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Economic evaluation of wood pellets in equine husbandry in consideration of ethological and stall climatic parameters

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While straw and wood shavings are among the most commonly used bedding materials in the field of equine husbandry and their properties have been described in a large number of studies, wood pellets as a bedding material are still relatively unknown and hardly any research has been conducted in this area so far. Consequently, the wood pellets were tested in a practical environment at a horse farm with single stalls and compared with wheat straw and wood shavings. In addition to providing an economic comparison of the three bedding materials, differences in horse behaviour and stall climate were also investigated.

From an economic point of view, the use of wood pellets proved to have the lowest labour and material costs. However, the horses spent less time foraging and lying down with wood pellets and higher dust and ammonia concentrations in the air were measured. However, the climatic limits of the stall were clearly undercut with all three types of bedding. Wheat straw was found to be the bedding material that came closest to the horses' needs, while the wood pellets were convincing due to their high potential for cost savings.

Keywords
Bedding, horse, wood pellets, stall climate, horse behaviour, costs

Given favourable individual farm conditions, horse boarding represents a welcome source of income for agricultural enterprises (Hassenpflug and Schindler 2011). Single stalls are still the most popular and predominant method of keeping horses (Zeitler-Feicht 2015). Regular and thorough mucking-out and bedding contribute to the good reputation of a horse boarding farm (Marten 2004). Since, in addition, the longest possible working life of the horses is to be strived for in order to compensate for the high costs of keeping, training and rearing, maintaining the health of the horses (Hoffmann 2011) is also essential in terms of animal protection (TierSchG 2006).

The "Leitlinien zur Beurteilung von Pferdehaltungen unter Tierschutzgesichtspunkten" (Guidelines for the assessment of equine husbandry from an animal welfare perspective) (BMELV 2009) describe the requirements for stall floors and bedding. Floors must be stable and slip-resistant and the resting area must be malleable. The bedding materials should have a high degree of absorbency and prevent the development of increased concentrations of harmful substances. Furthermore, they should be dry and of high quality. It also makes reference to the fact that the material should be free of mould, dust and toxic substances (BMELV 2009).

There has hardly been any research on wood pellets as a bedding material. According to the manufacturer, the pellets are made of 100% untreated softwood without any additives and are therefore harmless to the health of horses. The manufacturer claims the use of wood pellets results in 80% less

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manure volume, faster rotting, good composting properties, space-saving storage, low consumption and savings in terms of time and money.

The aim of the study was to compare the use of wood pellets as bedding material with the use of wheat straw and wood shavings in single stalls from an economic point of view. For this purpose, the bedding consumption, the manure volume and the working time requirements were evaluated within a practical framework at a farm in Southern Germany. Furthermore, horse behaviour as well as dust and ammonia concentrations in the air of some stalls were examined.

State of knowledge

Economy

With regard to the economic efficiency of bedding material, the bedding price in connection with consumption (Buck 2012) also plays an important role in addition to labour economics (Haidn et al. 2002). In addition, the boarding stable operator should consider seasonal as well as regional availability, delivery conditions, required storage capacities and manure quantities (Buck 2012).

According to KTBL (2016), a price of € 120/t could be estimated for straw square bales in 2016 (price range: € 70-180/t). When using softwood shavings without bark, KTBL (2016) applied a calculation value of € 379/t for the same period (price range: € 294-514/t). For unprocessed lignocellulose pellets, a calculation value of € 188/t was also used for 2016 (price range: € 180-195/t) as well as € 410/t (price range: € 380-450/t) for processed lignocellulose pellets (KTBL 2016).

The data on the amount of supplementary straw for rebedding per stall varied between 30 and 55 dt/a with Jaep (2004) and Marten (2004). Likewise, Nebe (2005) with 9.45 kg of supplementary straw for rebedding per stall and day (35 dt/a) and Häussermann et al. (2002) with 10.8 kg of supplementary straw per stall and day using the part muck-out system (39 dt/a) reported a rebedding quantity of the same scale. This also applied to the consumption of coarse wood shavings by Häussermann et al. (2002). With the part muck-out system this was 10.6 kg daily (39 dt/a).

Mucking-out takes up most of the time spent on routine work with single stalls, whereby the working time required per stall is largely independent on the size of the farm (Haidn et al. 2002). Haidn et al. (2002) reported the working time requirement for the muck-out independent of the bedding material at 61.91 working hours per horse and year, whereas Fuchs et al. (2012) reported only just under half the working time requirement at 4.39 working hours per horse and day (26.7 working hours per year). Jaep (2004) states 30 hours per horse and year for a large horse with grazing and 47 hours per horse and year for mucking-out and bedding without grazing. In a study conducted by von Borstel et al. (2010) a working time of 22.8 hours per horse and year was determined for the maintenance of a stall with straw using the deep litter system. Nebe (2005) reported a daily working time of 10 min/stall for straw bedding (61 h/a), 7.5 min/stall for wood shaving bedding (46 h/a) and 8 min/stall for wood pellet bedding (49 h/a).

Horse behaviour

Equine husbandry should always be based on the natural, innate behaviour of the animals and the resulting needs (Zeitler-Feicht 2013). The basic needs of horses have remained virtually unchanged to this day (BMELV 2009). Therefore, the smaller the deviation from the time budget of free-living equidae is, the more animal-friendly the husbandry of horses is (Pirkelmann et al. 2008). Horses living freely in the Camargue region spend 60% of the day eating, 20% standing, 10% lying down and 10% doing other things (Duncan 1980 and Kiley-Worthington 1989 quoted from Zeitler-Feicht 2015).

Stall climate

A further vital aspect for the assessment of bedding materials is their influence on the climate in the stall, as a horse's respiratory tract reacts extremely sensitively to excessive concentrations of specific gases and dust (Fleming 2008). Poor air quality in the stall can be the cause of diseases of the respiratory system of horses (Fritz and Maleh 2016). Respiratory diseases can be of infectious origin, but can also be caused by irritant or toxic gases or by inhaling dust particles (Meyer et al. 2014). Just how strong the negative consequences of dust can be fundamentally depends on the size of the particles (Art et al. 2002, Garlipp 2011). Based on this, a classification is made into inhalable particles (PM < 100 µm), thoracic particles (PM < 10 µm) and the alveolar fraction (PM < 5 µm) (DIN EN 481 1993 cited after Garlipp 2011). While the coarse dust (inhalable particles, PM > 10 µm) has a relatively low damaging effect, the smaller dust fraction (alveolar particles, PM < 5 µm) poses a health risk (Fuchs et al. 2012). According to Meyer et al. (2014), a proportion of dust particles of 0.2 to 0.8 mg/m^3 is generally found in horse stables.

Ammonia is one of the most harmful gases in horse stables (BMELV 2009). Excessively high concentrations can impair the health of horses (Everything Horse 2018, Oke n.y.). High exposure can cause irritation and, as a consequence, micro lesions in the mucous membranes of the respiratory tract, which act as an open point of entry for germs (Fritz and Maleh 2016). Furthermore, this impairs the exchange of gases in the lungs (Pirkelmann et al. 2008). In order to avoid endangering the health and well-being of horses, the limit value of 10 ppm should not be exceeded (BMELV 2009).

Materials and methods

Examination site and animals

At a farm in Southern Germany, the use of wood pellets as a bedding material was compared to the use of wheat straw and wood shavings in single stalls. For the investigations, which took place in summer 2016, extending over two periods of six days each, 14 stalls in one of the stable wings were used (Figure 1). The horses were warmbloods and were between three and 15 years old.

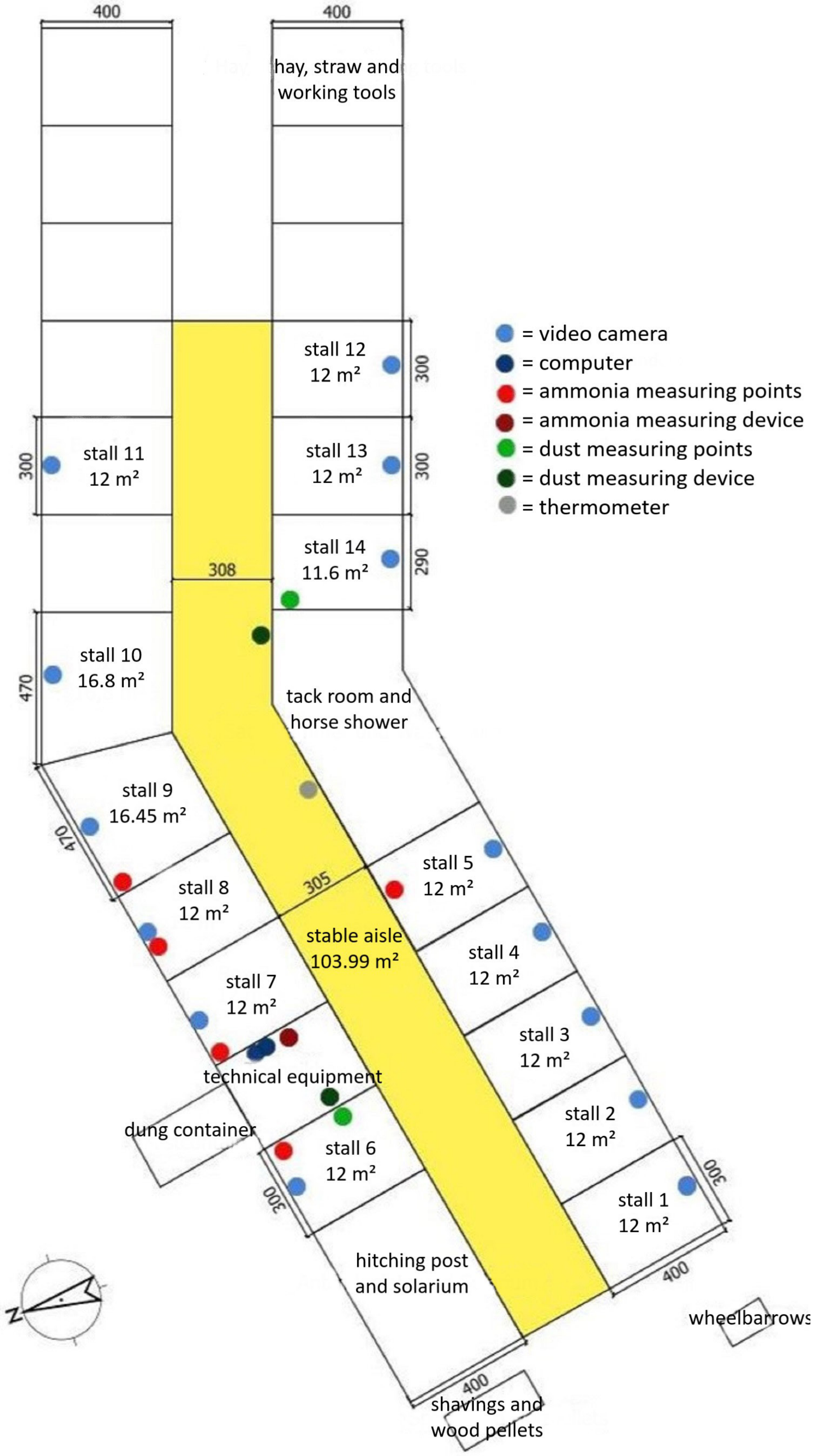

Figure 1: Stable plan with indication of the locations of the measuring devices and the corresponding measuring points

Examination procedure

During the first week of the study in early August, half of the 12 m^2 stalls were spread with wheat long straw, the other half with wood shavings. Adjacent stalls were selected according to the bedding already used (wheat straw/wood shavings) so that an additional acclimatisation period was not necessary and a comparison of the wood pellets with the usual materials could be made. At the end of the first week of the study, 12 of the 14 stalls were changed over to wood pellet bedding. One wheat straw stall and one wood shavings stall each were retained as control stalls in order to be able to identify and evaluate any environmental influences on the study. Following a period of acclimatisation, the second data collection took place at the beginning of September. To ensure that the examinations could take place in both weeks under similar climatic conditions, the acclimatisation period was limited to four weeks.

Temperature and relative humidity were measured every five minutes during data collection with the centrally located multi-data logger "DL-181THP" (Voltcraft, Conrad Electronic SE, Hirschau, Germany). The comparability of the two examination phases was given, since only a slight difference was determined regarding the temperature (WT: p = 0.813; period 1: 20.88 ± 3.4 °C; period 2: 20.73 ± 3.4 °C) and the relative humidity (WT: p = 0.99; period 1: 65.40 ± 10.5%; period 2: 67.80 ± 8.1%).

The manure was removed manually twice a day with a wheelbarrow. Given the practical conditions, different mucking-out systems were used. The wheat straw and wood shavings stalls were mucked-out using the part muck-out system and the wood pellet stalls using the deep litter system. Rebedding with wheat straw was performed daily and with the wood shavings and wood pellets as required. The initial spreading of the wood pellets was done as per the manufacturer's instructions with 1 sack/m^2 stall surface and was moistened with 8 litres of water/sack to accelerate the formation of a deep litter bed. According to the manufacturer, the weekly rebedding of 1-2 sacks of wood pellets of 15 kg each and the daily superficial removal of horse manure as well as soaked spots should maintain the functionality of the deep litter. The work was carried out by two workers who were assigned the same stalls during both phases of the study. The samples can therefore be described as dependent.

Bedding consumption per horse and day was measured on the basis of the amount of wood pellet sacks, wheat straw and wood shaving bales consumed. For wood pellets and wood shavings, the number of sacks or bales consumed per stall were recorded, while the weight of the straw bale was divided by the number of stalls with one bale. This procedure was repeated for three bales of straw and the values were then averaged. The manure was filled into a box to collect the manure mass and weighed with the digital box scale "profiscale TARA PS 7600" (Burg-Wächter KG, Wetter, Germany). Its measuring accuracy is +/- 100 g for weights up to 10 kg and +/- 1% for weights over 10 kg. The workload was assessed solely on the basis of working time. To this end, the working time expenditure was recorded based on the time element method (Jungbluth et al. 2005). The working time expenditure refers to the time actually spent on a work task by a worker (WP) (Jungbluth et al. 2017). It is expressed in WPh, WPmin and WPcmin (Jungbluth et al. 2017). The time measurement was carried out for the time elements "mucking-out", "rebedding", "emptying wheelbarrow" and "sweeping stable aisle" using a Microsoft Excel add-in.

The wheat straw was purchased in the period under examination at €120 net/t free farmyard and the 100-litre wood shaving bales each for €5.05 net free farmyard (€220 net/t). The farm was able to buy the wood pellets in 15 kg sacks at a price of €3.25 net free farmyard (€217 net/t). A cost comparison was carried out on the basis of a collectively agreed minimum wage of €8.60 in agriculture

(1.01.17 - 31.10.17; Statistisches Bundesamt 2017). Wage costs, including ancillary wage costs in the form of the employer's contribution to social insurance (Sozialversicherung für Landwirtschaft, Forsten und Gartenbau 2017), therefore resulted in a total of € 10.27 per worker and hour.

The wage costs and material costs were included in the cost comparison. These costs included not only the costs of daily work and bedding but also, for example, the full muck-out twice a year after deworming and the corresponding new initial bedding of the stalls twice a year. For the full muck-out, a working time of 15 minutes per stall was estimated for straw and wood shaving stalls and 30 minutes per stall for pellet stalls. The work required for the subsequent initial bedding was determined for the wood pellets. It amounted to 17.18 WPmin (median) including moistening of the pellets (min. = 13.34; max. = 17.22). The working time required for the initial bedding of straw and shavings was extrapolated to the amount of initial bedding on the basis of the amount of rebedding. The initial bedding quantities were based on the manufacturer's recommendations (shavings, pellets) or on literature (straw, Fleming 2008). For straw, an initial bedding quantity of 40 kg was calculated, for wood shavings four bales and wood pellets 12 sacks. The variable machine costs as well as the wage costs for providing the bedding and the removal of the manure were not included in this calculation, as these can vary from farm to farm depending on the respective storage capacities. In addition, the break-even prices of the bedding materials were also included in the calculation.

The behaviour of 13 horses was recorded using 24-hour video recordings with LED day-night infrared cameras (VC, Ettlingen, Germany) with the type designation VFKUP-700/311/R. The behaviours relevant to the study were selected from the entire behavioural inventory of the species, named and described in advance (Zeitler-Feicht 2015), recorded based on their duration and then graphically displayed in an ethogram. A distinction was made between the following types of behaviour: resting while lying down, subdivided into prone and lateral position, also resting while standing, feeding, foraging, remaining time and absence of the horses (Zeitler-Feicht 2015). The horses' requirements in terms of social contact and free movement (Zeitler-Feicht 2013) were not part of the study.

The ammonia measurements were conducted with the concentration meter „M.A.C 2240" (Ansyco, Karlsruhe, Germany). The measurements were performed in five stalls by means of semi-continuous photoacoustic infrared spectroscopy. The dust measurements were performed with the "DustTrak Aerosol Monitor Model 8520" (TSI Incorporated, MN, USA) in two stalls. An inlet nozzle with 10 µm was chosen to filter thoracic particles. Both measurements were carried out at a height of 30 cm above the bedding (Benz et al. 2013). Ammonia concentrations were measured simultaneously in three stalls using the three measuring channels of the measuring device. The measurements were carried out semi-continuously, with the measuring channel being changed every five minutes. With a measuring process of approximately 20 seconds, one measuring interval corresponds to about 15 measuring processes. The mean value of these individual measurements was stored by the device before it switched to the next channel. Only one stall could be sampled at a time during dust measurement. The dust concentration was measured continuously and was also averaged and stored every five minutes. The ammonia and dust measurements were scheduled for ten days in each phase. However, owing to technical problems, the planned duration of individual measurements was not achieved. The collection of the ammonia and dust concentrations is shown in Table 1.

Table 1: Overview of the stalls examined, the number of examination days and the chosen study phase for the determination of the parameters ammonia and dust concentration

Measurement of ammonia concentration							
Bedding material	**Wheat straw**		**Wood shavings**		**Wood pellets**		
Stall (no.)	9	5	7	8	7	6	8
Duration of study in days	10	10	10	10	4	8	10
Study phase	1	2	1	1	2	2	2

Measurement of dust concentration				
Bedding material	**Wheat straw**	**Wood shavings**	**Wood pellets**	
Stall (no.)	14	6	14	6
Duration of study in days	3	5	4	8
Study phase	1	1	2	2

The choice of stalls was primarily determined based on the possibilities for installing the measuring equipment. The exact positions of the individual measuring points are depicted in Figure 1. The ammonia values were collected in five stalls and the dust data in two stalls. Each stall was equipped with a window of about 1 m^2. These and the two large gates at both ends of the stable wing were permanently open. In addition, all stall fronts were fitted with ventilation slits, which also enabled air circulation in the floor area.

Data analysis

The data was processed and the graphics and tables were created with the Microsoft Excel 2010 and 2013 spreadsheet programs. The statistical software R, version 3.3.1 or 3.4.1 (R Core Team 2015) with the R Commander package was used to analyse the data.

In addition to descriptive statistics, inductive statistics test procedures were also applied. As some data did not show a normal distribution (Shapiro-Wilk test), non-parametric test procedures were used. In the economic part, the Generalized Linear Model (GLM) was used. The corresponding formulas are listed in Table 2. The data for the ethological and stall climatic part were analysed using the Wilcoxon-signed-rank test (WT) for pair-by-pair mean comparisons for non-parametric dependent data and the Spearman rank correlation test (SRC). The tests were bilateral. As the sample size was $n < 30$, no Bonferroni correction was applied (Nakagawa 2004). This would lower the statistical power and reduce the probability of being able to statistically represent an existing effect (Nakagawa 2004). The following levels of significance were distinguished: Significant was $p < 0.05$ (*), highly significant was $p < 0.01$ (**) and the highest degree of significance exhibited all values corresponding to $p < 0.001$ (***).

Table 2: Formulas of the Generalized Linear Models (GLM); the designation has been adopted in the results

Name	Formula
GLM1	*glm(manure mass.kg. ~ absence.h. + Stall no. + Stall size.m^2. + Manure.density.kg.m^3. + Bedding + hay.kg. + Worker+ temperature.C., family=gaussian(identity), data=dataset)*
GLM2	*glm(working_time_mucking-out.min.cmin. ~ absence.h. + Stall no. + Stall size.m^2. + Bedding + hay.kg. + Worker + rel.air humidity_mucking-out + Temp._mucking-out..C., family=gaussian(identity), data=dataset)*
GLM3	*glm(working_time_mucking-out.min.cmin. ~ absence.h. + Bedding_name + worker, family=gaussian(identity), data=dataset)*
GLM4	*glm(working_time_mucking-out.min.cmin. ~ absence.h. + Hay quantity.kg. + Rel. air humidity_mucking-out + Temp._mucking-out..C. + Week, family=gaussian(identity), data=dataset)*

Results

Influence of bedding on economic efficiency

On average, 0.5 sacks of wood pellets or 0.57 bales of wood shavings or 13.64 kg of wheat straw per horse and day were used for rebedding. However, the daily manure mass did not vary statistically significant between the bedding materials used (GLM1: n = 78, t = 0.20, $p > 0.05$). On the other hand, the bedding material influenced the average working time required for mucking-out significantly (GLM2: n = 78, t = -4.43, $p < 0.001$). The median was 9.72 WPmin per stall and day when wood pellets were used (min. = 5.05, max. = 14.24) and was lower than with wheat straw (GLM3: n = 78, t = 7.83, $p < 0.001$) and wood shavings (GLM3: n = 78, t = 3.31, p = 0.001). Using wood shavings, a median of 10.50 WPmin per stall and day (min. = 6.42, max. = 13.49) was required, which differs significantly from the use of wheat straw with a median of 12.71 WPmin per stall and day (min. = 8.78, max. = 16.58) (GLM3: n = 78, t = 4.28, $p < 0.001$). The working time expenditure for mucking-out was presented here as an example of the working time expenditure for activities related to bedding (wood pellets: 68.59 WPh/horse; wood shavings: 81.55 WPh/horse; wheat straw: 96.62 WPh/horse), as it accounted for 86% of the annual working time expenditure determined during this study in the case of bedding with wood pellets, 78% with wood shavings and 80% with wheat straw. The daily working time expenditure, under consideration of all activities occurring during the year, is depicted in Figure 2. The working time expenditure for mucking-out differed depending on the respective worker (GLM2: n = 78, t = 6.81, $p < 0.001$). No difference was observed between the working time for mucking-out the control stalls from study phase 1 to study phase 2 (GLM4: n = 12, t = -0.30, $p > 0.05$).

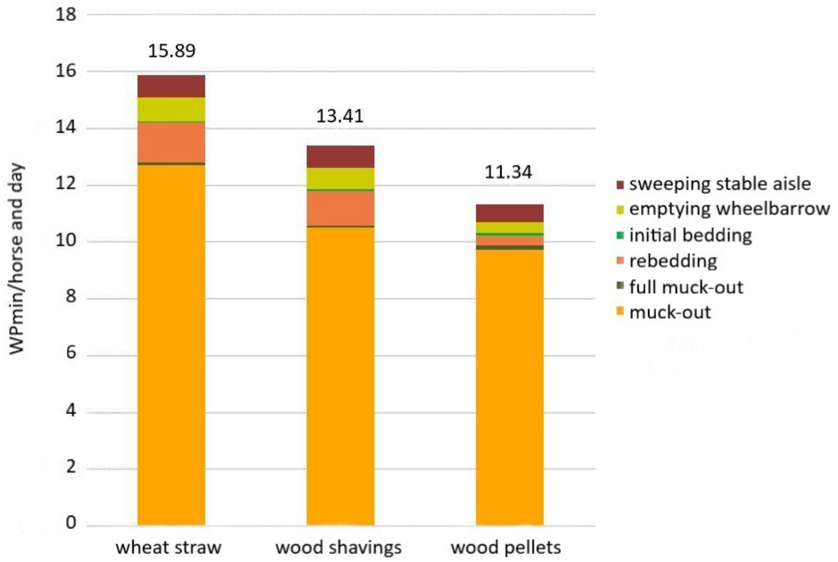

Figure 2: Daily working time expenditure, under consideration of all activities during the year when using the bedding materials wheat straw, wood shavings and wood pellets in WPmin/horse and day

Compared to bedding with wheat straw or wood shavings, the use of wood pellets can result in savings of €328 and €655 per horse and year respectively (Table 3). In these studies, wood pellet bedding was the most cost-effective method. Compared to wood shavings and wheat straw, the use of wood pellets exhibited both the lowest material costs (Table 3) and the lowest working time expenditure per horse and year (68.59 WPh/horse). The calculation of the break-even prices for the common bedding materials shows that for the same wood pellet price, price reductions of more than 54% and 60% respectively are necessary to make the bedding with wheat straw or wood shavings more cost-effective than the bedding with wood pellets. If the prices of wheat straw and wood shavings remain at the same level, wood pellet bedding remains the more cost-effective method compared to wheat straw bedding even if the price increases by more than 50% (price increase up to < 58%) and even if the price doubles (price increase up to < 116%) compared to bedding with wood shavings.

Table 3: Annual costs of bedding in €/horse when employing wood pellets, wood shavings and wheat straw in single stall housing; wage costs/WPh incl. employer's contribution to social security: € 10.27; material costs/dt for the pellets € 21.67, for the shavings € 21.96 and the straw € 12.00

	Wheat straw	**Wood shavings**	**Wood pellets**
Wage costs		**in €/horse and year**	
Muck-out	794.07	656.00	607.27
Full muck-out	5.14	5.14	10.27
Rebedding	88.23	76.14	17.66
Initial bedding	1.43	2.94	5.88
Emptying wheelbarrow	54.06	47.86	23.17
Sweeping stable aisle	49.39	49.39	40.23
Total wage costs	992.31	837.47	704.47
Material costs	603.76	1,085.30	563.88
Total costs	1,596.07	1,922.77	1,268.34

Influence of bedding on horse behaviour

In this survey, the difference in the duration of observed resting while standing (wheat straw/wood shavings: WT: n = 13; p = 0.234; wheat straw/wood pellets: WT: n = 17; p = 0.149; wood shavings/wood pellets: WT: n = 18; p = 0.999), absence from the stall (wheat straw/wood shavings: WT: n = 13; p = 0.295; wheat straw/wood pellets: WT: n = 17; p = 0.525; wood shavings/wood pellets: WT: n = 18; p = 0.051) and feeding (wheat straw/wood shavings: WT: n = 13; p = 0.731; wheat straw/wood pellets: WT: n = 17; p = 0.216; wood shavings/wood pellets: WT: n = 18; p = 0.189) was not significant between the three bedding materials. Horses kept on wood pellets spent an average foraging duration of 449 ± 47 min/day and those on wheat straw 544 ± 54 min/day, which resulted in a significant difference between the two materials (WT: n = 17; p = 0.009). On wood shavings, the horses spent 449 ± 61 min/day foraging, which resulted in a significant difference (WT: n = 13; p = 0.35) to the horses on wheat straw (544 ± 54 min/day). On average, the remaining time of the horses on wood pellets was 128 ± 37 min/day and on wheat straw was 53 ± 12 min/day, which represents a significant difference (WT: n = 17; p = 0.001). The average remaining time on wood shavings was 74 ± 38 min/day, so that a significant difference to the wood pellets (128 ± 37 min/day) was observed (WT: n = 18; p = 0.014). On average, the total lying time of the horses in the stalls with wood pellets was 91 ± 37 min/day and 155 ± 38 min/day in the stalls with wheat straw bedding, so that there was a significant difference (WT: n = 17; p = 0.014). The horses, which were housed in stalls spread with wood shavings, spent an average of 141 ± 40 min/day lying down, which constitutes a significant difference (WT: n = 18; p = 0.011) to the horses kept on wood pellets (91 ± 37 min/day). These relationships are graphically depicted in Figure 3.

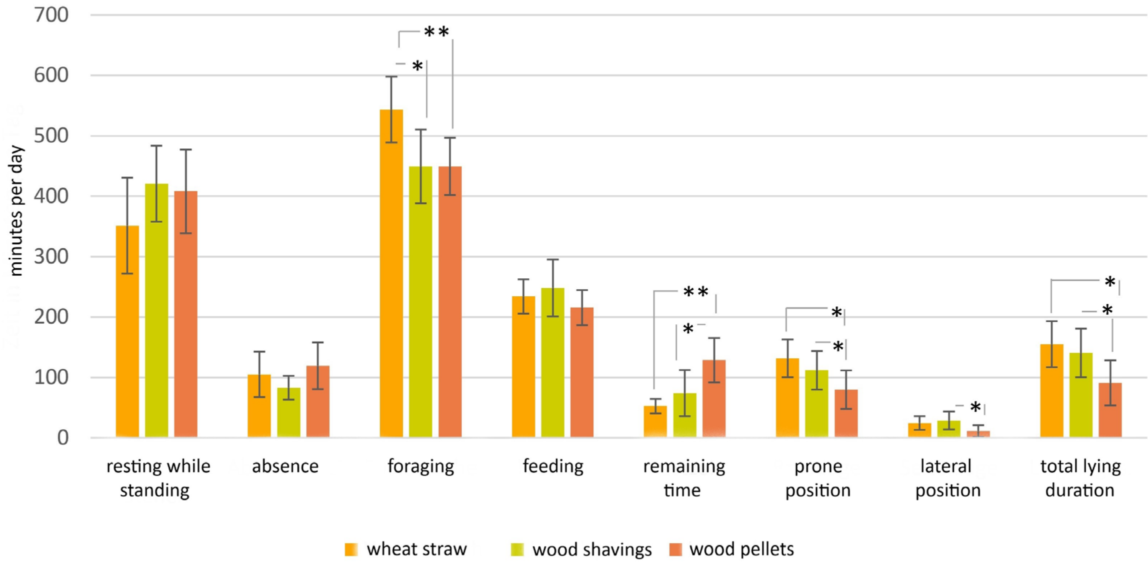

Figure 3: Duration of the behaviours exhibited in minutes per day for bedding with wheat straw, wood shavings and wood pellets, the standard deviations and the significance level (Wilcoxon test) for the differences between the three bedding materials (foraging: wheat straw/wood shavings: p = 0.035, wheat straw/wood pellets: p = 0.009; remaining time: wheat straw/wood pellets: p = 0.001, wood shavings/wood pellets: p = 0.014; prone position: wheat straw/wood pellets: p = 0.014, wood shavings/wood pellets: p = 0.046; lateral position: wood shavings/wood pellets: p = 0.041; total lying duration: wheat straw/wood pellets: p = 0.014, wood shavings/wood pellets: p = 0.011)

Influence of the bedding on stall climate

The mean values for ammonia concentrations in the stable air were highest for wood pellets, both during the day and over the entire test period, followed by wood shavings, and the lowest contents were observed with wheat straw (day mean value: wood pellets: 2.033 ppm, wood shavings: 1.152 ppm, wheat straw: 0.843 ppm; period mean value: wood pellets: 1.714 ppm, wood shavings: 1.152 ppm, wheat straw: 0.796 ppm). The wood pellets exhibited a significant increase to wheat straw (WT: n = 93; $p < 0.001$) and a significant increase to bedding with wood shavings (WT: n = 93; p = 0.005). With the exception of bedding with wood pellets, significant increases in ammonia concentrations were also observed during feeding and mucking-out (wheat straw: no action/feeding: $p < 0.001$, no action/mucking-out: $p < 0.001$; wood shavings: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$, no action/mucking-out: $p < 0.001$), whereby the influence of the mucking-out procedure was more pronounced here. This relationship is depicted graphically in Figure 4.

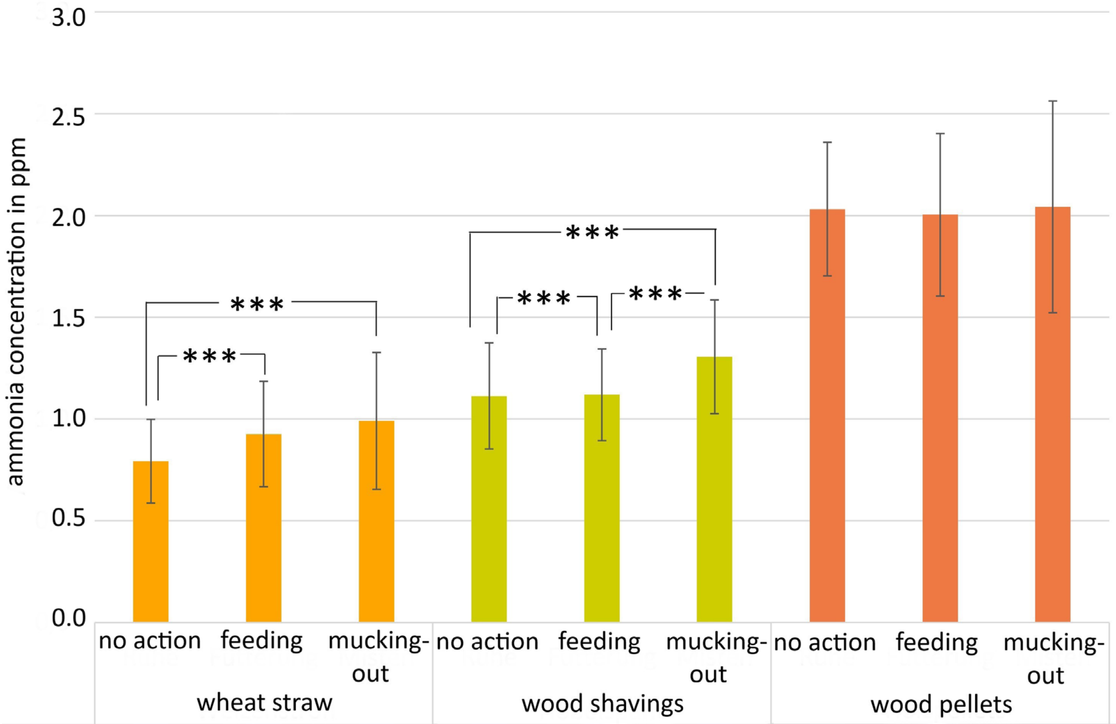

Figure 4: Average ammonia concentrations of the periods without action and the feeding and mucking-out periods in ppm, distributed according to the three bedding materials with indication of standard deviation and significance level (Wilcoxon test) (wheat straw: no action/feeding: $p < 0.001$, no action/mucking-out: $p < 0.001$; wood shavings: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$, no action/mucking-out: $p < 0.001$)

The situation was similar for the dust concentrations (< 10 µm) in the stable air. Here, too, the bedding with wood pellets exhibited the highest average values both during the course of the day and during the study phase, and the bedding with wheat straw the lowest. The amount of dust in the stable air, caused by the bedding with wood shavings, was also in the middle range (day mean value: wood pellets: 0.056 mg/m^3; wood shavings: 0.030 mg/m^3; wheat straw: 0.019 mg/m^3; period average value: wood pellets: 0.052 mg/m^3; wood shavings: 0.027 mg/m^3; wheat straw: 0.020 mg/m^3). The wood pellets produced significantly higher dust concentrations in the stable air than wheat straw (WT: $n = 22$; $p < 0.001$) and wood shavings (WT: $n = 22$; $p = 0.045$). Furthermore, mucking-out and feeding activities had a considerable effect. This led to significant differences in the dust concentration of the wood pellets between the periods without action and feeding periods and the feeding and mucking-out periods (wood pellets: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$). In the case of wheat straw and wood shavings, this could be observed between the periods without action and the feeding and mucking-out periods (wheat straw: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$, no action/mucking-out: $p < 0.001$; wood shavings: no action/feeding: $p < 0.001$, feeding/mucking-out: $p = 0.012$, no action/mucking-out: $p = 0.014$) The values observed for all materials exhibited the highest concentrations in the stable air during feeding. Figure 5 illustrates these relationships. All results are shown in Table 4 in order to provide a comparison at a glance.

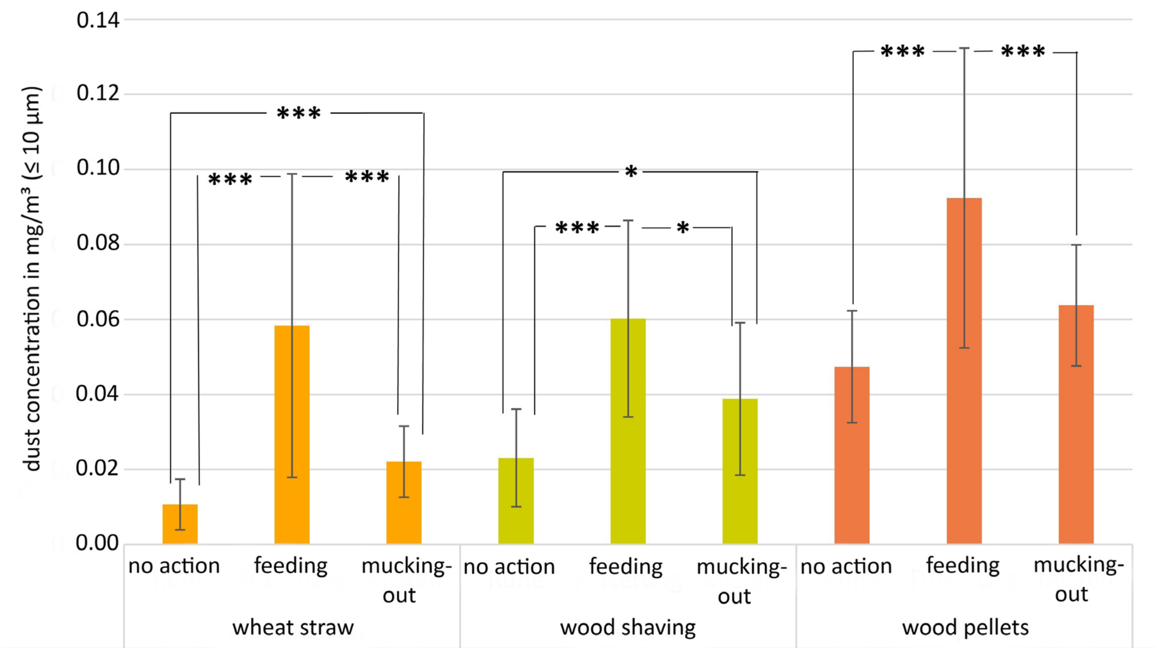

Figure 5: Mean dust concentrations (particle size ≤ 10 µm) of the periods without action and the feeding and mucking-out periods in mg/m^3, distributed according to the three bedding materials with indication of standard deviation and significance level (Wilcoxon test) (wheat straw: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$, no action/mucking-out: $p < 0.001$; wood shavings: no action/feeding: $p < 0.001$, feeding/mucking-out: $p = 0.012$, no action/mucking-out: $p = 0.014$; wood pellets: no action/feeding: $p < 0.001$, feeding/mucking-out: $p < 0.001$)

Table 4: Overview of the study results, indication of the medians or calculations based on the medians

	Unit	Wheat straw	Wood shavings	Wood pellets
Ethology				
Foraging and feed intake	h/d	12.97	11.62	11.07
Lying time	h/d	2.58	2.35	1.52
Resting while standing	h/d	5.85	7.01	6.80
Remaining time	h/d	0.88	1.23	2.13
Stall climate				
Average ammonia concentration	ppm	0.796	1.152	1.714
Average dust content	mg/m^3	0.020	0.027	0.052
Economy				
Manure mass/horse and year	t	15.44	14.95	14.64
Bedding consumption/horse and year	dt	50.31	49.43	26.03
Work time expenditure/horse and year	WPh	96.62	81.55	68.59
Costs/horse and year	€	1,596	1,923	1,268

Discussion

Since straw and wood shavings are among the most commonly used bedding materials in western and southwestern Germany (Beck 2005, Nover 2013), these two materials were used to enable a comparison with wood pellets. The part muck-out system is not only the most widespread for the use of straw and wood shavings (Arndt 2001, Fader 2002, Köster 2015), it is also preferred for hygienic reasons (Fader 2002, Marten 2004, Köster 2015) and is visually appealing to the horse owner (Neubert 2011). Furthermore, the choice of mucking-out systems depending on the bedding material chosen not only corresponded to common practice, but also to the recommendation of Häussermann et al. (2002). According to Häussermann et al. (2002), high spreading volumes, such as those found with cereal straw and coarse wood shavings, are well suited to completely cover the stall area with low bedding consumption using the part muck-out system. Häussermann et al. (2002) again recommend the use of a deep litter for dense bedding materials with a high water-binding capacity. Wood pellets can be counted among these materials, for which the manufacturer also recommends the deep litter system.

Nevertheless, the influence of different mucking-out systems on the results of this study should be taken into account. The mucking-out system influences the working time (Haidn et al. 2002, Neubert 2011), as well as the bedding consumption (Neubert 2011). If the wheat straw and wood shavings stalls were managed in the same way as the wood pellet stalls using the deep litter system, a lower working time expenditure and a different bedding consumption could be expected. At the same time, the mucking-out process seems to have an influence on ammonia concentrations. Van den Weghe et al. (2008) compared different mucking-out systems using straw. The deep litter with daily muck-out caused the lowest concentrations, followed by the deep litter without any mucking-out. Full mucking-out resulted in higher ammonia concentrations. Consequently, the bedding materials wheat straw and wood shavings when used in the deep litter system would have tended to produce even lower ammonia concentrations in the present study. However, it should be noted that the full muck-out in Van den Weghe et al. (2008) is not the same as the part muck-out system used here. In addition, Van den Weghe et al. (2008) examined the influence of different mucking-out systems on the particle concentration using straw as an example. Although a lower particle concentration was measured in a deep litter without daily removal of faeces and wet spots, the particle concentration of a daily full muck-out did not differ significantly from the particle concentration of a deep litter with daily removal of faeces. Therefore, there is no evidence to assume any influence of the mucking-out systems used in the present study on the dust concentration. Given the potential influence of the mucking-out process on the results, the statements made in the present study can only be transferred to practical use of wheat straw and wood shavings using the part muck-out system and wood pellets using the deep litter system.

As described by Haidn et al. (2002), the higher working time required for mucking-out in this study compared to the literature (Haidn et al. 2002, Jaep 2004, Nebe 2005, von Borstel et al. 2010, Fuchs et al. 2012) can be justified, among other things, by the fact that the work in the various studies was carried out by different people, whereby their accuracy, motivation and routine must be regarded as influencing factors. The working time for mucking-out also varied in these studies depending on the person working. Nevertheless, fluctuations should not be seen as a disadvantage; on the contrary, they could be described as practical.

As described above, the working time required for the full muck-out of the stalls was estimated. However, the assumption was made that deviations from the estimated values would have hardly any effect on the result of the cost comparison, as these represent a small proportion of the total annual working time expenditure due to the fact that full muck-out only takes place twice a year. The same applied to the working time required for the initial bedding.

Straw consumption in this study, at a good 50 dt per stall and year, was at the upper end of the range recorded in other studies (Häussermann et al. 2002, Marten 2004, Jaep 2004, Nebe 2005). At 49 dt per stall and year, the consumption of wood shavings was slightly higher than in the case of Häussermann et al. (2002).

The economic calculations led to quite clear results. Here the low total costs when applying wood pellets, based on the lowest material and labour costs, have to be emphasised. The savings potential is enormous and due to the level of break-even prices, which allow price changes of more than 50%, the use of wheat straw and wood shavings in the part muck-out system is unlikely to become cheaper than bedding with wood pellets in the deep litter system, as price changes of this magnitude are not to be expected. Overall, the overall order of the total costs for the use of the three bedding materials can thus be described as stable, i.e. that the use of wood pellets will probably always cause the lowest total costs and that of wood shavings will probably always cause the highest total costs, even if individual prices may change. Nevertheless, seasonal price fluctuations and regional availability must be taken into account (Buck 2012). The price of wood pellets is influenced by the price fluctuations of heating pellets. The lack of availability of straw in grassland regions could lead to high transport costs. In this case, wood pellets could be an interesting alternative to wood shavings, which may currently be the preferred option in these regions. For farms with their own grain production, the opportunity costs for using the straw on their own farm could be lower, taking into account the work involved in marketing the straw and fluctuating market prices. If the straw quality is good, these farms could additionally advertise the positive characteristics of the straw. Whilst from an economic point of view, the results suggest that wood pellets are the most advantageous bedding material, the animal welfare aspects mentioned should not be neglected.

As horses are flight animals, steppe animals and herd animals, Zeitler-Feicht (2015) reveals a conflict with regard to the species-appropriate nature of stall keeping. In order to quantify a possible deviation from the time budget of free-living equidae, the behavioural parameters feeding, resting and lying behaviour were examined. Against this background, it is essential to ensure the smallest possible deviation from the natural time budget of horses. In comparison, the use of wood pellets exhibited the highest deviation from the time budget of free-living equidae (Duncan 1980 and Kiley-Worthington 1989 cited according to Zeitler-Feicht 2015), especially in terms of lying behaviour. Instead, the horses spent the shorter lying periods with resting while standing and remaining time. The shortened lying time on the wood pellets could be attributable to the fact that the acclimatisation period was not sufficiently long. This assumption is supported by the fact that the lying time of the two usual bedding materials wheat straw and wood shavings exhibited no significant differences. In a similar study by Werhahn et al. (2009), there was also no significant difference in the lying time between straw and wood shavings bedding. Furthermore, as Pirkelmann et al. (2008) describes, horses only lie down when their sense of safety or relaxation is sufficiently high. This applies in particular to the lateral position, which on the wood pellets averaged only 11 ± 10 minutes/day and thus showed a very high standard deviation. According to Zeitler-Feicht (2015), the dream phase which is crucial for the well-being of the horse can only take place while lying down. Although sleep patterns may vary between individuals, they are relatively constant in the same animal. Shortened lying periods are therefore to be seen as negative, especially a prolonged REM sleep deficiency can lead to severe psychological and physical stress (Fuchs 2017). However, this study does not assess the extent to which lying times would normalise through a long-term use of the materials or whether the use of wood pellets would result in health consequences. Other husbandry conditions also play a role here. If, for example, the horses have the possibility to use a sand paddock connected to the stall, the shorter lying times are compensated there (Köster 2015). Likewise, the somewhat higher dust and ammonia values of the wood pellets could be neglected for horses that spend most of the day outside the stall or have a paddock as an alternative.

The mean values of the ammonia concentrations of the three bedding materials all differed significantly in this study (see results). Nevertheless, the highest value (3.53 ppm) was clearly below the limit value of 10 ppm specified by the BMELV [Federal Ministry of Food, Agriculture and Consumer Protection] (2009). As the manure mass of the various bedding materials was relatively consistent in the parallel economic study, it can be assumed that the level of ammonia content was not influenced by the amount of excrement excreted, but is directly attributable to the bedding. These correlations were also demonstrated in comparable measurements by Van den Weghe et al. (2008).

Van den Weghe et al. (2008) measured increases in ammonia during routine work. In the present study, highly significant differences were also observed between the periods without action and the feeding and mucking-out periods and the materials wheat straw and wood shavings (Figure 4), with larger differences being observed during mucking-out. No significant increases between the three periods were observed for wood pellets, but the overall values were higher. This suggests that both the activity and the bedding have a significant influence.

The mean values of dust concentrations (thoracic particles < 10 μm) of wheat straw and wood shavings in the stable air differed significantly from those of wood pellets (Figure 5 and Table 4). Nevertheless, the highest value (0.198 mg/m^3) is below the proportion of dust particles of 0.2 to 0.8 mg/m^3 in the stable as stated by Meyer et al. (2014). In contrast, in a similar survey by Van den Weghe et al. (2008), the mean dust concentration was highest for straw bedding in the barn. Under laboratory conditions, Vandenput (1997 quoted after Szabo 2008) concluded that less dust is generated by good quality straw than by wood shavings. It can therefore be assumed that this can be attributed to the strongly fluctuating qualities of straw. In addition, there are also significant differences in the dust content of the stable air in this study between the periods without actions and the feeding and mucking-out periods and the bedding materials (Figure 5). This confirms their influence on the generation of dust, whereby a particular manifestation was observed during feeding. These correlations were also found in the investigations of Van den Weghe et al. (2008) and thus essentially confirm the statement of the present study.

For the parameters ammonia and dust, the values recorded in this study were generally low compared to other studies (Van den Weghe et al. 2008, BMELV 2009, Meyer et al. 2014), which also investigated dust concentrations in the range of < 10 μm. This can be described as positive, as the strain on the respiratory system of the horses, based on the limit values, is relatively low and no negative consequences are to be expected. As a basic principle, as low concentrations as possible should always be pursued.

Further research is required concerning the acceptance of wood pellets by the customers of horse boarding farms, the composting properties and the fertilising effect of wood pellet manure. Further studies should also be carried out to determine whether shortened lying times resulting from wood pellet bedding can lead to long-term damage to health or whether lying times will normalise if wood pellets are used over a long period of time. It would also be interesting to repeat the studies in different housing systems and using the same mucking-out system for all bedding materials and to record other gases relevant to the climate of the stable (nitric oxide, methane, hydrogen sulfide) as well as the individual dust particle sizes (inhalable, thoracic, alveolar).

Due to the methodical approach, the findings from the present study can be transferred to farms with similar husbandry and management systems and are therefore meaningful. However, it is difficult to draw general conclusions, as farms can differ greatly from one another (Haidn et al. 2002) and the mucking-out procedure can have an influence (Haidn et al. 2002, Van den Weghe et al. 2008, Neubert 2011). Consequently, the decision for a bedding material should be weighed individually for each farm. It should be clarified whether shortened resting and foraging periods with wood pellet bedding can be compensated by management measures, such as extensive grazing.

Conclusions

In conclusion, it can be said that the decision for or against a bedding material is always dependent on the specific farm. The bedding materials straw and wood pellets stood out in this study. The wood shavings ranked in the midfield in terms of the ethological and stall climate results and became less important in this study due to the high costs. Straw proved to be the bedding material that came closest to the horses' needs, while the wood pellets were the most convincing because of their low overall costs per horse and year.

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