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Development and validation of a measuring method for quantifying the residual soiling mass after the removal of dung from solid floor surfaces, and results of comparative measurements at pilot-plant scale

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Abstract

Clean, dry floor surfaces in dairy housing have a positive impact on claw health, the cleanliness of the animals and ammonia-emission reduction. Cleaning quality depends on residual soiling mass, i.e. the manure remaining on the floor after dung removal. The aim of this study was to develop and validate a method for quantifying residual soiling mass on solid floor surfaces, as well as to compare the effect thereon of different scraping tools, types of floor surface and types of manure at pilot-plant scale.

A method for quantifying residual soiling mass on solid floor surfaces was developed step-by-step at pilot-plant scale. The experimental area was defined as 1 m^2 with a frame waterproofed with a rubber seal. The residual soiling mass inside the frame was diluted with water and collected using a water vacuum cleaner, weighed, and defined as an indicator of cleaning quality.

A pilot-plant-scale experiment and an application of the method on a practical scale were conducted. In the experiment, the residual soiling mass [g m^{-2}] left by five different scraping tools (metal blade, hard rubber lip, soft rubber lip, brush, combined tool consisting of hard rubber lip & brush) was determined on two different types of floor surface (rubber mat; concrete) and for two different types of manure (dry matter (DM) content: 13% DM from feeding aisle and 14.6% DM from aisle between cubicles). The aim of the application in practice was to test the described method under genuine housing conditions while considering further investigations on a practical scale. The experiment was conducted in a feeding aisle in commercial dairy housing. The floor was equipped with rubber mats and a scraper with a hard rubber lip.

In the pilot-plant experiment, residual soiling mass on the rubber mat (min 153 g m^{-2}; max 301 g m^{-2}) was significantly lower than on the concrete floor surface (min 459 g m^{-2}; max 672 g m^{-2}). Residual soiling on both types of floor was lower when rubber or brush scraping variants were used than when a metal blade was used for scraping. Type of manure had no significant influence on residual soiling mass.

In practice, the results of each repetition were nearly identical, confirming that the method under investigation is not only suitable for pilot-plant-scale trials, but is also suitable for quantifying the residual soiling mass on solid floors on a practical scale.

Keywords: residual soiling, cleaning quality, method, solid floor surfaces, scraper

1 Introduction

Over the last 20 years, the percentage of dairy loose housing in Switzerland has risen from 3% to 44% (Federal Office for Agriculture, 2003; Kupper et al., 2013). This means that soiled surfaces (walking aisles, outdoor exercise area) have increased in size by three to four times (Eurich-Menden, Döhler & Van den Weghe, 2010; Zähner, 2005). Cows' excrement accumulates in the aisles, and is then scraped off (Oechsner, 1993). Clean, dry floor surfaces have a positive influence on claw health (Fiedler, 2012) and the cleanliness of the animals, as well as contributing to a reduction in ammonia emissions (Schrade et al., 2011).
Cleaning quality depends on the scraping efficiency of different technical systems. Residual soiling refers to the soiling remaining on the solid floor after dung removal. In previous studies, the type and proportion of soiling before scraping was estimated visually with an evaluation scheme proposed by Korth (2008) and Schrade et al. (2011). Haufe (2006, cited in Korth, 2008) attempted to determine the mass of excrement on solid surfaces with the use of a vacuum cleaner. Dung was collected from perforated floor surfaces with a scoop (Pfadler, 1981, cited in Benz, 2002). Cleanliness after scraping was determined by calculating the residual soiling from the difference between total mass on the floor surface and mass removed from the surface (Hesterberg, 2007). Meyer (1985, cited in Benz, 2002) used a filter-paper method to determine the moisture in the area in question. These methods are imperfect for determining the residual soiling mass on both a pilot-plant and a practical scale.
Dung removal with scrapers is performed with different scraping tools. In practice, such tools are often equipped with a metal blade (Schrade & Steiner, 2012). The manufacturers of scraping tools recommend various rubber lips or a brush for better cleaning quality, especially for aisles designed with rubber mats.
The present study had the following objectives:

- To develop and validate a measuring method for quantifying residual soiling mass after the removal of dung from solid floor surfaces on both a pilot-plant and practical scale;
- To compare the cleaning quality of five scraping tools on two types of floor surface containing two types of manure at pilot-plant scale;
- To test and validate the measuring method on a practical scale with a view to the future optimisation of the scraping tools.

2 Materials and methods

2.1 Developing a measuring method

A measuring method for quantifying the residual soiling mass on solid floor surfaces was developed step-by-step at pilot-plant scale. The experimental area was defined as 1 m^2 and framed with a rubber seal (Cellular rubber RG (140 kg m^{-3}) CR) which has width of 3 cm and height of 1 cm, and was fixed on a 1-metre-square (surface inside of frame) wooden frame. The frame was weighted with a force of 2.6 N cm^{-2} to ensure a waterproofed border (Figure 1). The residual soiling inside the frame was diluted with cold water (<10°C; 1 l) for complete collection using a water vacuum cleaner equipped with a crevice tool (Kärcher, WD 2.400 M). Vacuuming time was defined as 7 minutes. During the collection of residual soiling from the experimental area, the cold water and the defined vacuuming duration reduced the evaporation of water from the residual soiling and rendered it constant at outside conditions within the 19°C to 24°C range. After each collection of residual soiling, the entire water vacuum cleaner with the collected residual soiling inside was weighed. The residual soiling mass [g m^{-2}] was determined by calculating the difference between the full vacuum cleaner and the empty vacuum cleaner with the water used for dilution.
This method should be suitable for use in pilot-plant experiments (Figure 2), as well as in investigations conducted under practical conditions.

Figure 1: Scheme of the measuring method: Defined area with waterproofed frame; addition of water for dilution; vacuuming of residual soiling with water vacuum cleaner.

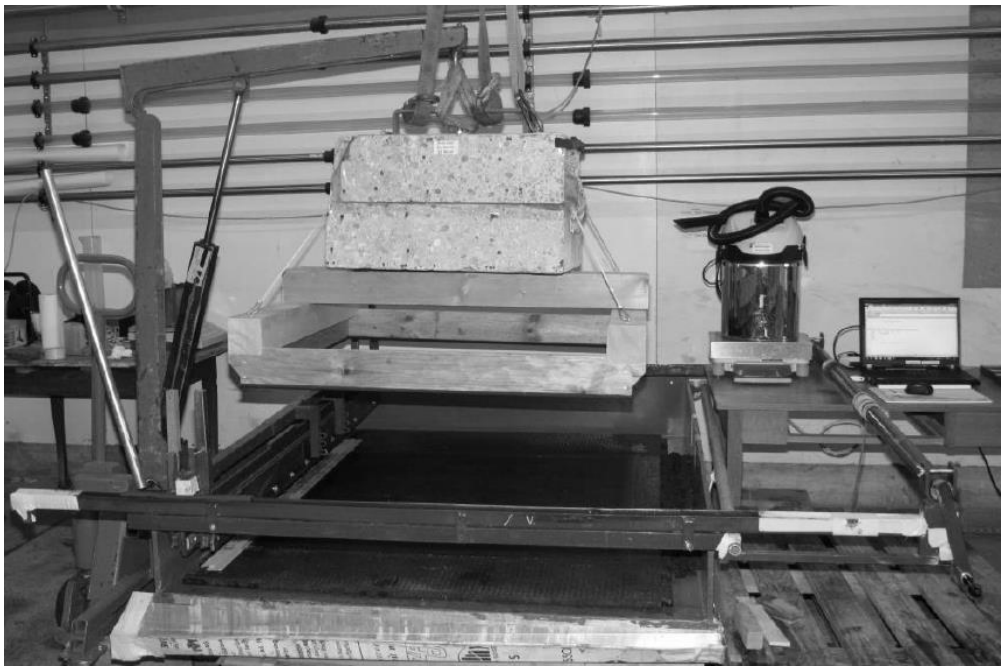

Figure 2: Pilot-plant experimental installation: Dung removal with the option of changing scraping tool and floor surface, with equipment for measuring residual soiling (frame, water vacuum cleaner, scales).

2.2 Pilot-plant experiment: comparison of two types of floor surface, five scraping tools, and two types of manure

In a pilot-plant-scale experiment, we systematically determined and compared residual soiling mass [g m^{-2}] after the use of five different scraping tools – metal blade, hard rubber lip, soft rubber lip, brush, and a combined tool consisting of hard rubber lip & brush. The mass of all five scraping tools was nearly the same (around 10 kg per metre). In addition to the scraping tools, we compared two different floor surfaces (rubber mat; concrete floor C30/37, max particle 16 mm with surface treatment and with 1.4 kg m^{-2} quartz sand (0.7-1.2 mm)) containing two different types of manure (dry matter (DM) content: 13% DM from feeding aisle and 14.6% DM from aisle between cubicles). The manure was collected in the dairy housing of the Institute for Sustainability Sciences in Tänikon, Switzerland and frozen to ensure the same characteristics in all repetitions of the experiment. 1.5 kg of manure was then distributed over the experimental area (1 m^2). Twenty different combinations of scraping tool, floor-surface type and manure type were then repeated eight times (Figure 3). Because they had served for the preparation of standard conditions, the first two repetitions of each variant were deemed irrelevant for the results.

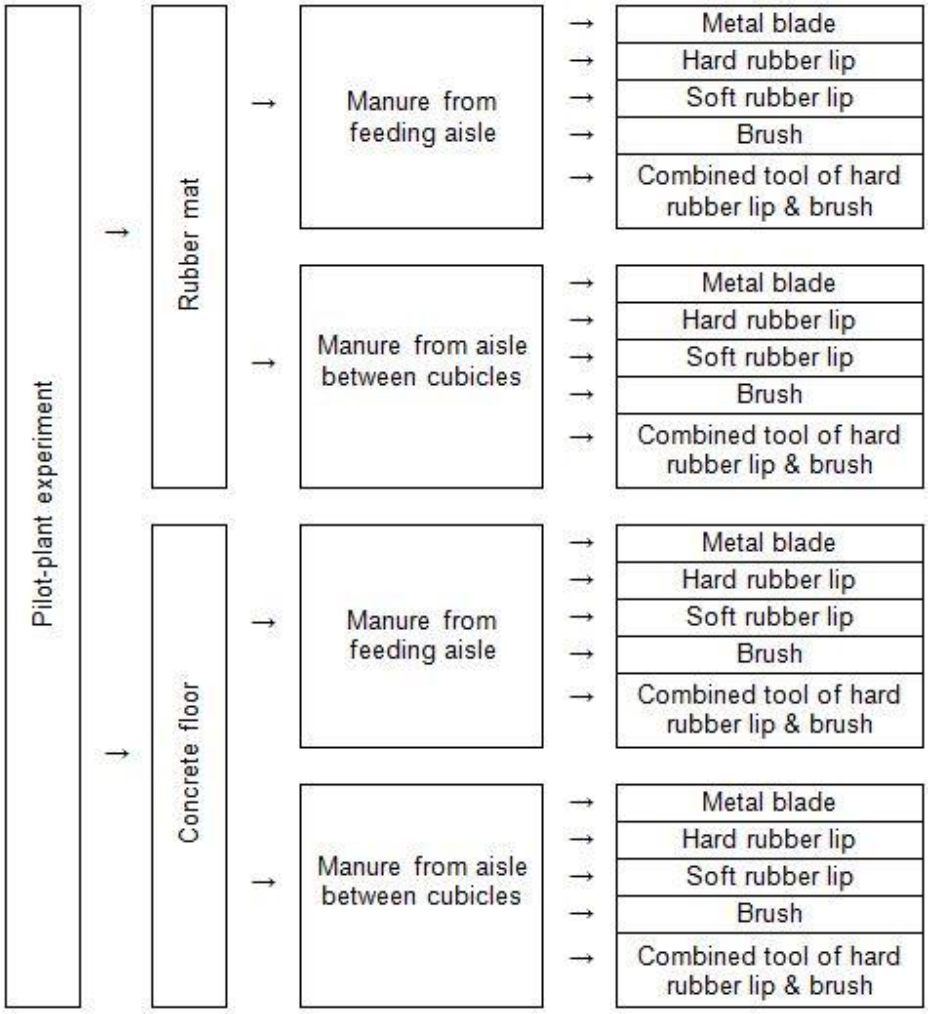

Figure 3: Overview of pilot-plant experiment variants: Two types of floor surfaces, five scraping tools, and two types of manure.

Air temperature, relative humidity, floor temperature, dilution-water temperature and dry-matter content of the manure were recorded during the experiment. The statistical analysis was conducted with the TIBCO Spotfire S+ statistics program for Windows. Variance analysis was used to investigate residual soiling mass as a function of different factors. Step by step, the following model was developed:

$$y_{ijk} = \mu + M_i + F_j + T_k + MF_{ij} + FT_{jk} + MT_{ik} + e_{ijk} \quad (1)$$

y_{ijk} – mass of residual soiling,
μ – intercept,
M_i – type of manure,
F_j – type of floor,
T_k – type of scraping tool,
MF_{ij} – interaction of type of manure and type of floor,
FT_{jk} – interaction of type of floor and type of scraping tool,
MT_{ik} – interaction of type of manure and type of scraping tool,
e_{ijk} – error.

2.3 Validating the measuring method on a practical scale

The aims of the experiment conducted on a practical scale were to validate the measuring method and to amass experience under practical conditions with a view to optimising the methodology. Based on the findings and experience gleaned from the study at pilot-plant

scale, the scraping variant with a hard rubber lip and the floor surface with rubber mats were chosen. The trial took place in commercial dairy cubicle loose housing (56 cows) with rubber mats on the feeding aisle.
The basic principle of the method (water dilution, vacuuming duration etc.) was virtually identical to that of the pilot-plant experiments. A total of seven individual measurements were taken. The frame with the weights was moved by a front loader (Figure 4). To ensure that the floor surface was completely soiled, there was no dung removal the morning before the measurements began. Cows were not in the housing while the measurements were being made.

Figure 4: Handling of frame with weights between two residual-soiling collection processes on a feeding aisle in the commercial dairy housing

Figure 5 shows the experimental area after collection of the residual soiling on the feeding aisle, with a visible difference between the clean floor surface and the floor surface covered with residual soiling.

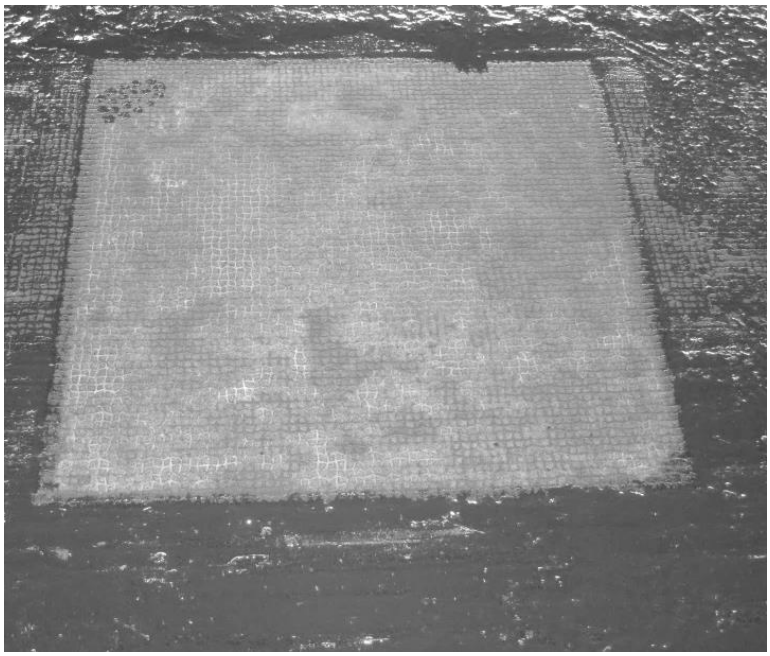

Figure 5: Rubber mat on feeding aisle after collecting residual soiling with a water vacuum cleaner and removing frame.

3 Results

3.1 Pilot-plant experiment

Figure 6 shows the results of 20 experimental variants of scraping tool, floor surface and manure, each with 6 relevant repetitions. The difference in residual soling mass between the two types of flooring is obvious. With values of between 153 and 301 g m^{-2} and 459 to 672 g m^{-2}, respectively, the residual soiling mass on the rubber mat was significantly lower than that on the concrete floor. The effect of the scraping tool on the residual soiling mass was statistically significant. The highest soiling mass remained after scraping with a metal blade on the rubber mat (min 244 g m^{-2}; max 301 g m^{-2}) and on the concrete floor (min 613 g m^{-2}; max 672 g m^{-2}). The most efficient scraping tools were rubber lips and brush on both types of floor. Although residual soiling mass was not influenced significantly by type of manure, the interactions between the three variables 'type of floor', 'type of scraping tool' and 'type of manure' did exert a significant impact on this target variable.

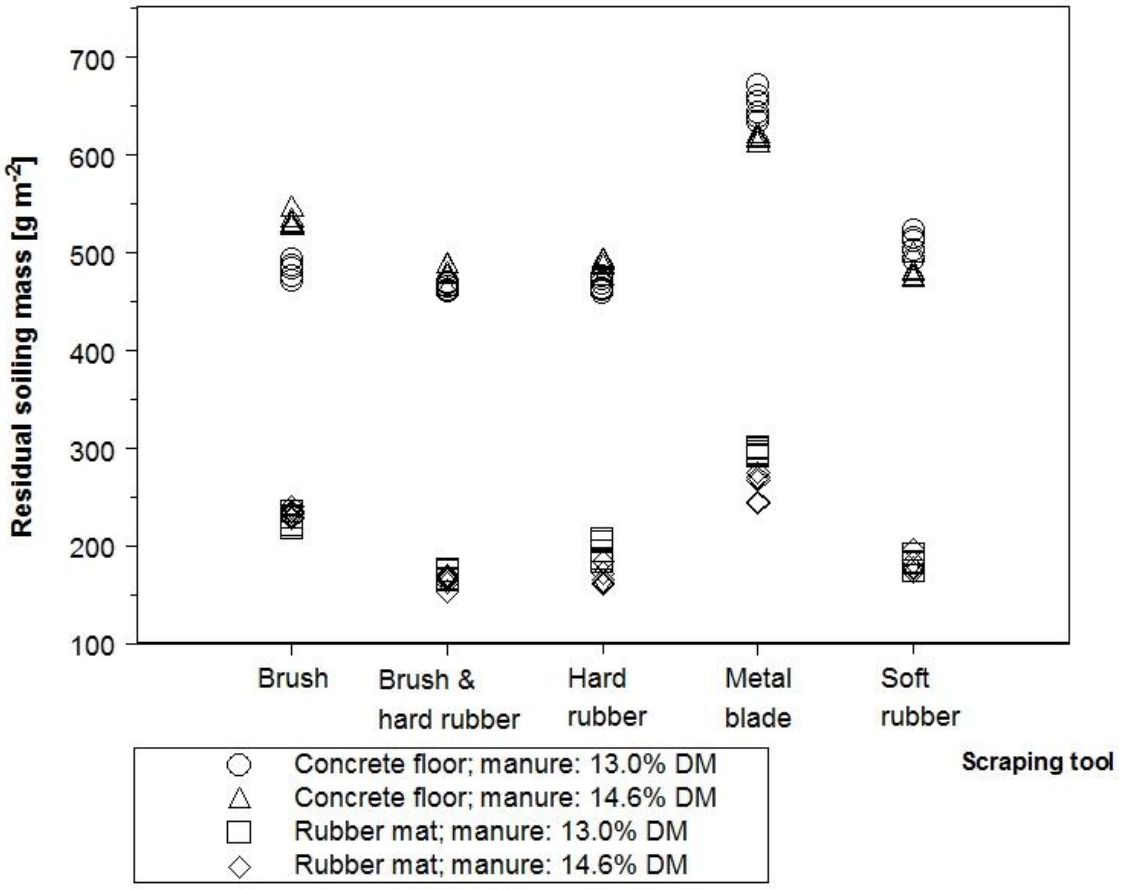

Figure 6: Residual soiling mass [g m^{-2}] as individual values per scraping tool (metal blade, hard rubber lip, soft rubber lip, brush, combined tool of hard rubber lip & brush), differentiated according to floor-surface type (concrete floor; rubber mat) and manure type (13% DM from feeding aisle; 14.6% DM from aisle between cubicles).

3.2 Validation of the measuring method on a practical scale

The method was successfully implemented under practical conditions. All repetitions were performed on the feeding aisle with rubber mat and scraper with a hard rubber lip, at an air temperature of between 13 and 17°C and an atmospheric humidity of between 78 and 87%. Residual soiling mass ranged from 300 to 409 g m^{-2}. The difference between an arithmetic mean (344 g m^{-2}) and median (334 g m^{-2}) was slight (10 g m^{-2}).

4 Discussion

The developed measuring method has proven useful and accurate in defining residual soiling mass on both a pilot-plant and practical scale.
In our case, residual soiling was weighted rather than being calculated from the difference between total manure on the floor before scraping and removed dung (Hesterberg, 2007). Methodological options for ensuring the accuracy of the measuring method were combined, and were as follows: defined experimental area having a clearly defined border with a rubber seal, and collection of bordered residual soiling (own experiments) with a water vacuum cleaner (Haufe, 2006, cited in Korth, 2008) using a standardised procedure. Our measurement principle showed potential for use with very low residual soiling mass under practical conditions, in contrast with Hesterberg's (2007) pilot-plant experiment, in which the total mass of manure and the experimental surface were weighted.
The new measuring method was used in a pilot-plant experiment for comparing different variants of scraping tools, floor surfaces and manure. The results confirmed minor (i.e. not detectable to the naked eye) differences between scraping tools, and obvious differences between types of floor surface (Figure 6). The masses of each repetition of individual variants lay close together.
Regardless of which scraper was used, the residual soiling mass on the rubber mat was lower than that on the concrete floor. This was consistent with the different roughnesses of the two floor surfaces (Steiner, Kilian, Haidn & Keck, 2010). The metal blade proved less efficient at removing dung than the other tools, which were flexible and elastic. This demonstrates the importance of the interrelation between floor surface and scraping tool for cleaning quality. Type of manure did not have a significant influence on residual soiling mass, possibly because of the very small difference between the dry matter of the two types of manure from the two aisles (13% DM from the feeding aisle and 14.6% DM from the aisle between cubicles).
Scaling up the values from pilot-plant scale (area: 1 m^2) to dairy-housing scale with a floor area of 300 m^2 yields a residual soiling mass of 50 kg for the most effective variant (combined tool of hard rubber & brush on rubber mat) and of around 190 kg for the least effective variant (metal blade on concrete floor). This confirms the importance of and need for experiments on a practical scale for optimising the dung-removal process and improving scraping tools.
The experiment on a practical scale had a higher residual soiling mass than the pilot-plant experiment (average residual soiling mass of rubber mat and hard rubber lip variant: 182 g m^{-2} on pilot-plant scale and 344 g m^{-2} on a practical scale). This could be due to a higher total mass of manure to be removed from the floor surface at the practical scale. The evaluated measuring method and its validation in practice make a substantial potential contribution to future research.

5 Conclusions

Dung-removal quality is becoming increasingly important in terms of improving claw health and reducing ammonia emissions. With a view to improving dung-removal technology – i.e., scraping tools – a measuring method for quantifying residual soiling mass as an indicator of cleaning quality was developed at pilot-plant scale and successfully implemented on a practical scale. This new method for quantifying residual soiling mass on solid floor surfaces is appropriate for comparing different scraping tools. The results of systematic experiments at pilot-plant scale revealed significant differences in residual soiling mass for different scraping tools and floor surfaces. The interrelation between floor surface and scraping tool is important for good cleaning quality. Our recommended variant is an elastic floor surface (rubber mat) combined with a scraper with a rubber lip and/or brush. The validation of the measuring method in commercial dairy housing confirmed its potential for use in quantifying residual soiling mass in future experiments on a practical scale.

6 Acknowledgements

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