doi: 10.17221/7/2016-RAE

Manure leachate production and change in manure weight during the storage depending on the amount of bedding

Jiří Vegricht*, **Josef Šimon**, **Jiří Bradna**

Research Institute of Agricultural Engineering, Prague, Czech Republic

**Corresponding author: jiri.vegricht@vuzt.cz*

Abstract

Vegricht J., Šimon J., Bradna J. (2017): Manure leachate production and change in manure weight during the storage depending on the amount of bedding. Res. Agr. Eng., 63: 62–70.

In the experiment, a group of 10 dairy cows was housed in a pen bedded with various amounts of wheat straw (5.2–13 kg/cow per day). The resulting mixture of feces, urine and bedding was stored in cubic containers with a volume of 1.5 m^3. At regular intervals, the containers containing manure were weighed and manure leachate production was assessed. Daily changes in individual monitored variables over time in accordance with the amount of bedding per livestock unit per day (1 livestock unit = 500 kg live weight) were modelled using nonlinear mixed regression models. It was determined that manure weight changes and daily production of manure leachate released from manure stored in containers were related to storage duration and bedding amount in a statically significant manner. The results support the hypothesis that the amount of bedding has a statistically significant effect on the properties of manure stored in a manure pile.

Keywords: manure weight; bedding amount; manure leachate production

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.

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).

The total production of nitrogen depends upon farm animals´ species, their weight, feeding, utilization and other factors. The great importance for decreasing environmental impacts from nitrogen has proper management of the production, storage, application and use of manure from livestock (ASAE 2005; Agricultural Waste Management 2011; Powell et al. 2013).

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 (Council Directive 1991 (Nitrates Directive); 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 (Vegricht et al. 2010).

Supported by the Ministry of Agriculture of the Czech Republic, Project No. NAZV QJ1330214.

doi: 10.17221/7/2016-RAE

A major source of pollutants is manure produced from livestock in farms. Many animals on Czech farms are kept in barns with bedding (Vegricht 2014). 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, mixed with other manure and unconsumed feedstuffs, removed from the barn, and then it 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 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. (ASAE 2005; Agricultural Waste Management 2011; Misselbrook et al. 2004).

Bedding and its properties and amount also affect the quantity of gas emissions from the stored manure. Increasing proportions of bedding and correspondingly boosting 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).

From this perspective, there is a pressing need for more detailed understanding of the processes occurring in the stored manure, and in particular manure leachate production.

Manure leachate, which is released from manure during storage, is a substantial source of environmental pollution, which can contaminate surface and underground water if not stored properly (Brandjes et al. 1996; Sommer, Jacobsen 1999; Vegricht et al. 2012).

Manure leachate is formed not only during manure storage, but also within the cattle barn in the cases of such stabling systems that enable its separate collection (Jeppsson 1999; Misselbrook, Powell 2005; Horlacher, Rutzmoser 2015).

The main source of manure leachate, however, is manure stored in a manure pile. The properties of the stored manure and the amount of manure leachate released are affected by a number of factors and influences. These include in particular the following:

- species, weight, feeding and use of the livestock;
- type, amount, quality and physical and mechanical properties of the bedding;
- climatic conditions during storage;
- manure treatment during storage;
- height of the stored manure layer;
- losses during storage.

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; Nennich et al. 2005; Government of the Czech Republic 2013, Horlacher, Rutzmoser 2015).

The amount of released manure leachate is influenced by the production of feces and urine and the quantity and characteristics of bedding. Some authors indicated that with sufficient amount of bedding absorbing urine and manure leachate did not release from the stored manure (Misselbrook, Powell 2005; Horlacher, Rutzmoser 2015).

Chopped cereal straw is most often used for bedding. Bedding absorbs a part of urine and contributes to an increase of manure dry matter and reduction of manure leachate production. Bedding absorption ability significantly affects dry matter of produced manure and is dependent on the type of bedding and its properties. Bedding absorbency consisting of chopped straw identified by various authors is given in Table 1.

Practical experience shows that during storage changes in the weight and volume of the stored manure also occur as well as nutrient losses due to microbial activity, manure leachate production, and emissions of water vapour and other gases (Hubbard, Lowrance 1998; Gilhespy et al. 2009; Weerden et al. 2013). However, there is no detailed information about changes in the properties of the stored manure that occur during the storage process.

This is essentially a deeper understanding of the changes in weight during manure storage and dynamics and the overall production of manure leachate from the stored manure depending on the quantity and characteristics of bedding and storage duration.

This understanding is important for defining principles for the proper storage and treatment of manure during storage and application. It is also important for the proper design and building of manure storage facilities and sizing of tanks for collecting manure leachate, which is required by

doi: 10.17221/7/2016-RAE

Table 1. Bedding absorbency of chopped straw by various authors (kg of urine/kg of bedding)

Ohio Builten 604/06 (2006)	Misselbrook and Powell (2005)	Horlacher and Rutzmoser (2015)	Kavka et al. (2008)	Dostál et al. (2014)
2.2	2.9	1.8	2.4	2.8–3.5

the applicable legislation (Council Directive 1991; Government of the Czech Republic 2013).

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

There is 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 properties of manure during storage in a pile. These are in particular change in weight of the stored manure, amount of manure leachate released and the dynamics of that release during storage in a pile.

The objective of these experiments was to test the assumptions expressed in the hypothesis and contribute to a better understanding of changes in the properties of 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 group of dairy cows housed in a pen bedded with varying amounts of wheat straw. The pen had a flat and impermeable concrete floor sealed against leakage of fluids. The determined amount of bedding was spread at regular intervals over the entire pen. Dairy cows were free to move around the entire pen and their movements mixed their excrements into the bedding.

Experimental conditions:
Number of dairy 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: 14–16%
Bedding amount: 4–10 kg/LU per day (1 livestock unit = 500 kg live weight), i.e. 5.2–13 kg/cow per day
Average daily production of manure (bedding amount 4 kg/LU per day): 41.5 kg/LU, i.e. 54 kg/cow.

In order to create sufficient manure and ensure cow cleanliness and comfort, bedding corresponding to the amount to be provided over 2 days was put down in the pen at the start of the experiment.

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 2.

After each 48 h, the mixture of feces, urine and bedding was removed from the pen and mixed using a front-end loader and then placed in storage containers with watertight bottoms and walls and having the following dimensions:
– width: 1,135 mm
– length: 1,135 mm
– height: 1,170 mm
– volume: 1.507 m^3

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

Table 2. Bedding amounts added to the pen for individual treatments

Item	Treatment				
	4 kg/LU[2]	6 kg/LU	7 kg/LU	8.5 kg/LU	10 kg/LU
Bedding amount (kg/LU per day)	4.0	6.0	7.0	8.5	10.0
Bedding amount (kg/cow per day)	5.2	7.8	9.1	11.1	13.0
Total bedding amount in pen for 10 cows[1] (kg)	104.0	156.0	182.0	222.0	260.0
Specific amount of bedding in pen[1] (kg/m^2)	1.3	1.9	2.2	2.7	3.2

[1]bedding corresponding to twice the daily amount was put down in the pen at the start of the experiment; [2] LU = livestock unit (500 kg live weight)

doi: 10.17221/7/2016-RAE

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 and the amount of released manure leachate was weighed.

Each experiment was repeated 2 times, always with the same amount of bedding. Exception was the experiment with bedding of 6 kg/LU per day. It was repeated 4 times. This experiment was repeated more frequently due to the need to understand in more detail the behaviour of stored manure with 6 kg bedding/LU per day. That amount is considered under Czech law (Government of the Czech Republic 2012) 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.

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

$$m_p = m \times 1{,}000/M_1 \qquad \text{(kg)}$$

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

Other monitored variables (volume, density) were converted for evaluation purposes in a similar manner.

Daily changes in individual variables monitored over time according to the amount of bedding per 1LU/day were modelled using nonlinear regression models with mixed effects. 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 the methods used, daily changes in manure leachate production were logarithmically transformed. The remaining variables were not transformed.

The relationship between total manure leachate production over 50 days of storage and bedding amount was further studied and was modelled using quadratic regression. Total weight decrease over 50 days was analysed similarly.

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

Based on the results acquired using the aforementioned methodology and the stated hypothesis, the following changes and processes were analysed and evaluated occurring in manure stored in individual containers according to the bedding amount and storage duration.

Parameters that were analysed and evaluated:

– manure leachate production from stored manure according to the bedding amount;
– relationship between total manure leachate production over 50 days of storage and bedding amount;
– changes in stored manure weight according to the bedding amount;
– relationship between total manure weight decrease over 50 days of storage and the bedding amount.

Fig. 1 displays the relationship between the bedding amount and daily production of manure leachate from manure during storage. In all experiments, daily manure leachate production increased rapidly during the first days after filling and reached its peak on day 8 to 10 of storage. The highest manure leachate production intensity was demonstrated by the containers with the lowest amounts of bedding. Daily production of manure leachate released from the stored manure decreased with increasing bedding amounts. During further storage, manure leachate production intensity gradually decreased and the effect of bedding amount on the amount of manure leachate released also decreased. Manure leachate production ceased after approximately 55 to 60 days of storage.

To evaluate this relationship statistically, a linear mixed model was used in which the monitored variable (i.e. daily manure leachate amount) was modelled in logarithmically transformed form as: (time + 1/time) × bedding amount.

The calculated model found a statistically significant relationship between daily manure leachate production and bedding amount ($P < 0.001$).

Fig. 2 displays the cumulative production of manure leachate from manure with various bedding

doi: 10.17221/7/2016-RAE

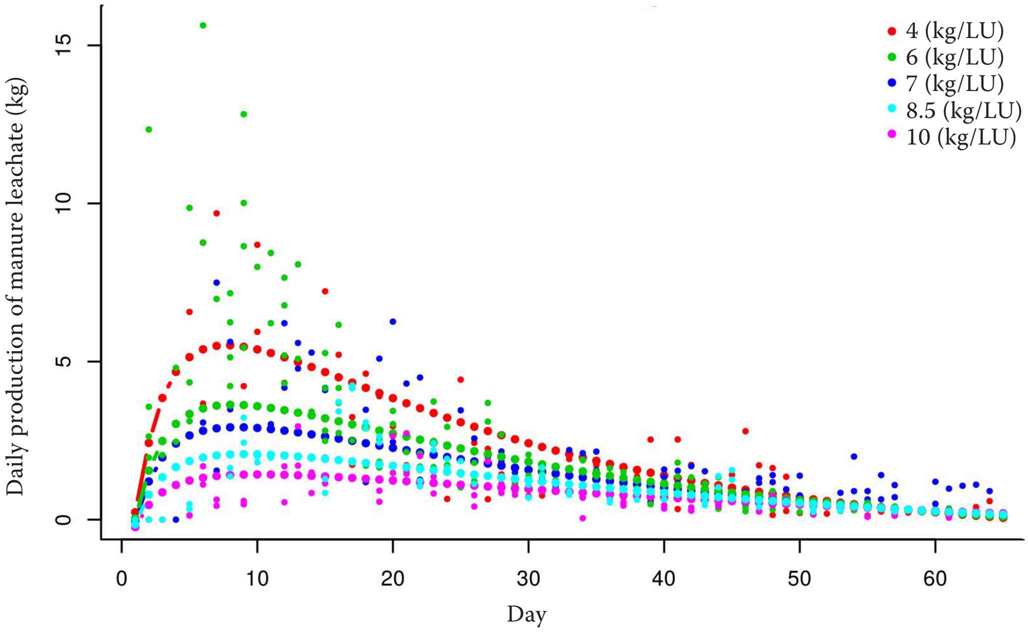

Fig. 1. Daily production of manure leachate released from manure with various amounts of bedding per livestock unit (1 LU = 500 kg live weight) stored in containers depending on storage duration and bedding amount

amounts stored in individual containers plotted against storage duration.

This essentially uses the data from monitoring daily production of manure leachate production (Fig. 1). The total amount of manure leachate released for the storage period was calculated as:

$H_n = h_1 + h_2 + ...h_n$

where: H_n – the total amount of manure leachate released over the monitored storage period (kg); n – the total number of storage days; h_n – the amount of manure leachate released on day N of storage (kg)

Fig. 2 illustrates both the determined statistically significant relationship between manure leachate production and bedding amount (P = 001, Fig. 1)

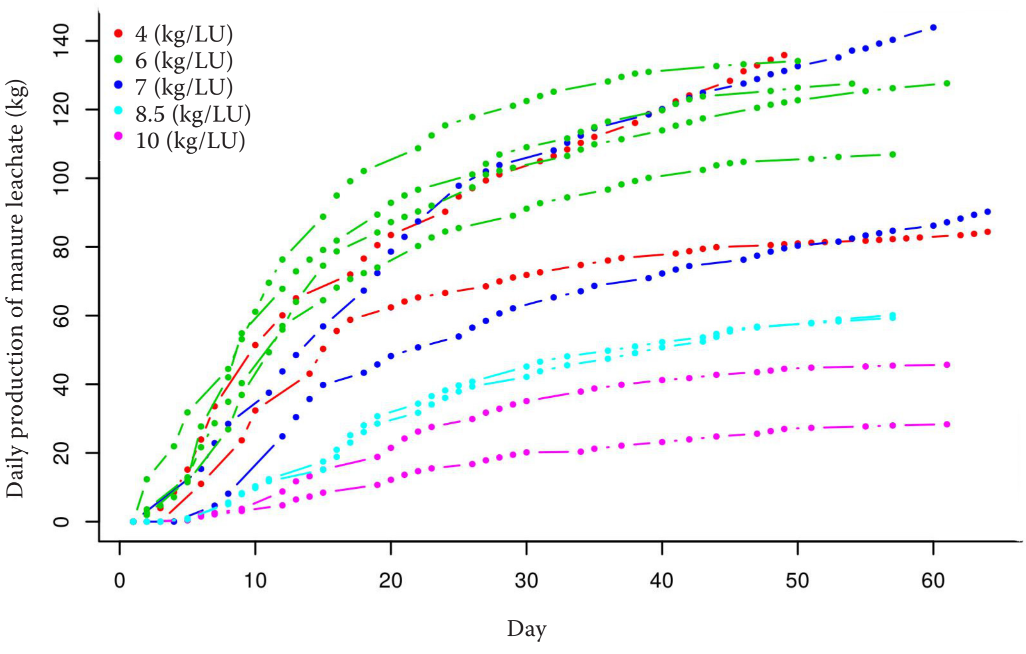

Fig. 2. Cumulative manure leachate production from manure with various amounts of bedding per livestock unit (1 LU = 500 kg of live weight) stored in individual containers over the course of storage

doi: 10.17221/7/2016-RAE

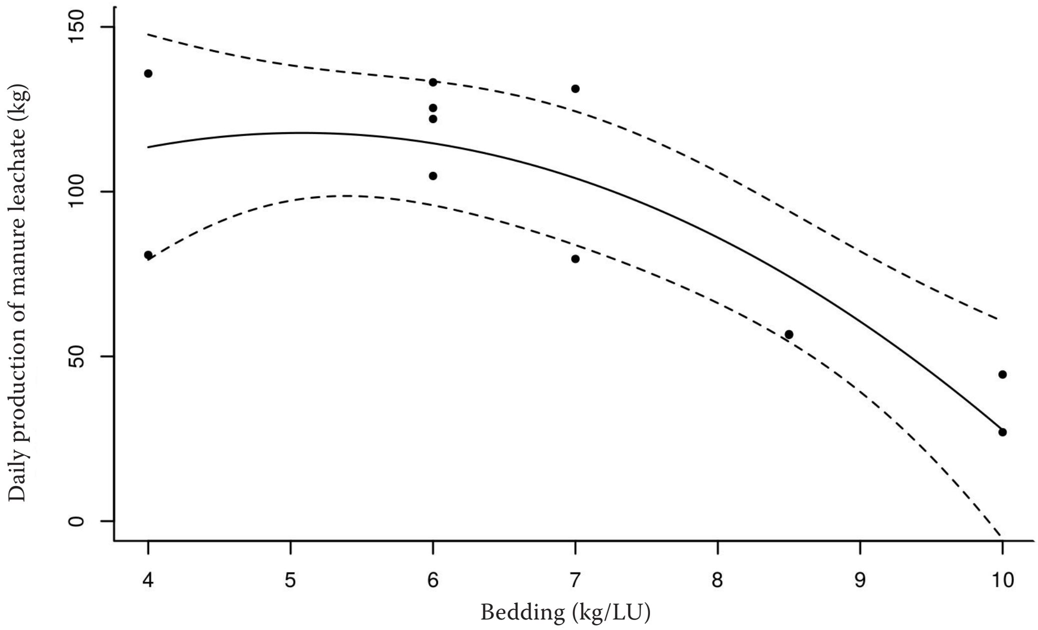

Fig. 3. Relationship between bedding amount and total amount of manure leachate released from manure with various amounts of bedding per livestock unit over a total of 50 days of storage.

and the variability of manure leachate production in individual containers, which was accounted for in the model. In all experiments, manure leachate production rapidly increased immediately after loading and the growth in total manure leachate amount slowed around day 20–30 depending on the amount of bedding; the amount of released manure leachate reached approximately 3–15% of the weight of manure after loading.

The overall amount of manure leachate production from the stored manure is important for sizing manure leachate storage facilities. It is clear from Fig. 2 that manure leachate production intensity diminished with increased bedding amounts, and so did the total amount of manure leachate released. Total manure leachate production decreased the most with bedding amounts greater than 6 kg/LU. For example, total manure leachate production over 50 days of storage was three to five times higher when bedding was 4 to 6 kg/LU than it was for bedding of 10 kg/LU.

This is illustrated by Fig. 3, which depicts the relationship between bedding amount and the total amount of manure leachate released over 50 days of storage.

The relationship between total manure leachate production and the amount of bedding per LU using quadratic regression was modelled.

In the calculated model, bedding amount had a statistically significant effect (P = 0.003) on total leachate production.

Total production of manure leachate during the first two months of storage is less than 15% compared to the weight of manure at the time of loading, regardless of amount of bedding. The production decreases with increasing amounts of bedding. Our measured output is lower than reported in the literature.

Government of the Czech Republic (2013) with straw bedding 4.0 kg/LU per day (suction capacity 2.4 kg of urine/kg of straw) reports manure leachate production (no process water) corresponding to 18.6% of the weight of fresh manure. However, when counting in process water (15 kg/1 cow per day), which is stored with manure leachate, the total mass of manure leachate and process water corresponds to 54% of the weight of fresh manure. This fact agrees well with Betriebsplanung Landwirtschaft (2014), which show that with the bedding of 5.4 kg/LU per day for dairy cows the total amount of manure leachate (obviously including the process water and the proportion of rainfall), is more than 60% of the weight of fresh manure at the time of loading. One of the reasons for the different outcomes of the total production of manure leachate can therefore be attributed to the different

doi: 10.17221/7/2016-RAE

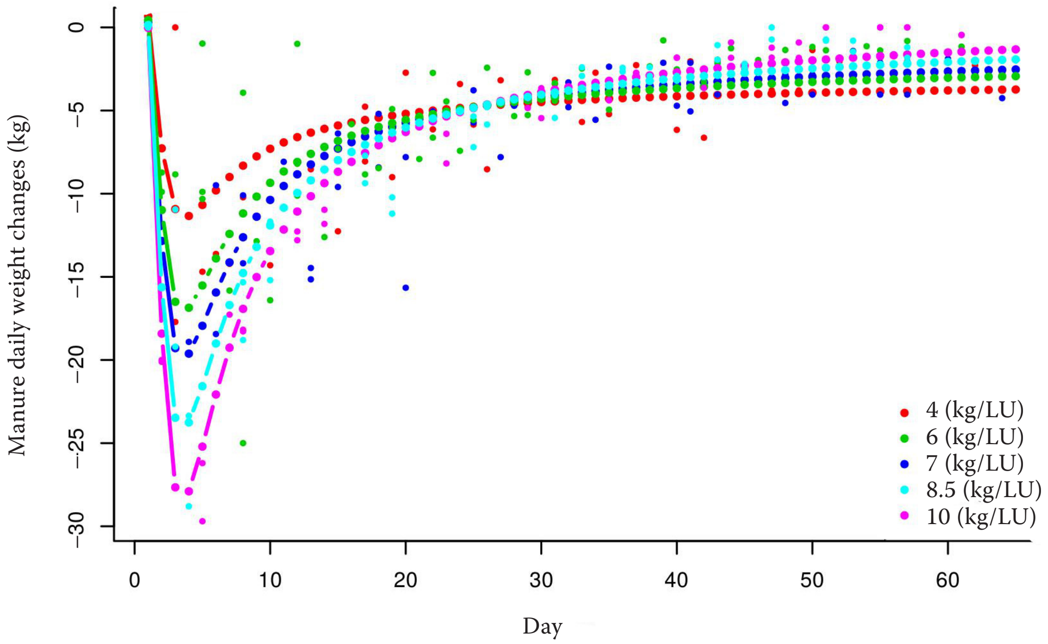

Fig. 4. Changes in manure weight during the storage according to the amount of bedding

methodology of our experiments (not taking into account technological water and rainfall). The obtained data from scientific literature count with a certain proportion of process water and rainfall in stored manure.

The observed correlation between the total production amount of manure leachate and bedding (Fig. 3) is statistically significant (P = 0.003) and its progress is rather polynomial. This finding is not supported by the data of Horlacher and Rutzmoser (2015) who assume a linear dependence.

Fig. 4 presents daily changes in manure weight during storage according to the bedding amount. In all cases, a similar progression was found in dependence when largest daily decreases in stored manure weight occurred during the first days of storage.

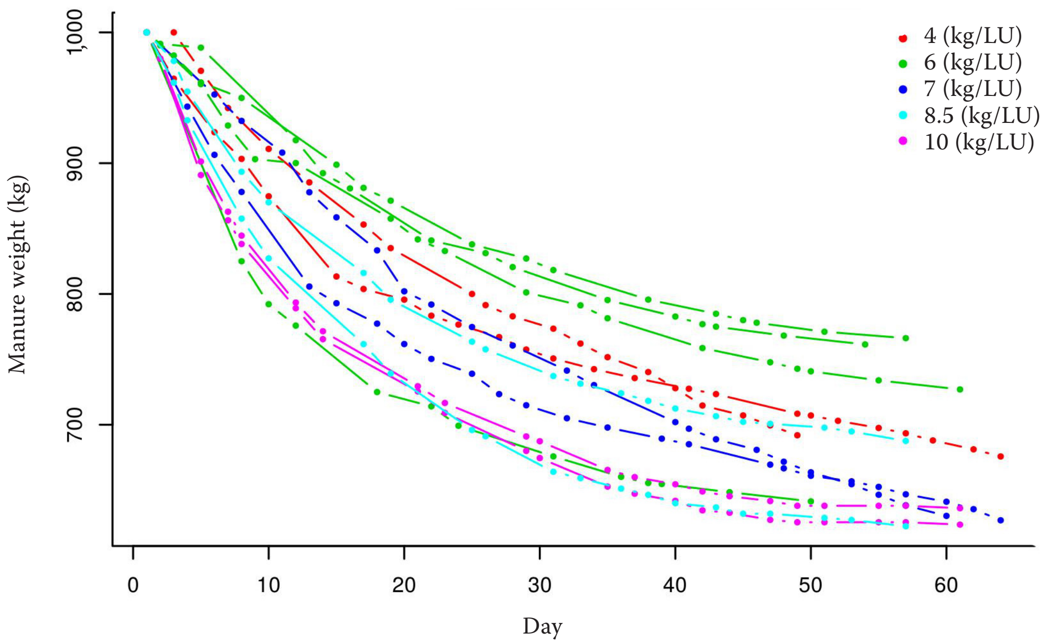

Fig. 5. Changes in weight of the stored manure according to the amount of bedding

doi: 10.17221/7/2016-RAE

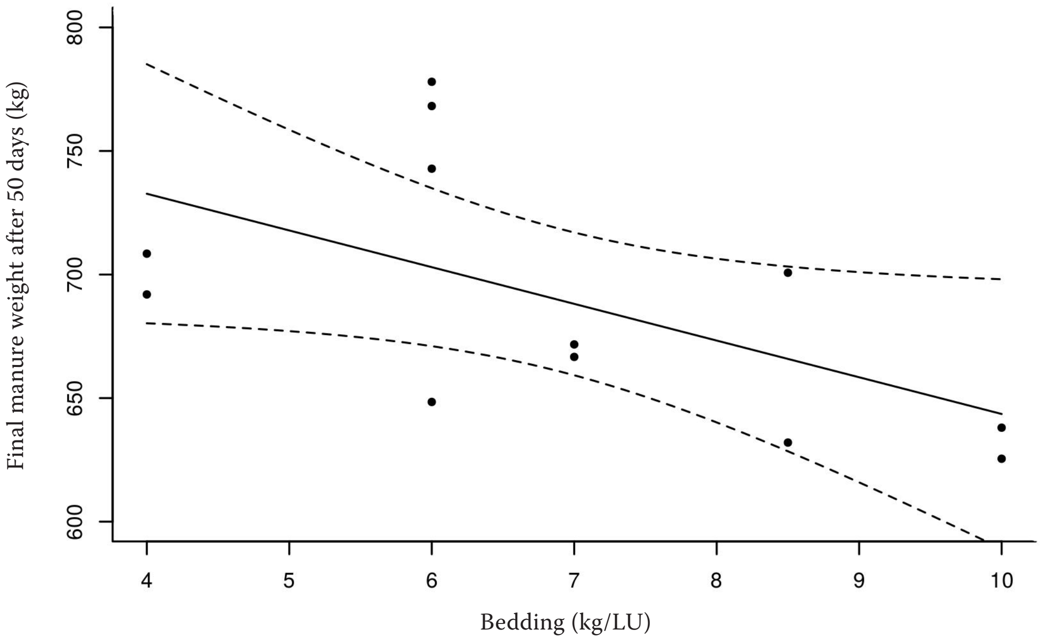

Fig. 6. The relationship between manure weight change and the amount of bedding

Manure weight decreased the fastest for manure with the most bedding. This can be explained by the manure with the most bedding having the greatest microbial activity. By days 20 to 25 of storage, the effect of bedding amount on daily weight decrease was relatively small. At the same time, it appears that the character of weight decreases was changing during this period and the weight of manure with less bedding was decreasing more slowly than was that of manure with more bedding. A possible explanation for this is a slower maturation process and less microbial activity in manure with less bedding.

In the calculated model, daily changes in manure weight were related to the bedding amount in a statistically significant manner ($P < 0.001$).

Fig. 5 depicts the total change in manure weight over the course of storage. As stated above, decreases in stored manure weight can be attributed to a release of manure leachate and emissions of gases, primarily water vapour, as a result of microbial activity and increased manure temperature over the course of storage.

Over the 2 months of storage, manure weight decreased by 20% to 35% compared to its weight at loading (Fig. 5). This corresponds to data from scientific literature (Hubbard, Lowrance 1998; Betriebsplanung Landwirtschaft 2014; Dostál et al. 2014).

In order to determine the proper field application rate for manure, it is necessary to know the total change (decrease) in manure weight during storage. Fig. 6 illustrates the change in manure weight during 50 days of storage according to the bedding amount. Similarly as in the case of daily weight changes, this relationship was multifactorial and weight change did not depend solely on the bedding amount.

The relationship between total manure weight decrease over 50 days of storage and the amount of bedding/LU using linear regression was modelled.

In the calculated model, a statistically significant relationship between manure weight decrease over 50 days and bedding amount ($P = 0.052$) was not found, i.e., it was not demonstrated that the weight loss of manure for 50 days depended on the amount of bedding. However, the value of $P = 0.052$ is very close to the limit value of $P = 0.05$ and it is therefore possible to assume that there is a close relationship between the amount of bedding and weight loss of the stored manure.

CONCLUSION

The acquired results confirmed the formulated hypothesis that bedding amount affects the properties of stored manure and changes in those properties during storage. It was demonstrated that bedding amount had a significant effect on the daily manure leachate production, the total amount of manure

doi: 10.17221/7/2016-RAE

over 50 days of storage and daily changes in manure weight. It was also demonstrated that the overall weight change of stored manure is dependent on the daily amount of bedding. The used methodology is suitable for investigating the impact of bedding to change of the stored manure properties and it can be recommended to continue in research of the bedding amount impact on the properties of manure.

References

Agricultural Waste Management (2011): Field Handbook. Part 651. 2011. United States Department of Agriculture, Washington, D.C., Natural Resources Conservation Service (210–VI–AWMFH, Amend. 44, April 2011).

Amon B., Amon Th., Boxberger J. (2001): Emissions of NH_3, NO_2 and CH_4 from dairy cows hosed in a farmyard manure tying stall (housing, manure, manure spreading. Nutrient Cycling in Agroecosystems, 60: 103–113.

Aguerre M.J., Wattiaux M.A., Hunt T., Lobos E. (2012): Effect of nitrogen content and additional straw on changes in chemical composition, volatile losses, and ammonia emissions from dairy manure during long term storage. Journal of Diary Science, 95: 3454–3466.

ASAE (2005): Manure Production and Characteristics. ASAE Standard, D384.2. American Society of Agricultural Engineers, St. Joseph, USA.

Betriebsplanung Landwirtschaft 2014/2015 (2014): Darmstadt, KTBL.

Brandjes P.J., de Wit J., van der Meer H.G., van Keulen H. (1996): Environmental impact of animal manure management. Livestock and the environment, Finding a balance. International Wageningen, Agriculture Centre.

Dostál et al. (2014): Monitoring produkce statkových hnojiv. AGROEKO Žamberk, s.r.o.

Gilhespy S.L., Webb J., Chadwick D.R, Misselbrook T.H., Kay R., Camp V., Retter A.L. Bason A.. (2009): Will additional straw bedding in buildings housing cattle and pigs reduce ammonia emissions? Biosystems Engineering, 102: 180–189.

Government of the Czech Republic (2012): Nařízení vlády č. 262/2012 Sb. o stanovení zranitelných oblastí a akčním programu, Ministerstvo zemědělství ČR.

Government of Czech Republic (2013): Vyhláška č. 377/2013 Sb. ze dne 25. 11. 2013 o skladování a způsobu používání hnojiv. Sbírka zákonů České Republiky.

Horlacher D, Rutzmoser, K. (2015): Festmist- und Jaucheanfal. Darmnstadt, KTBL.

Hubbard R.K., Lowrance R.R (1998): Management of dairy cattle manure. In: Wright R.J, Kemper W.D.,. Milner P.D, Power J.F., Korcak R.F. (Eds.): Agricultural Uses of Municipal Animal and Industrial Byproducts. US Department of Agriculture, Agricultural Research Service, Conservation Research, Report No. 44: 91–102.

Jeppsson K.H. (1999): Volatilization of ammonia in deep-litter systems with different bedding materials for young cattle. Journal of Agricultural Engineering Research, 73:49–57.

Kavka M. et al. (2008): Výběr z normativů pro zemědělskou výrobu ČR pro rok 2008/2009. Prague, UZPI.

Kohn R.A. (2015): Nitrogen Emissions from Animal Agricultural Systems and Strategies to Protect the Environment. In: CAB International 2015. Livestock Production and Climate Change: 61–73.

Misselbrook T.H., Powell J.M. (2005): Influence of bedding material on ammonia emissions from cattle excreta, Journal of Diary Science, 88: 4304–4312.

Nennich T.D., Harrison J.H., VanWieringen L.M., Meyer D., Heinrichs A.J., Weiss W.P., St-Pierre N.R., Kincaid R.L., Davidson D.L., Block E. (2005): Prediction of manure and nutrient excretion from dairy cattle. Journal of Diary Science, 88: 3721–3733.

Ohio Livestock Manure Management Guide (2006): Bulletin 604, Ohio State University. Available at www.ohioline.ag.ohio-state.edu

Powell J.M., MacLeod M., Vellinga T.V., Opio C., Falcucci A., Tempio G., Steinfeld H., Gerber P. (2013): Feed–milk–manure nitrogen relationships in global dairy production systems. Livestock Science, 152: 261–272.

R Core Team (2014): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available http://www.R-project.org/

Sommer S.G., Jacobsen O.H. (1999): Infiltration of slurry liquid and volatilization of ammonia from surface applied pig slurry as affected by soil water content. The Journal of Agriculture Science, 132: 297–303.

Vegricht J., Klír J., Ambrož P., Fabiánová M., Miláček P., Šimon J. (2010): Využití statkových hnojiv v rostlinné výrobě, Náš Chov, 70: 31–33.

Vegricht J., Ambrož P., Šimon J., Klír J. (2012): Modelování produkce dusíku ve statkových hnojivech a jeho ztrát v závislosti na způsobu ustájení, skladování a aplikace na poli. Náš chov, 72: 32–34.

Vegricht J. (2014): Zpráva o plnění veřejné zakázky „Finanční strategie financování implementace směrnice v roce 2014". Prague, VÚZT.

Weerden T., Luo J., Dexter M., Kear M. (2013): Does adding straw or sawdust to catle excreta reduce ammonia, nitrous oxide and methane emission during storage? Available at http://flrc.massey.ac.nz/workshops/13/Manuscripts/Paper_VanDerWeerden_2013.pdf

Received for publication January 22, 2016
Accepted after corrections May 25, 2016