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The effect of bedding amount on gas emissions from manure during storage

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Abstract. One of the major agricultural pollutants of environment is manure from livestock. We focused on dairy cows kept in the barns with straw bedding commonly used in the Czech Republic. We tested the hypothesis that the amount of bedding used daily relative to the number and size of animals kept has a significant effect on the emissions of gases from manure stored in a manure pile. In the experiment, a group of 10 dairy cows of Holstein and Czech Red Pied breed was housed in a stable bedded with various amounts of wheat straw (4–10 kg/livestock unit per day). The manure was removed from the stable after 48 h and mixed was stored in cubic containers with drain floor allowing measurement of manure leachate release. For 50 days we measured weight, volume, weight of manure leachate and manure temperature. Decreasing stored manure weight can be attributed to release of manure leachate and emissions of gases, primarily water vapor, as a result of microbial activity and increased temperature in the manure during storage. Using the calculated model, we found that daily production of emissions of water vapor and other gases was related to bedding amount in a statistically significant manner ($P < 0.001$). The cumulative amount of gas emissions grew rapidly in all treatments. Also total amount of emissions was related to bedding amount in a statistically significant manner ($P = 0.004$). We also found the relationship between internal manure temperature and the logarithm of the amount of emissions produced to be statistically significant ($P < 0.001$).

Key words: dairy cows, manure storage, bedding amount, gas emissions.

INTRODUCTION

Animal agriculture is a source of many substances having environmental impacts. It involves in particular the production of nitrogen, which is released into the environment from livestock housing as well as during storage and field application of manure from farm animals.

Nitrogen is released into the environment from livestock housing in the form of gas emissions (NH_3, N_2O, NO) and it pollutes water sources (as NH_4+, NO_3, organic N) through leakage and seepage during storage and field application of manure.

Animal excreta (urine and feces) contain environmentally reactive nitrogen, which, unless it is incorporated into a crop or converted into molecular nitrogen, begins moving into the air and water from the time it leaves the animal (Amon et al., 2001; Powell et al., 2013; Kohn, 2015).

Measures aiming at reducing environmental impacts occurring in connection with agriculture, and in particular animal farming, are being sought and introduced around the world. The European Union and many other developed countries have devoted a particularly great deal of attention to methods for storing and applying manure from livestock with the objective of minimizing their negative environmental impacts (Nitrates Directive, 1991; Ohio Livestock Manure Management Guide, 2006; Agricultural Waste Management, 2011).

This topic is also highly relevant in the Czech Republic, where annual manure production is estimated at 10.3 million metric tons. Many animals on Czech farms are kept in barns with bedding. In these systems, the space where the animals rest is covered with a certain amount of bedding in order to create a soft and dry bed. Sometimes bedding is also added to manure gutters. The mixture of feces, urine, bedding, and potentially feed residues and other substances is mixed and subsequently pushed out of the animals' pens by their movement, is mixed with other manure and unconsumed feedstuffs, is removed from the barn, and then is stored in a suitable manure pile.

In addition to the animals' species, feeding, and housing system, manure properties are also affected by the bedding that is used. The amount and properties of bedding affect in particular the content of nutrients, organic materials, and dry matter of manure produced in stables. Bedding also has a considerable effect on manure's physical and mechanical properties (e.g. dry matter, volume, density, porosity, and air content), which in turn affect the storage process, manure leachate production, nutrient loss, gas emissions, and other aspects. (Misselbrook et al., 2004; ASAE, 2005; Agricultural Waste Management, 2011).

Bedding and its properties and amount also affect the quantity of gas emissions from stored manure. Increasing proportions of bedding and correspondingly boosting the amounts of oxygen in the manure support microbial processes occurring in the manure during storage as well the overall amount of gas emissions (Jeppsson, 1999; Misselbrook & Powell, 2005; Aguerre et al., 2012).

The literature contains a large amount of data on the production of manure and manure leachate in connection with animal farming, much of which has a normative character (ASAE, 2005; Oeneme et al., 2007; Government of the Czech Republic, 2013). Nevertheless, there is a need for more-detailed understanding of changes in stored manure's properties through the storage process.

Aim of this work is deepen understanding of production of water vapor and other gases from stored manure in accordance with the amount and properties of bedding as well as storage duration. This understanding is important for defining principles for the proper storage and treatment of manure during storage and application.

To better understand the properties of stored manure and changes to them during the storage process depending upon bedding amount, we therefore established controlled experiments focused on understanding these variables within manure produced by dairy farming operations using straw bedding.

We adopted the hypothesis that the daily amount of bedding relative to the number and size of livestock expressed as livestock units (LU, with 1 LU = 500 kg live weight) would significantly affect the emissions of water vapor and other gases from manure during storage in a pile and these emissions are also significantly affected by the course of temperature within stored manure.

The objective of these experiments was to test the assumptions expressed in the hypothesis and contribute to a better understanding of emissions of water vapor and other gases from stored manure according to the amount of bedding and duration of that storage.

MATERIALS AND METHODS

The effect of bedding on manure properties was evaluated on a dairy farm in the Czech Republic (Central Bohemia region). A group of 10 dairy cows was housed in a pen bedded with varying amounts of wheat straw (Fig. 1). The pen had a flat and impermeable concrete floor. The determined amount of bedding was spread at regular intervals over the entire pen. Dairy cows were free to move about the entire pen and their movements mixed their excrement into the bedding. The experiment was carried out in the autumn months (September – November).

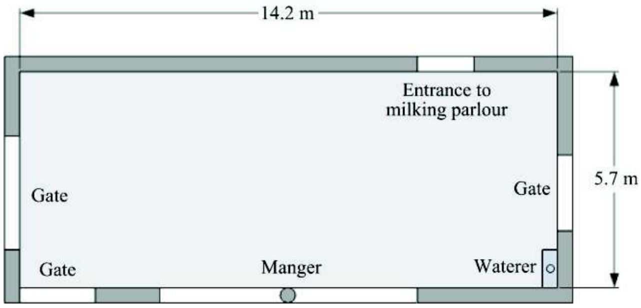

Figure 1. Floor plan of group pen for 10 dairy cows where in experiments utilizing various amounts of bedding were conducted.

Experimental Conditions

- ✓ Number of milk cows in the pen: 10;
- ✓ Pen area: 81 m^2;
- ✓ Cow breed: Holstein and Czech Red Pied;
- ✓ Mean cow weight: 650 kg (1.3 LU);
- ✓ Mean annual milk production: 8,500 kg;
- ✓ Bedding: wheat straw;
- ✓ Bedding dry matter: 84–86%;
- ✓ Bedding amount: 4–10 kg per LU per day (1 livestock unit = 500 kg live weight), i.e. 5.2–13 kg per cow per day;
- ✓ Feeding: TMR;
- ✓ Milking frequency: 2 times per day.

In order to create sufficient manure and ensure cow cleanliness and comfort, bedding corresponding to the amount to be provided over 2 d was put down in the pen at the start of the experiment. Straw was spread in the experimental pen by small wheel loader and manually.

Individual treatments were conducted under identical conditions other than to alter the amount of bedding added to the pen, the values for which are given in Table 1. Cows were weighted before the experiment to apply proper amount of the bedding.

Table 1. Bedding amounts added to the pen for individual treatments

Item	Treatment				
	4 kg per LU[2]	6 kg per LU	7 kg per LU	8.5 kg per LU	10 kg per LU
bedding amount, kg per LU per day**	4.0	6.0	7.0	8.5	10.0
bedding amount, kg per cow per day	5.2	7.8	9.1	11.1	13.0
total bedding amount in pen for 10 cows*, kg	104	156	182	222	260
specific amount of bedding in pen*, kg m^{-2}	1.3	1.9	2.2	2.7	3.2

* Bedding corresponding to twice the daily amount was put down in the pen at the start of the experiment.
** LU = livestock unit (500 kg live weight).

After each 48 h, the mixture of feces, urine, and bedding (collectively defined as 'manure' for the purposes of this article) was removed from the pen and mixed using a front-end loader and then unpressured placed in storage containers with watertight bottoms and walls and having volume 1,507 m^3 and the following inner dimensions: width 1,135 mm, length 1,135 mm, height 1,170 mm.

The containers' bottoms contained sealable drains enabling the daily drainage and subsequent weighing of manure leachate released from stored manure.

During the experiment, the containers were stored in shade on the northern side of the building and protected from sunlight. After being filled with manure, the containers were covered with corrugated roof panels to protect them from rain and enable continuous ventilation of gas formed during storage.

Throughout the experiment, containers with manure having the defined proportions of bedding were regularly weighed on a scale, the amount of released manure leachate was weighed, and the change in the volume of manure stored in the container was determined. The temperature of the manure at the center of the container was regularly measured using a rod thermometer.

Each treatment was repeated twice, always with the same amount of bedding, except that the treatment with 6 kg bedding per LU per day was repeated four times. This treatment was repeated more frequently due to the need to understand in more detail the behavior of stored manure with 6 kg bedding per LU per day. That amount is considered under Czech law to be the minimum necessary in order to store manure directly on the edge of land to be manured without the need for intermediary storage in a manure storage facility with a solid bottom.

Theory and modelling

In order to perform relevant comparisons of results from individual treatments and their variants, all measured values were converted for evaluation purposes to 1,000 kg manure weight at loading according to the equation:

$$m_p = m\frac{1{,}000}{M_1} \qquad (1)$$

where m_p – the converted value relative to 1,000 kg manure weight, kg; m – the measured value, kg; M_1 – the manure weight at loading, kg.

Decreasing stored manure weight can be attributed to release of manure leachate and emissions of gases, primarily water vapor, as a result of microbial activity and increased temperature in the manure during storage. This was used to calculate gas emissions from stored manure. The daily amount of gas emissions was defined as:

$$E_n = m_n - m_{n-1} - h_n \quad (2)$$

where E_n – gas emissions for day N of storage, kg; m_n – manure weight at day N of storage, kg; m_{n-1} – manure weight at day, (N_{-1}) of storage, kg; h_n – daily manure leachate production for day N of storage, (kg.

The total amount of released water vapor and other gases was calculated according to the equation:

$$E_{total} = M_1 - M_2 - H_h \quad (3)$$

where E_{total} – the weight of water vapor and other gases released, kg; M_1 – manure weight at loading, kg; M_2 – manure weight at the end of storage, kg; H_h – the weight of manure leachate released over the entire storage period, kg.

The daily amount of gas emissions according to bedding amount treatment was calculated in a similar manner.

Daily changes in individual variables monitored over time according to the amount of bedding per LU per day were modeled using nonlinear mixed regression models. Time and bedding amount were taken as fixed effects. The effect of the container was considered a random effect as each container bore specific error in relation to the specific cows, time of year, weather, method of manure handling, and so forth. The studied relationships were displayed in graphs of both daily and cumulative changes.

In order to meet the conditions for those methods used, daily changes in manure temperature was square root transformed. The remaining variables were not transformed.

We studied the relationship between total gas emission over 50 d of storage and bedding amount. We modeled this relationship using quadratic regression.

Test results with $P < 0.05$ were considered as statistically significant. Statistical analyses were performed in R statistical package version 3.0.2 (R Core Team, 2014).

RESULTS AND DISCUSSION

Daily gas emissions from stored manure (Fig. 2) rapidly increased immediately after manure loading and peaked around day 6 to 8 of storage. The highest emission values were from manure with the most bedding. The emissions subsequently decreased and production of gas emissions from stored manure gradually ceased around day 35 of storage. The course of gas emission is clearly related to intensity of microbial activity and stored manure temperature, as can be concluded from the similar course of manure temperature (Fig. 3).

We modeled daily production of emissions according to the amount of bedding per LU using a linear mixed model as: (1/time + 1/exp(time)) × bedding amount. Using the calculated model, we demonstrated that daily production of emissions was related to bedding amount in a statistically significant manner ($P < 0.001$).

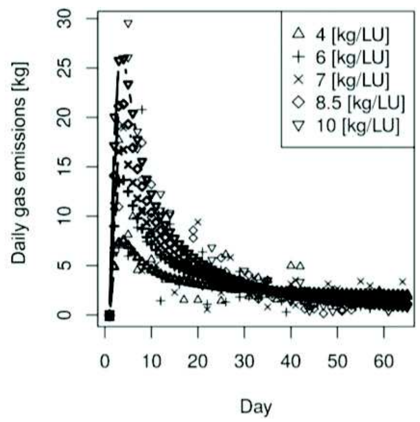

Figure 2. The course of daily emissions of water vapor and other gases from stored manure according to the amount of bedding per livestock unit (LU, with 1 LU = 500 kg live weight).

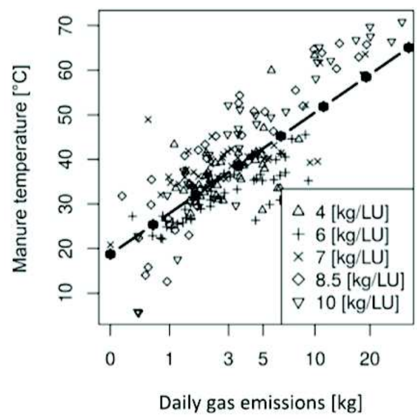

Figure 3. Correlation of internal manure temperature with various amounts of bedding per livestock unit (LU, with 1 LU = 500 kg live weight) and the daily amount of emissions produced.

Fig. 4 illustrates the cumulative course of gas emissions, clearly depicting that gas emissions depended on storage duration. The cumulative amount of gas emissions grew rapidly in all treatments. It is also possible to observe the effect of bedding on emission amounts.

Fig. 5 presents the total amount of gas emissions over 50 d of storage according to bedding amount. This figure also shows that the total amount of gas emissions grows with increased bedding amounts. This is clearly related to increased microbial activity and to the increased temperatures in manure with more bedding.

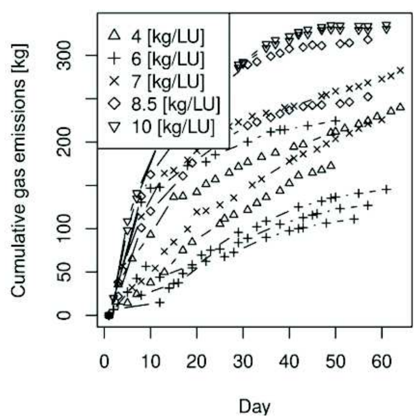

Figure 4. Cumulative emissions of water vapor and other gases from stored manure with various amounts of bedding per livestock unit (LU = 500 kg live weight) depending on storage duration.

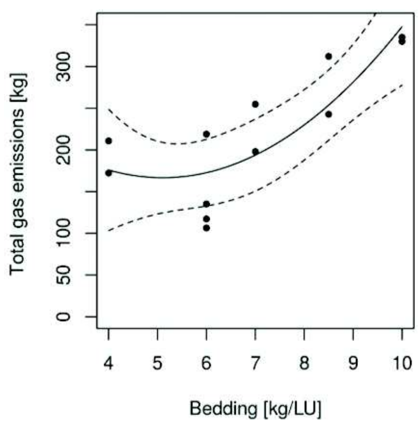

Figure 5. Total gas emissions over 50 d of manure storage according to the amount of bedding per livestock unit (LU, with 1 LU = 500 kg live weight). The solid line depicts the modeled relationship and the dashed line indicates the 95% confidence bands around the regression model.

We modeled the relationship between total gas emission and the amount of bedding per LU using quadratic regression. In the calculated model, the total amount of emissions was related to bedding amount in a statistically significant manner ($P = 0.004$). We have demonstrated that total gas emissions from stored manure for the entire duration of storage grew with increased bedding amounts.

The acquired results demonstrated that bedding amount had a significant effect on the properties of stored manure and thus confirmed the results of studies by other authors (Amon et al., 2001; Misselbrook & Powell, 2005; Gilhespy et al., 2009; Powell et al., 2013).

The selected methodical approach enabled acquisition of new data about the effect of bedding on the properties of stored manure and the course of their changes during storage. Data on gas emissions enable specification of current recommendations for manure management and manure-storage facility design (Ohio Livestock Manure Management Guide, 2006; Agricultural Waste Management, 2011). They will also be used to specify Czech law (Government of the Czech Republic, 2013) and principles for nitrate management in Nitrate Vulnerable Zones pursuant to EU requirements (Nitrates Directive, 1991; Government of the Czech Republic, 2012).

CONCLUSIONS

The acquired results confirmed the formulated hypothesis that bedding amount affects the amount of daily gas emissions and the total amount of emissions over 50 d of storage. We demonstrated a correlation between the amount of gas emissions and the internal temperature of stored manure. The daily and total amount of gas emissions grows with increased bedding amounts. This is clearly related to increased microbial activity and to the increased temperatures in manure with more bedding. The results show a new perspective on manure storage in the relation to the amount of bedding. Data on gas emissions enable specification of current recommendations for manure management and manure-storage facility design.

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