magellan 25 grooved flooring ($p < 0.001$) with its median of 1.2 kg per m^2 as well as from the SG6 grooved flooring ($p < 0.01$) with its median of 1.5 kg per m^2. There were no significant differences between the residual soiling mass of the Magellan 25 and that of the SG6 grooved flooring. The residual soiling mass of the one SG6 grooved floor was more than three times higher than that of the other. One reason for the better cleaning quality seems to be the installation of a brush on the scraping robot. This highlights the importance of adapting the scraping tool to the floor surface. The significantly higher residual soiling masses of the Magellan 25 compared to the profiDRAIN might be attributable to the more prominent profiling on the floor surface of the Magellan 25, in which more residual soiling remains after dung removal. Except for one profiDRAIN grooved floor, the residual soiling mass of all the grooved floors examined was markedly higher than that of the solid floors without (0.2 kg per m^2) and with a slope (0.3 kg per m^2) for 12-times-daily dung removal in both cases (POTEKO et al. 2018). Since residual soiling mass is an indicator of cleaning quality, most farms with grooved flooring have an even greater need for optimised adaptation of the cleaning tool to the floor surface.

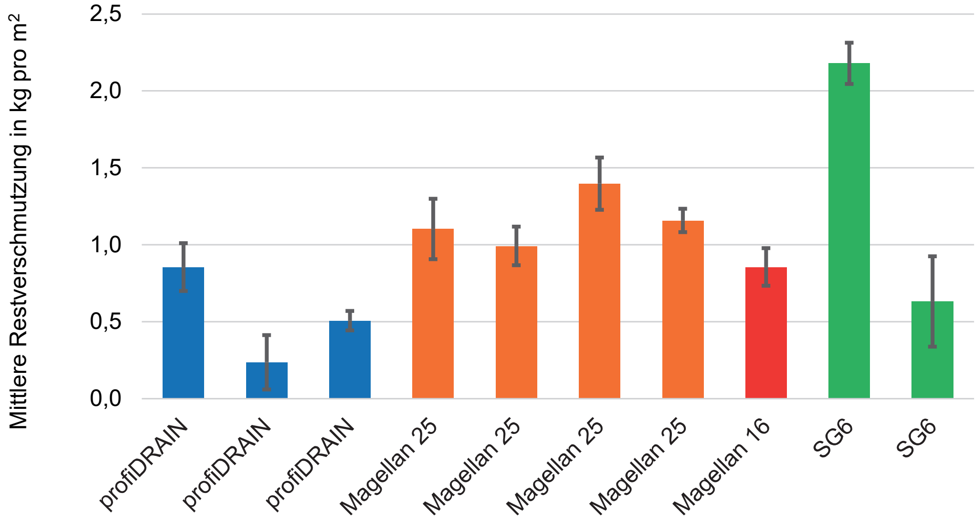

Figure 6: Residual soiling mass in kg per m^2 according to grooved-flooring type and farm (profiDRAIN: n = 3, Magellan 25: n = 4, Magellan 16: n = 1, SG6: n = 2)

Conclusions

A survey carried out on 22 dairy farms cited the improvement of slip resistance, a dry floor surface and hence dry hooves, the reduction of NH_3 emissions and participation in subsidy programmes as the main reasons for installing grooved floors and solid floors with a slope. The scoring revealed a significantly higher percentage of urine soiling on grooved floors than on solid floors with a slope. Sloped flooring enables better urine drainage from the surface. When installing grooved flooring, care must be taken to ensure the precise construction of the substructure to avoid hollows and depressions in which urine puddles can form. The results in terms of soiling height show that soiling can be significantly reduced by more frequent dung removal. A minimum dung-removal frequency of once every two hours is recommended. Residual soiling mass is an indicator of the cleaning quality of the flooring. The residual soiling mass of the grooved floors examined was usually significantly higher than the values in a study of solid floors with and without a slope (Poteko et al. 2018). Major differences between different types of grooved flooring as well as within a type of grooved flooring highlight a need for optimisation on individual farms: to improve cleaning quality, the scraping tools must be properly adjusted to the surface structure of the flooring and regularly maintained or replaced.

For future studies to assess floors, it would be desirable to include stocking density (area per animal) or the actual use by the animals of the partial area investigated, and to survey slip-resistance (slip behaviour).

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