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PM10 emission measurements in six Swiss dairy cubicle-housing systems with natural ventilation and an outdoor exercise area

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Abstract

The data from the literature for particulate matter (PM10) emissions from dairy cattle are not representative of the loose housing systems with outdoor exercise area common in Switzerland. The aim of this study was to determine PM10 emissions for the most common situation in Switzerland – viz., dairy cattle in cubicle housing with outdoor exercise area – thereby filling a significant gap in the data needed for emission inventories.

Measurements were taken on six commercial farms over twelve measurement periods. Housing consisted of naturally ventilated loose housing with cubicles, solid floor surfaces and an outdoor exercise area alongside the housing. Herd sizes ranged between 20 and 74 animals. Climatic variation over the course of the year was covered by measurements taken in two out of three seasons (summer, transitional season, winter) per farm. Minimum duration of measurements was three days per measurement period.

A tracer ratio method using two tracer gases (SF_6, SF_5CF_3) was developed and successfully implemented to determine emissions in the case of natural ventilation. The diluted tracer gases were continuously dosed via a tube system with critical capillaries. An air-collection system consisting of a Teflon tube and glass critical capillaries allowed a representative sampling of the tracer gases to be taken in the spacious housing. The two tracer gases were analysed simultaneously by means of gas chromatography with electron-capture detector. PM10 was collected cumulatively with impactors with filters at a total of 9 to 14 measuring points collocated with the gas sampling, in the housing area, outdoor exercise area and in the background. The PM10 load was then quantified gravimetrically in the laboratory. As with studies of pig housing systems, a detection limit of 10 µg m^{-3} was obtained (Berry et al., 2005). Based on preliminary trials in a naturally ventilated dairy-housing system with an outdoor exercise area, a measuring time of 72 hours was specified to accumulate sufficient particulate-matter mass. Climate data and aisle/exercise-area soiling were recorded in addition to descriptive farm data in order to characterise the measuring situation in each case.

For the first time, PM10 emissions on dairy-cattle farms with natural ventilation and an outdoor-exercise area were quantified. PM10 concentrations in the housing and outdoor exercise area or cubicle access area/outdoor exercise area were usually just over or in the background concentration range. The determined PM10 emissions ranged between 0.02 and 2.1 g $LU^{-1}d^{-1}$ across all farms. Within the individual farms, there were detectable differences in emission levels between the seasons and between measuring period. With the present volume of data and based on the very slight difference from the background concentration, there was no recognisable link with the influencing variables considered.

Keywords: dust, PM10, emission, concentration, dairy housing

1. Introduction

According to estimates of the Federal Office for the Environment (FOEN), the total PM10 emissions for Switzerland in 2010 came to 20,000 t (FOEN 2013). The FOEN's calculations attributed 27% of these PM10 emissions to the agriculture and forestry sector, of which in turn around 34% derived from dairy housing.

To date, data sources for PM10 from loose-housing systems for dairy cows have been scant. Particulate matter from livestock farming has previously been viewed primarily from the angle of animal health and occupational safety (Hinz, 2002). Frequently, it was only the concentrations of various dust fractions or bioaerosols in specific individual situations such as feed distribution or strawing that were measured when considering adverse effects on human and animal health (Hanhela, Louhelainen, & Pasanen, 1995; Louhelainen, Kanga, Husman, & Terho, 1987; Louhelainen, Kanga, Reiman, & Kalliokoski, 1997).

Kaasik & Maasikmets (2013) provided concentrations for the dust fractions TSP, PM10, PM2.5 and PM1 from nine cubicle housing systems for dairy cattle, but these were only short-time measurements of over 1.2 to 2.5 hours.

PM10 emission data for dairy loose housing from the literature show a wide distribution. PM10 emission values from Takai et al. (1998) converted from total suspended particles (TSP) range from 0.12 to 4.05 g $LU^{-1}d^{-1}$. These data refer to dairy loose housings in the Netherlands, Great Britain, Germany and Denmark. It is only the PM2.5 and PM100 particle size fractions that were measured, however. PM10 emissions from a cubicle-housing system for dairy cattle in the Netherlands ranged from 0.08 to 0.41 g animal place^{-1} d^{-1} (Mosquera, Hol, Huis in 't Veld, Ploegaert, & Ogink, 2012). With dust measurements taken by Henseler-Passmann (2010) in a total of three dairy-housing systems in Germany, the derived value for PM10 emissions from a deep-litter housing system stood at 1.48 $LU^{-1}d^{-1}$ – as expected, higher than the value of 0.16 g $LU^{-1}d^{-1}$ for cubicle housing systems. Measurements taken in two naturally ventilated dairy-housing systems in the USA revealed markedly higher PM10 emissions of 11.9 to 15.0 g cow^{-1} d^{-1} (Joo, et al., 2013).

Emissions data for PM10 have heretofore not been available for the dairy housing systems with outdoor exercise area – and hence, for the correspondingly larger activity areas – common in Switzerland.

The aim of this study was to determine the PM10 emissions for the naturally ventilated loose housing with outdoor exercise area for dairy cows that is common in Switzerland, thereby making a contribution to emissions inventories.

2. Materials and methods

2.1 Farms

The dairy loose-housing system with outdoor exercise area common in Switzerland was selected for the measurements. The system consisted of naturally ventilated one-building housing with cubicles, solid floor surfaces and an outdoor exercise area arranged alongside the housing. The outdoor exercise area was spatially separated from the housing on three farms, and designed as a combined cubicle access aisle/outdoor exercise area on three farms (Fig. 1). The six commercial farms differed in terms of feeding, management, farming system, herd performance, size, and building and operational aspects, thereby ensuring the variety in practise for this housing system. Herd sizes ranged between 20 and 74 animals. The farms are described in detail in Schrade et al. (2012).

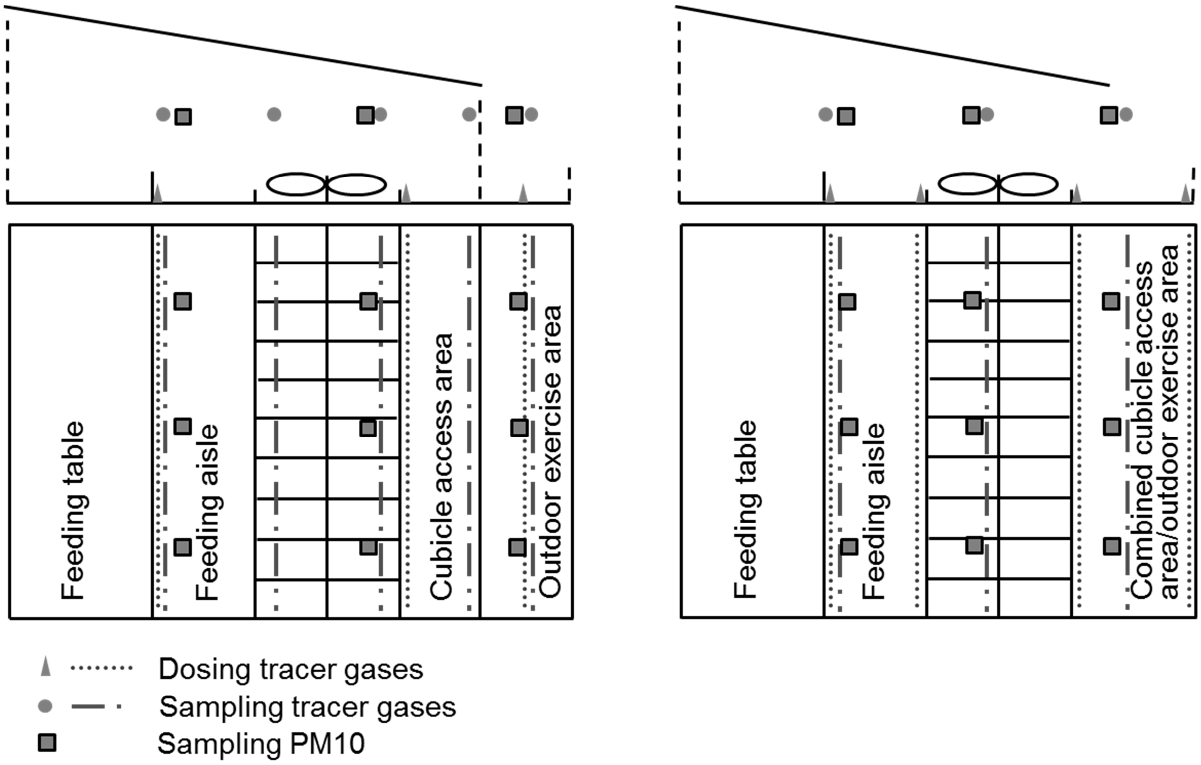

Figure 1: Schematic diagrams showing layout and section of both commercial dairy-housing concepts with dosing and sampling axes: outdoor exercise area separate from housing (left); combined cubicle access aisle/outdoor exercise area (right) (dashed lines in the section drawing stand for open or semi-open façades).

2.2 Measuring concepts and methods

In order to cover the variations in emissions between farms as well as seasonal effects, measurements were taken on the six farms in two out of three seasons (summer, winter, transitional season) in each instance. Each combination of seasons occurred on two farms. The studies were carried out between August 2007 and August 2008.

Particulate matter with an aerodynamic diameter of less than 10 µm (PM10) was determined via intermittent gravimetric sampling with impactors (PEM-200-4-10, MSP Corp., USA) (Fig. 2). To obtain a representative sampling of the housing and outdoor exercise areas, three to five impactors evenly distributed along each measuring axis at a height of approx. 3 m were simultaneously operated. This yielded 9 to 14 measuring points (Fig. 1), depending on the housing. Two impactors at a location not influenced by the housing served to determine the background concentration.

The impactors were protected from coarse dust, rain or high air speeds by a small aluminium cap. Controlled diaphragm pumps (GilAir 5, Sensidyne, USA), located in each case at a maximum distance of 1 to 2 m from the impactor in a crate protecting them from damp and dust, enabled an even volumetric flow rate of 4 litres min^{-1}. The aerosol-containing sample is accelerated in a nozzle with a defined volumetric flow rate and then redirected. Owing to their inertia, particles larger than 10 µm are deposited on a lubricated baffle plate. Smaller particles (PM10) remain in the gas stream, are held back on the subsequent filter (S & S, GF 10 HY, 37 mm), and are gravimetrically determined after being measured in the laboratory. The filters were conditioned for at least 24 hours both before and after measurement (temperature: 22 °C; relative atmospheric humidity: 50%). A detection limit of 10 µg m^{-3} was assumed on the basis of similar studies carried out in pig housing (Berry, Zeyer, Emmenegger, & Keck, 2005). The filters were exposed for 72 h in order to accumulate sufficient dust.

Impactor	PEM-200-4-10, MSP Corp.
Volume flow rate	4 l min^{-1}
Filter	S & S, GF 10 HY, 37 mm
Conditioning	24 h, 22 °C, 50% RH
Balance	Mettler AT 201, 0.01 mg

Figure 2: Impactor and conditions for sampling and gravimetric determination.

A tracer-ratio method with two tracer gases was developed in order to determine the emissions for natural ventilation and from diffuse sources, and was used with success. In addition to the already-established tracer gas sulphur hexafluoride (SF_6), trifluoromethyl sulphur pentafluoride (SF_5CF_3) was used. The dilute tracer gases (600-800 ppm each of SF_6 and SF_5CF_3) were continuously supplied next to the floor surfaces via a tube system with critical capillaries (Fig. 1). At these concentrations the density of the tracer gases differs by less than 1% from the ambient air and hence does not hinder mixing with the air in the housing. An air-collection system comprising a Teflon hose and glass critical capillaries enabled us to take a representative sampling of the tracer gases in the spacious housing. The two tracer gases were analysed simultaneously by means of gas chromatography with electron-capture detector (GC-ECD). The detection limit for both tracer gases was approximately 2 ppt. The tracer-ratio method is described in greater detail in Schrade (2009) and Schrade et al. (2012).

The PM10 concentrations recorded in each case over a measuring period of three days served as the basis for calculating the PM10 emissions. The median was formed from the PM10 concentrations of the individual measuring locations in the animal area (housing area and outdoor exercise area or cubicle access aisle/outdoor exercise area). The emissions were determined based on the 72 h averages of PM10 and the tracer gas concentrations.

In addition to descriptive farm data, the following parameters served to describe the measuring situation in each case, to determine the plausibility of measuring data, to act as reference values, and to aid in determining variables with a significant influence on emissions: outdoor climate as well as climate in the housing and outdoor exercise area (air temperature, wind speed and direction, relative humidity); location of the animals; soiling of floor surfaces, etc.

3. Results and Discussion

3.1 PM10 concentrations

Figure 3 shows the PM10 concentrations of a total of 17 three-day measurement over 12 measuring periods, separated according to the individual areas (housing area, outdoor exercise area or cubicle access aisle/outdoor exercise area, background. The PM10 concentrations over all measurements, areas and sampling locations ranged between values of < 10 µg m^{-3} (detection limit) in the background up to 69 µg m^{-3} in the housing area. For the summer measurement of Farm 5, the background concentration was markedly higher than the values in the cubicle access aisle/outdoor exercise area and housing area. The reason for this could be the cereal harvest on fields in the surrounding area, or an increased amount of dust from a gravelled service road approx. 20 m from the background measuring location. For this reason, an environmental-impact measurement value taken at an uninfluenced site – Winterthur Obertor – and averaged over this period, was used as a background value for this measuring period (Ostluft, 2008). For Farm 6, only one 24-hour measurement was carried out in the transitional season after a power outage caused by a storm. The wide dispersion of these values can be attributed to the short exposure time of the filters, and to the resultant measurement uncertainty.

PM10 concentrations in the housing area were slightly higher than in the outdoor exercise area or cubicle access aisle/outdoor exercise area in the majority of the measuring periods. A variance analysis showed that the background concentration differed significantly from the animal-area concentration (outdoor exercise area or cubicle access aisle/outdoor exercise area and housing area) across all measuring periods ($F_{1.17} = 14.62$; $p = 0.001$), with the mean background concentration standing at 17 µg m^{-3}.
The estimated average population-weighted PM10 ambient concentration in Switzerland was slightly higher in 2005 at 21.6 µg m^{-3} and in 2010 at 19.4 µg m^{-3} (FOEN, 2013). The average of the PM concentration for the animal area from our own measurements stood at 26 µg m^{-3}. At 11 to 41 µg m^{-3}, the PM10 concentrations of a dairy-loose housing with cubicles in the Netherlands fell within a similar range (Mosquera, et al., 2012). The PM10 concentrations for the measurements taken by Kaasik and Maasikmets (2013) in nine non-thermally-insulated cubicle housings for dairy cows in Estonia were significantly higher; here, average monthly PM10 concentrations ranged from 27 to 123 µg m^{-3} (MEAN 65 µg m^{-3}).

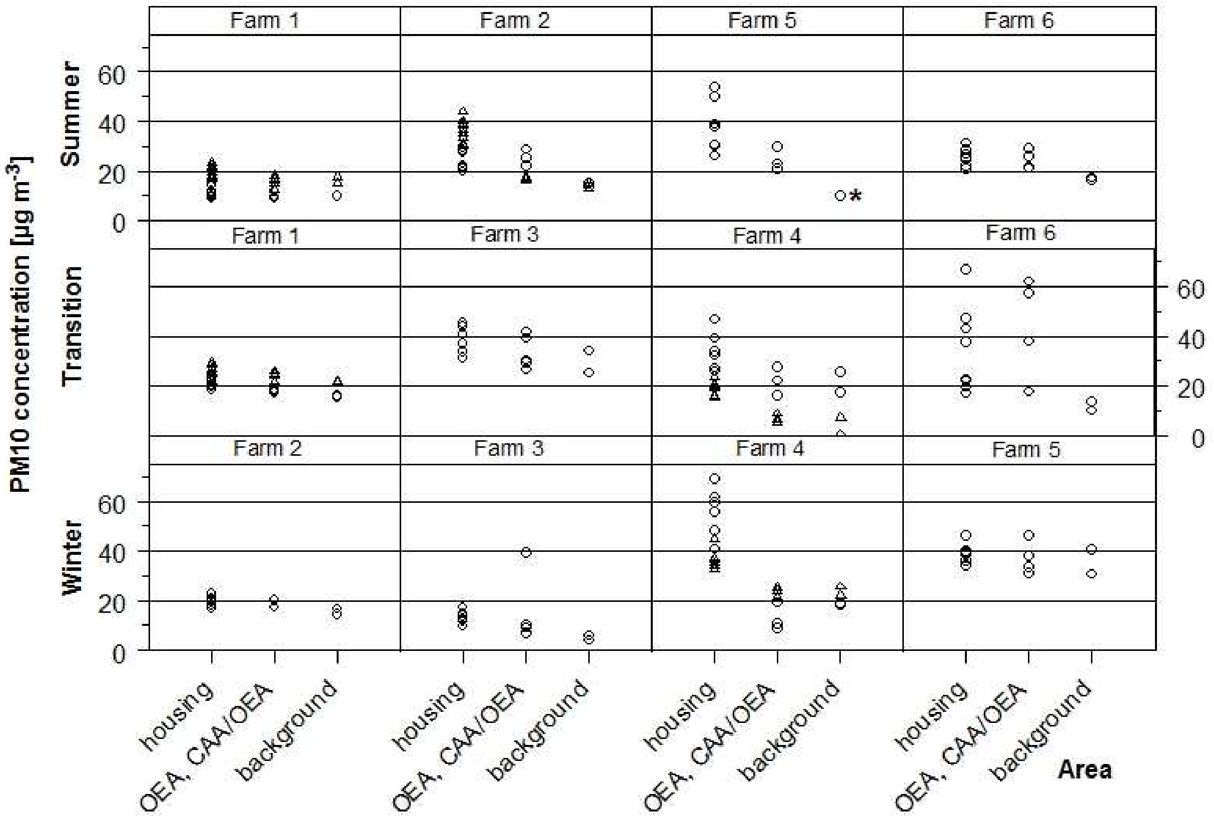

*Figure 3 PM10 concentrations [µg m^{-3}] in the individual areas (housing, outdoor exercise area (OEA) or cubicle access aisle/outdoor exercise area (CAA/OEA), background) according to farm and season, shown within the measuring periods as 3-day measuring period (O = measuring period 1; ∆ = measuring period 2); * characterises the value from environmental-impact measurements at the Winterthur Obertor site (Ostluft, 2008).*

3.2 PM10 emissions

Across all farms, PM10 emissions ranged between 0.02 and 2.1 g LU^{-1} d^{-1} (Figure 4). Within the farms, differences in emission levels between seasons and measuring periods were in some case identifiable. The seasonal effect is not systematic, however. According to a linear mixed-effects model which treats the farm as a random effect, none of the investigated influencing variables of season, outside temperature, or relative humidity in the housing pointed to a significant influence on the PM10 emissions. Since PM10 concentrations in the housing and outdoor exercise area or cubicle access aisle/outdoor exercise area were for the

most part just over or within the range of the background concentration, the calculated emissions are also burdened with a high level of relative uncertainty.
Data from the literature also display a large variance for PM10 emissions, and fall within a similar range. PM10 emission values for cubicle housing from Takai et al. (1998) converted from total suspended particles (TSP) range from 0.12 to 4.05 g $LU^{-1}d^{-1}$. In a cubicle housing system in the Netherlands, PM10 emissions of 0.08 to 0.41g animal $place^{-1}$ d^{-1} were measured on six measuring days spread throughout the year (Mosquera, et al., 2012). Henseler-Passmann (2010) derives PM10 emission values of 0.16 g $LU^{-1}d^{-1}$ for cubicle housing systems and of 1.48 $LU^{-1}d^{-1}$ for a deep-litter housing system from measurements on three dairy farms. Measurements taken at two naturally ventilated dairy housings in the USA with 11.9 to 15.0 g cow^{-1} d^{-1} yield markedly higher average PM10 emissions (Joo, et al., 2013). In these studies, PM10 emissions increased along with a rise in temperature (Joo, et al., 2013).

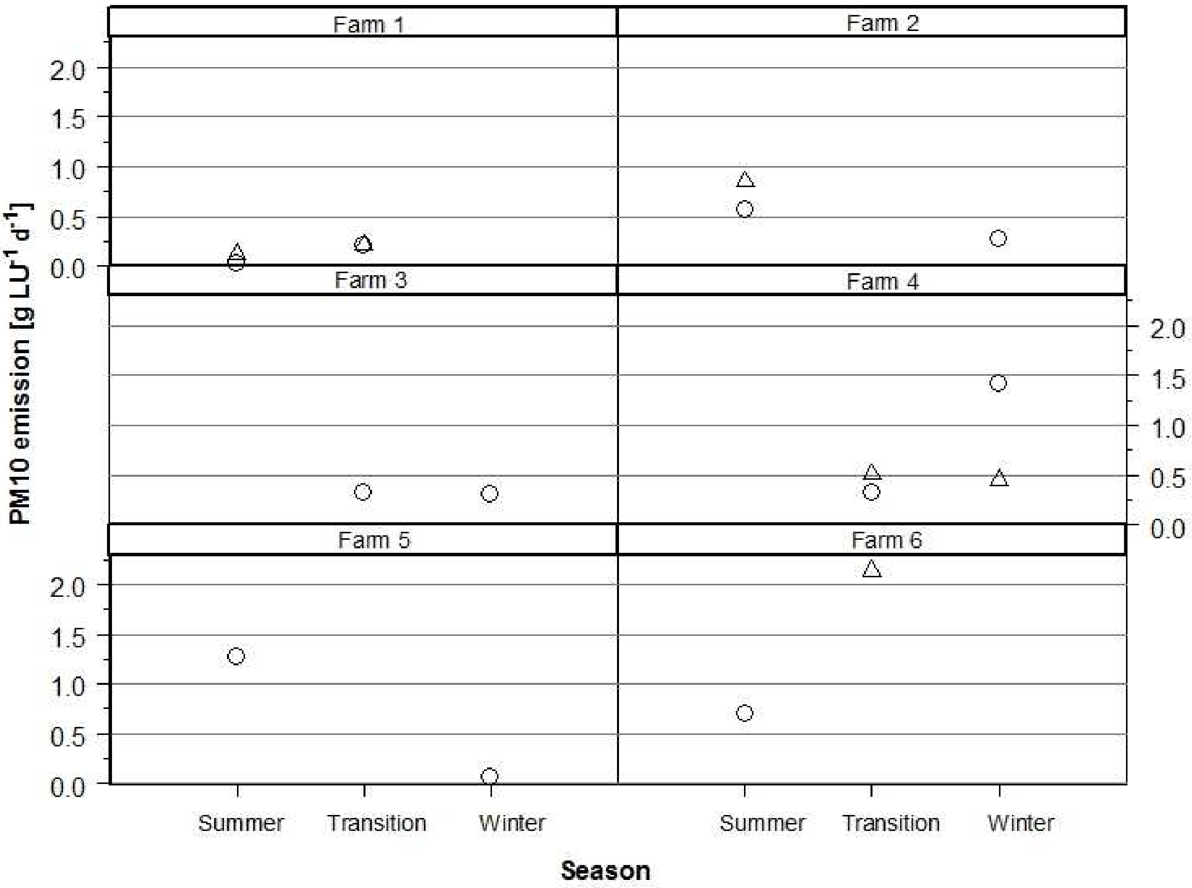

Figure 4: PM10 emissions [g GV^{-1} d^{-1}] according to farm and season, given per 3-day measuring period, calculated on the basis of the median of the PM10 concentration from the animal area (housing area, outdoor exercise area or cubicle access aisle/outdoor exercise area), shown within the seasons according to 3-day measuring period (O = Measuring period t 1; ∆ = Measuring period 2).

4. Conclusions

PM10 emissions from dairy-loose housings with cubicles, natural ventilation and outdoor exercise areas were quantified in different seasons for the first time. PM10 concentrations in the housing and in the outdoor exercise area or the cubicle access aisle/outdoor exercise area were for the most part slightly over or within the background concentration range. Accordingly, the calculated emissions are burdened with a high level of relative uncertainty. Within the farms, differences in emission levels between the seasons and between measuring periods are detectable. With the existing volume of data and in view of the scant distinction to the background concentration, no connection with the investigated influencing variables could be detected.

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