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The impact of differently solved machine lines and work procedures of feeding and bedding on dust concentration in stables for dairy cows

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Abstract. The measurements were aimed at the impact of differently solved feeding and bedding systems on dust concentration in stables for dairy cows. Dust particles can be found in the environment in which the animals are housed and can affect their welfare and health, and can also negatively affect equipment in livestock buildings. Measurements of dust aerosol on 7 different farms for dairy cows in 9 stables in total were carried out. We focused on the impact of differently solved machine lines and work procedures of feeding and bedding, especially feeding with a mixer feeder wagon, bedding with a bedding wagon (equipped with a floor conveyor, a milling cylinder and a transversal conveyor), bedding with a straw blower, laying of deep litter with a wagon equipped with a hydraulic arm and manual distribution. Technical systems are especially affected by the presence of dust particles larger than 10 µm, which fall down very quickly and easily settle on the animals and surfaces in the stable. So, we measured the concentration of dust aerosol with an aerosol monitor by means of a 10 µm filter.
The results of the measurements show that feeding with a mixer feeder wagon increases the concentration of dust particles in the stables by the least amount. Straw bedding increases the concentration of dust particles in the stables by several times. This increase, however, is short in duration, and dustiness in the stables quickly returns to the state before bedding. There is a clear, substantive difference between the differently solved bedding systems.

Key words: dairy farm, feeding and bedding operations, dust concentration.

INTRODUCTION

The aim of the measurements was to determine the impact of the most commonly used systems of feeding and bedding on the concentration of dust aerosol in a stable environment. To determine the effect of feeding and bedding on the concentration of dust aerosol in a stable environment, it is important to observe changes in the dust concentration before commencing work operations, concentration changes during work operations, and how quickly the concentration of dust aerosol returns to the state before commencing work operations.

Dust settles down on most building surfaces and may lead to a deterioration of building materials and equipment in buildings for livestock. Grains of sand can penetrate into electronic devices and settle down on the temperature and humidity sensors of climate control systems. Dust can also settle down on fan motors and may result in overheating. A study of corrosion in heat exchangers used in animal stables showed that water condensate and dust on the heat exchanger surfaces enabled microorganisms to grow and created a corrosive microenvironment.

Dust in the ventilation stream in livestock stables has been implicated in transporting and even magnifying odour. Odorous molecules (odorants) are absorbed on particle surfaces and then desorbed in large local concentrations in the nasal epithelium, where the olfactory nerve cells are located. Dust in pig houses contains volatile fatty acids (VFA),which are assumed to be indicator compounds for odour (Takai et al., 1998).

For comparison, the U.S. Environmental Protection Agency's (US EPA, 2006) National Ambient Air Quality Standards (NAAQS) limit primary and secondary dust concentrations (PM_{10}) for a 24-hour average sampling period to 150 μg m^{-3}. The purpose of the primary standard is the protection of public health, and the purpose of the secondary standard is to protect the public from known or anticipated adverse effects.

Cathomas et al. (2002) mention that the particles greater than 10 μg (PM_{10}) represent on average approximately 63% of all dust particles in the atmosphere of stables in the Alpine region and that the amount of dust particles varies throughout the year. This amount also depends on the type of construction of the stable. The measured values of airborne dust PM_{10} ranged between 76–4,862 μg m^{-3}, while the higher values were recorded in the summer period.

Jílek et al. (1998) mention that the movement of dust particles in the atmosphere depends on their size, while very small particles don´t settle down at all. The rate of sedimentation for larger particles depends on their size. From the viewpoint of the impact on the health of livestock, the less harmful particles are those exceeding 10 μm, which are captured in the nasal cavity (Jílek et al., 1998). Smaller particles are inhaled. While particles 5–10 μm are captured in the upper part of the respiratory tract, smaller particles can readily penetrate into the lungs (Dolejš et al., 2005).

The dust particles are deposited on stable equipment and reared livestock. These particles represent a breeding ground for various microorganisms and molds. Emission limits are specified for the permissible concentrations of dust in the air. Under these emission limits, we understand the maximum permissible amount of a pollutant emitted into the atmosphere from a pollution source is expressed as a mass concentration of a pollutant or a mass flow of a pollutant per unit of time or as the mass of a pollutant per unit of production or human activity. The emission limit designed for the protection of human health is determined for particles that pass through a size-selective input filter, which has, using an aerodynamic diameter of 10 μm, a separation efficiency of PM_{10}.

For flue dust PM_{10}, a 24-hour limit of 50 μg m^{-3} is applied, and this limit may be exceeded up to 35 times annually. Another limit in force determines the highest average concentration for the whole year to be 40 μg m^{-3} (Czech Republic, 2012).

For employees, the Permissible Exposure Limit (PEL) for 8 working hours in the case of dust with predominantly non-specific effects, such as soil dust, is set at 10 mg m^{-3}. In the case of dust with a predominantly irritable effect, such as cereal dust, the PEL is determined to be 6 mg m^{-3} (Czech Republic, 2007).

From the viewpoint of livestock breeding, Jílek et al. (1998) state that the maximum permissible dust content in stable air should be 6–10 mg m^{-3}.

MATERIALS AND METHODS

In Central Bohemia on 7 different farms for dairy cows in 9 stables in total measurements of dust aerosol during bedding and feeding operations were carried out.

We focused on the basic descriptions of stables and used technologies in Table 1. All of the stables were free stall designs, but they differed in the type of housing, bedding materials, and used technology. In all the stables, TMR (total mixed ration) is used for feeding cows, except dry (non milk producing) cows on Farm 1, Stable B, where forage is used. We focused on the impact of differently solved machine lines and work procedures of feeding and bedding operations, especially feeding with a mixer feeder wagon, bedding with a bedding wagon (using a floor conveyor, a milling cylinder and a transversal conveyor), bedding with a straw blower, laying of deep litter with a wagon using a hydraulic arm grapple and manual distribution.

Table 1. Description of measured technologies

Measurement	Housing *	Bedding	Work operation	Machine
Farm 1 Stable A	6-rowfreestall stable, volume 53 m^3 cow^{-1}	dried manure solids	feeding	Faresin Leader 1400 self-propelled feeding wagon
Farm 2	4-row free stall stable, volume 45 m^3 cow^{-1}	rubber mats	feeding	Zetor 6911, Silo-King Duo mixer feeder
Farm 3	4-row free stall stable, volume 45 m^3 cow^{-1}	chopped wheat straw	bedding	Zetor 5211, Kamzík Mini feeding and bedding wagon
Farm 4	3-row free stall stable, volume 62 m^3 cow^{-1}	chopped wheat straw	bedding	Zetor 6911, ZP 5-005.1feeding and bedding wagon
Farm 5	4-row free stall stable with calving pens, volume 48 m^3 cow^{-1}	chopped wheat straw	bedding	John Deere 5090M, ZP 5-005.1feeding and bedding wagon
Farm 6 Stable A	4-row free stall stables, volume 45 m^3 cow^{-1}	chopped wheat straw	bedding	Zetor 6911, obsolete bedding wagon discharging in the front
Farm 6 Stable B	4-row free stall stable, volume 45 m^3 cow^{-1}	chopped wheat straw	bedding	Zetor 6911, obsolete bedding wagon with discharging on the side
Farm 1 Stable B	shelter shed for dry cows, volume 55 m^3 cow^{-1}	chopped wheat straw (deep bedding)	bedding	Zetor 7015, wagon with discharging hydraulic arm grapple
Farm 7	2-row free stall stable, volume 35 m^3 cow^{-1}	chopped wheat straw	bedding	Zetor 7211, Romet straw blower

* All stables are naturally ventilated.

We measured the concentration of dust aerosol (fraction of PM_{10}) with a DustTrak 8520 aerosol monitor with a 10 μm filter inside the stable. Simultaneously, microclimate conditions were indicatively measured with an Almemo 2290-4 multichannel data logger with a FHA646-E1 temperature and humidity sensor and a FVA915-SMA1 wind speed sensor. In each stable, we carried out two measurements and used these to calculate the average values.

The aerosol monitor was placed in the middle of the feed passage 1m above the floor and at least 3 m away from the walls and dairy cows.

Before work operations commenced, we measured the concentration of dust aerosol in the background c_b for 15 minutes. During feeding and bedding, we tracked the concentration c_o during the whole operation and then tracked it back to the concentration level prior to the state before commencing work operations and for at least 15 minutes thereafter.

RESULTS AND DISCUSSION

The microclimate conditions of the measurements are shown in Table 2. In all the stables, a system of natural ventilation is used, and the wind speeds are highly variable. For this reason, the measured average wind speed shown is only indicative.

Table 2. Microclimate conditions of measurements

Measurement	t_e °C	RH_e %	w_e m s^{-1}	t_i °C	RH_i %	w_i m s^{-1}
Farm 1, Stable A	12.2	68.5	2.4	16.3	61.4	3.1
Farm 2	18.4	48.2	0.8	17.0	53.0	0.4
Farm 3	8.5	95.3	3.3	10.2	92.4	2.7
Farm 4	20.4	50.8	1.2	18.6	61.2	0.4
Farm 5	3.3	86.6	0.5	4.6	92.1	1.7
Farm 6, Stable A	20.3	39.4	2.4	20.5	42.9	4.5
Farm 6, Stable B	20.6	39.2	2.7	19.0	54.0	4.0
Farm 1, Stable B	12.4	64.1	2.3	13.1	62.8	2.1
Farm 7	17.5	77.2	0.3	20.5	72.7	0.5

t_e – outdoor temperature, RH_e– outdoor relative humidity, w_e – outdoor wind speed, t_i – indoor temperature, RH_i – indoor relative humidity, w_i – indoor wind speed.

The concentration of dust aerosol in dairy stables depends on the type of work operation and the machines used. The results of the measurements are summarized in Table 3.

Table 3. Measured concentrations of dust aerosol PM_{10} during work operations

Measurement	Work operation	$c_{b\ avg}$ mg m^{-3}	$c_{b\ max}$ mg m^{-3}	$c_{o\ avg}$* mg m^{-3}	$c_{o\ max}$ mg m^{-3}
Farm 1, Stable A	feeding	0.031	0.692	0.072	2.345
Farm 2	feeding	0.037	0.046	0.066	0.555
Farm 3	bedding	0.152	0.554	2.810	15.740
Farm 4	bedding	0.046	0.693	16.762	81.620
Farm 5	bedding	0.072	1.128	4.131	20.005
Farm 6, Stable A	bedding	0.026	0.867	2.950	24.503
Farm 6, Stable B	bedding	0.031	0.931	2.344	12.837
Farm 1, Stable B	bedding	0.068	1.492	0.198	3.439
Farm 7	bedding	0.082	0.260	4.235	10.033

* c_{oavg} – maximum of 1-minute average.

The average concentration of dust aerosol in the background $c_{b\ avg}$ varied from 26 to 152 µg m^{-3}. Almost all the values were below the 24-hour limits of the NAAQS150 µg m^{-3} (US EPA, 2006) standard, and more than half of them were lower than the 24-hour limit of 50 µg m^{-3} (Czech Republic, 2012). The maximum concentration of dust aerosol in the background $c_{b\ max}$ varied from 46 µg m^{-3} (shelter shed) to 1.128 mg m^{-3}.

The technical systems used significantly affected the presence of dust particles larger than 10 µm, which fall down very quickly and easily and settle down on animals and surfaces in the stable. In order to determine how the machine lines affect the concentration of dust aerosol, we used the absolute maximum of concentration $c_{o\ max}$ and the maximum of the 1-minute average $c_{o\ avg}$, which is significantly lower than the absolute maximum. The difference between these values shows how quickly dust particles settle down.

During feeding operations, the maximum concentration of dust aerosol $c_{o\ max}$ was higher when using a self-propelled feeding wagon (2.345 mg m^{-3}) than when using a Zetor 6911 tractor with a semi-trailer mixer feeder (0.555 mg m^{-3}). The maximum of the 1-minute averages during feeding operations were almost equal at 0.066 and 0.072 mg m^{-3}, respectively.

Bedding with straw increases the concentration of dust particles in the stables by several times. This increase, however, is short, and dustiness in the stables quickly returns to the state before bedding.

The lowest concentration during the bedding operation was achieved when using a hydraulic arm grapple in the shelter shed for dry cows. The absolute maximum concentration was 3.439 mg m^{-3}, and the maximum of the 1-minute average was only 0.198 mg m^{-3}.

The maximum of the 1-minute average concentration of dust aerosol during bedding operations using bedding wagons and straw blower was 2.344–4.235 mg m^{-3}, except for Farm 4 where the bedding material was apparently very dry and dusty and the measured concentration exceeded 16 mg m^{-3}.

An indicative measurement of microclimate conditions, in accordance with the methodology used by Fabianová et al. (2014), didn't show any effect on the measured data.

All measured concentrations of dust aerosol are in accordance with the dairy stable environment recommendations of Jílek et al. (1998). Except for Farm 4, however, the excess concentrations were short in duration. All measured concentrations are also in accordance with the given 8-hour PEL in the workplace in the Czech Republic (2007).

In the graphs in Figs 1 and 2, an example of the measured concentration of dust aerosol during straw bedding operations, using a straw blower and wagon with a discharging transverse conveyor, is shown. The maximum of the 1-minute average concentration was higher during bedding operations using a straw blower. However, the straw blower passed through the stable more quickly, and the dust particles settled down within a short time.

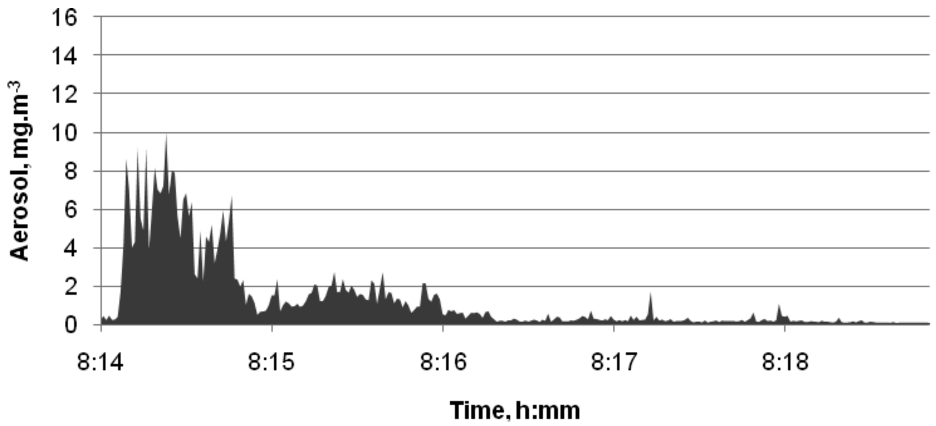

Figure 1. Concentration of dust aerosol during the laying of straw bedding with a straw blower (Farm 7), PM_{10}.

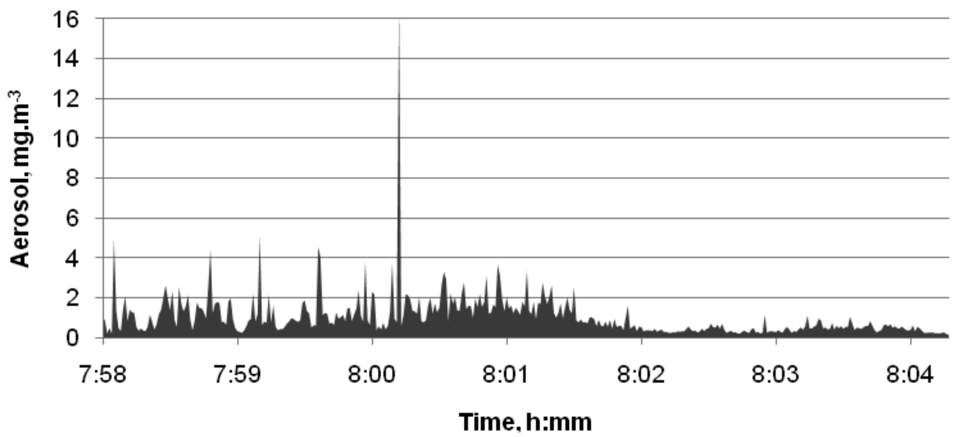

Figure 2. Concentration of dust aerosol during the laying of straw bedding with a wagon using a discharging transverse conveyor (Farm 3), PM_{10}.

CONCLUSIONS

We observed that differently solved systems of feeding and bedding have a significant impact on the concentration of dust aerosol in animal stables, except for feeding with a mixer feeder wagon which does not significantly increase dust concentration in animal stables. By contrast, bedding with chopped straw increases the concentration of dust particles in the stables by several times. This increase, however, is short in duration, and the dust concentration in the stables quickly returns to the state before the bedding operation.

There is a difference between the differently solved bedding systems. The lowest concentration was measured in naturally well-ventilated shelter shed for dry cows where bedding operations used a wagon with a discharging hydraulic arm grapple. The highest concentration was measured in a 3-row free stall stable where bedding operations used a ZP 5-005.1 feeding and bedding wagon with discharging on the side, where a very dry straw seemed to be used.

Based on our findings, we recommend further research to very precisely identify how bedding operations using a straw blower affect dustiness in a stable, because a low concentration of dust particles was observed, contrary to our expectations.

Increased attention should be paid to the quality of the bedding straw, because there is a reasonable suspicion that, in particular, the material of bedding, the cutting length of straw, and its physical and mechanical characteristics can significantly influence the concentration of dust aerosol in a stable during bedding operations.

These results contribute to a better understanding of how the systems of feeding and bedding influence dust concentration in animal stables, which is a significant parameter for the welfare of livestock.

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