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Comparisons of recycled manure solids and wood shavings/sawdust as bedding material—Implications for animal welfare, herd health, milk quality, and bedding costs in Swedish dairy herds

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ABSTRACT

Increasing shortages and costs of common bedding materials have led dairy farmers in Sweden to consider using recycled manure solids (RMS), which are readily available and low cost, as an alternative bedding material. The main risks are effects on udder health and milk quality, but RMS could also affect animal welfare and claw health. The advantages and disadvantages of using RMS bedding have not been fully investigated, and findings in other countries cannot be directly applied to Swedish conditions and climate. This observational cross-sectional study investigated the use of RMS as bedding, regarding associations with certain aspects of animal welfare, herd health, milk quality, and bedding costs in Swedish dairy herds. Thirty-four dairy farms using RMS or wood shavings/sawdust (each n = 17) were compared. Each farm was visited 2 times during the housing period from 2020 to 2021, once from October to December and once from March to May. Dairy barns were observed, animal welfare was assessed, and freestall dimensions were measured. Farm owners were interviewed about housing system characteristics, herd performance, and herd management. Data on milk production and herd health were obtained from the Swedish official milk recording scheme for the indoor period from October to March. The prevalence of claw disorders and abnormal claw conformation were collected from the national claw health database for the period from October to May. On each farm visit, composite samples of unused bedding outside the barn and used bedding material from the freestalls, respectively, were taken for total bacterial count and DM analysis. Samples of bulk tank milk for determination of total bacterial count were taken in connection to the visits. In addition, samples of unused and used bedding material and manure from alleys for analysis of 3 *Treponema* species associated with digital dermatitis (DD) were gathered and analyzed. Total bacterial count was significantly higher in unused (8.50 $\log_{10}$ cfu/g) and used RMS bedding (9.75 $\log_{10}$ cfu/g) than in wood shavings/sawdust (used 4.74; unused 8.63 $\log_{10}$ cfu/g), but there were no significant differences in bulk milk total bacterial count (median 4.07 vs. 3.89 $\log_{10}$ cfu/mL) or SCC (median 243,800 vs. 229,200 cells/mL). The aspects of animal welfare assessed did not differ significantly between the 2 bedding systems, whereas the prevalence of total claw disorders (25.9% vs. 38.0% of trimmed cows), dermatitis (6.9% vs. 16.2% of trimmed cows) and sole ulcers (2.0% vs. 4.0% of trimmed cows) were significantly lower in the RMS herds. *Treponema* spp. were not detected in unused RMS material, but all RMS herds had presence of DD recorded at foot trimming. An economic assessment based on the interview results and price level from winter 2021 revealed that the costs of RMS bedding varied with amount of RMS produced. Thus, RMS is a potential alternative bedding material for dairy cows in Sweden and can be a profitable option for large dairy herds. However, the high level of total bacteria in the material requires attention to bedding and milking routines as well as regular monitoring of herd health.

Key words: dairy cows, somatic cell count, total bacterial count, claw health, *Treponema*

INTRODUCTION

Use of recycled manure solids (**RMS**) as bedding for dairy cows in Sweden is increasing due to increased un-

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certainty of availability and rising costs of other common bedding materials, mainly straw and wood shavings/sawdust (**WSS**). Summer droughts and associated harvest reductions due to future climate change will probably cause shortages of straw, and the availability and cost of WSS will be affected by growing demand for wood waste for energy production in thermal power plants. By using RMS, farmers may be able to better control the availability and cost of bedding material (Leach et al., 2015). However, the effects of RMS bedding on animal welfare and health, hygiene, milk quality, and bedding costs have not been investigated on Swedish dairy farms.

The main risk of using RMS bedding for dairy cows is effects on udder health and milk quality. Mastitis is one of the most important health problems in Swedish dairy production from both an economic perspective, due to its effects on milk quality, and an animal welfare perspective (Nielsen et al., 2010). Recent studies investigating the associations between RMS bedding and incidence of clinical mastitis (**CM**) or subclinical mastitis, SCC, and total bacteria count (**TBC**) in bulk tank milk have found that RMS did not increase the incidence of CM or subclinical mastitis compared with straw (Fréchette et al., 2021, 2022a) or sand (Rowbotham and Ruegg, 2016). No difference in SCC was detected when RMS was compared with peat (Frondelius et al., 2020), although inorganic bedding material reduced bulk milk SCC compared with RMS (Rowbotham and Ruegg, 2015). A review by Leach et al. (2015) found no influence of RMS bedding on CM and SCC. No difference in bulk milk TBC was found on comparing RMS with sand and sawdust bedding (Bradley et al., 2018) or on comparing inorganic bedding with organic non-manure bedding and manure-based bedding (Rowbotham and Ruegg, 2015). However, bulk tank milk microbiota may be influenced by RMS bedding, affecting milk quality (Patel et al., 2019; Gagnon et al., 2020; Wu et al., 2022).

Udder health is associated with cow cleanliness, especially of the udder and hind legs (Reneau et al., 2005). Dairy cows spend 12 to 14 h per day lying down, and during this time their udder and teats come into direct contact with the microbiota in the bedding material. Teat end microbiota has been shown to be correlated with bedding microbiota (Zdanowicz et al., 2004). Reducing bacterial exposure at the teat end is important for prevention of environmental mastitis (Rowbotham and Ruegg, 2016). The microbial quality of unused RMS is inferior to that of organic non-manure bedding and inorganic bedding (Beauchemin et al., 2022; Ray et al., 2022). Additionally, environmental pathogens in bedding on the rear part of stalls originate from manure, claws, urine, and milk from leaking teats, and the microbiota is thus altered in used bedding (Magnusson et al., 2008; Ray et al., 2022). Guarín et al. (2017) found that teat skin bacterial counts were significantly higher with dirtier udders. A higher proportion of clean udders was observed with deep-bedded manure solids, but a lower proportion with shallow-bedded manure solids on mattresses, compared with deep beds with new sand or recycled sand. Hence, the lower microbial quality of RMS could, to some extent, be compensated for by an advantage in terms of udder cleanliness. Cow cleanliness is also important for milk quality (Schreiner and Ruegg, 2003; Reneau et al., 2005) and is associated with cow comfort and welfare (EFSA, 2009). Use of RMS as bedding has been shown to improve cow cleanliness compared with peat (Frondelius et al., 2020).

Lying is an important behavior for dairy cows (Tucker et al., 2021). They may sacrifice feeding in favor of lying down when deprived of both, and will work for access to lying area and show frustration and rebound behavior when lying behavior is limited (Forkman and Keeling, 2009; Tucker et al., 2021). Hence, disturbances that affect resting in dairy cows are highly relevant for their welfare (Forkman and Keeling, 2009), with comfort when lying being an important factor. In freestalls with mattresses, cows prefer large amounts of bedding material (Tucker and Weary, 2004; McPherson and Vasseur, 2020), and RMS can be available in large quantities (Leach et al., 2015). Cows prefer dry bedding (Fregonesi et al., 2007; Reich et al., 2010), and unused RMS has a low DM content compared with other bedding materials, although it dries out rather rapidly in freestalls (Lendelová et al., 2016).

Prevalence of hock lesions is high in Swedish dairy herds; for instance, in a study of 3,217 cows from 99 herds, prevalence of hair loss on the hock (mild hock lesion) was 68%, and prevalence of swelling (severe hock lesion) was 6% (Ekman et al., 2018). Hock lesions are associated with the bedding used in freestalls (Rutherford et al., 2008) and also with freestall design (Brenninkmeyer et al., 2013; Kester et al., 2014; Ekman et al., 2018). Hock lesions and swellings are more frequent in cows lying on abrasive and hard surfaces (Kester et al., 2014). Frondelius et al. (2020) obtained significantly lower scores for hock lesions with RMS bedding compared with peat bedding in freestalls with mattresses. However, Lombard et al. (2010) observed higher prevalence of severe hock lesions in dairy cows on dry and composted RMS bedding compared with sand, straw, and sawdust.

Claw disorders cause lameness, which leads to reduced feed intake, decreased milk yield, reduced body condition, and reproduction disorders, and can affect culling rate (Alvergnas et al., 2019). Bedding also has a direct effect on lying time, which is associated with claw disorders and lameness (Cook et al., 2004). Less time standing or walking in the alleys reduces exposure to suboptimal flooring and claw disorders and lameness (Cook and Nordlund, 2009). Type of bedding material can also affect claw cleanliness and general claw health (Norring et al., 2008). The association between RMS and claw health has only been examined in a few studies. Timms (2008a) found that introduction of composted RMS improved foot and leg health, and Adamski et al. (2011) subjectively observed that cattle housed on RMS had dry feet.

Digital dermatitis (**DD**) is an infectious disease and is a major cause of lameness in dairy cows (Corlevic and Beggs, 2022). The etiology of the disease is still not fully understood, but the main pathogens of DD are considered to be different species of *Treponema*. Evans et al. (2009) isolated *Treponema pedis* from DD lesions, but Zinicola et al. (2015) found greater relative abundance of 6 other species (*Treponema denticola*, *Treponema maltophilum*, *Treponema medium*, *Treponema putidum*, *Treponema phagedenis*, and *Treponema paraluiscuniculi*) in active, ulcerative DD lesions (stage M2 and M4.1 according to Kofler et al., 2020) compared with healthy skin and inactive DD lesions (stage M3 and M4 according to Kofler et al., 2020). Zinicola et al. (2015) also found the species in rumen and feces. Identified risk factors include housing and flooring type, manure removal, and hygiene (Vermeersch and Opsomer, 2019; Weber et al., 2023). Klitgaard et al. (2014) found that manure could be a reservoir of DD treponemes, but no previous study has specifically investigated the association between RMS bedding and *Treponema* bacteria in manure and the prevalence of DD in herds using RMS.

Advantages of RMS include its good availability and low cost compared with other bedding materials (Leach et al., 2015). However, in economic evaluations of RMS bedding, the production costs must be considered and calculations made at the individual farm level, considering the investment in equipment, management time, and running costs, and the final quantity of RMS.

The advantages and disadvantages using RMS bedding have not been fully investigated, and results from other countries cannot be directly applied to Swedish housing systems, herd management, and climate conditions. The aim of the present study was thus to investigate the use of RMS as bedding, regarding associations with certain aspects of animal welfare, herd health, milk quality, and bedding costs in Swedish dairy herds. Farms using RMS were compared with similar farms using WSS. The hypothesis was that no negative associations would be found between RMS bedding and animal welfare, herd health, or milk quality.

MATERIALS AND METHODS

Project Layout

This observational cross-sectional study was performed on commercial dairy farms. The dairy cows were kept in their usual environment in the barns. Housing and management of the animals were not affected by the study and the animal welfare assessments were performed according to the routines of usual advisory service. Hence, ethical approval on animal experiments was not required. The study was carried out during the indoor period from 2020 to 2021 using herd data and samples of bedding material and milk from 34 Swedish freestall herds, of which 17 farms used RMS and 17 farms used WSS as bedding. The farms were located throughout Sweden, between latitudes 56.9°N and 65.3°N. The RMS farms were identified with the help of production advisers and vendors of manure separators. To participate in the study, the farms had to have used RMS for at least one year before the study period. The farms using WSS as bedding material were selected from the Swedish Official Milk Recording Scheme (**SOMRS**) forming pairs with the RMS farms to match the following criteria: (1) region of Sweden, (2) herd size, (3) milking system (automatic milking system, milking parlor, or rotary milking parlor), and (4) production system (conventional or organic).

Data on milk production and herd health for participating farms were obtained from SOMRS (Växa Sverige, Stockholm, Sweden) for the indoor period of October 1, 2020, to March 31, 2021. The prevalences of claw disorders and abnormal claw conformation were collected from the national claw health database (Växa Sverige, Stockholm, Sweden) for the period of October 1, 2020, to May 31, 2021. All farms were visited 2 times. The first visit occurred between October and December 2020, when the dairy barns were observed and the farm owners were interviewed about housing system characteristics, milk production, and herd management. On the second visit, carried out between March and May 2021, animal welfare was assessed and freestall dimensions were measured. On both visits, samples of unused fresh bedding and used bedding material were taken for microbial and DM analysis. Samples of bulk tank milk, taken within ±14 d of the bedding samples, were analyzed. On the second visit, samples of manure from the alleys were also collected. Samples of unused bedding, used bedding material, and manure were analyzed for the presence of 3 species of *Treponema*. Samples were taken and observations were made in groups with lactating cows. In herds with more than one dairy barn, the animal welfare assessment, freestall measuring, and sampling of bedding material and manure were performed in the main barn with most lactating cows.

Interview

The same person (production adviser from the farmers' association Hushållningssällskapet Halland, Eldsberga) visited all farms and interviewed the owners, using a questionnaire covering building type, milking system, bedding material and management, freestall design, frequencies of cleaning and bedding, type of flooring, type of separator, and presence and type of anaerobic digester and composter. Furthermore, factors for economic evaluation of bedding costs were included.

Assessment of Animal Welfare

In animal welfare assessments, animal-based measures (Table 1) were recorded using a standard method relevant for dairy cattle called "Ask the cow" (Sandgren et al., 2009). All recordings were made by 5 trained and calibrated assessors from the cattle farmers' association Växa Sverige, Stockholm. Paired farms were assessed by the same assessor. Group assessments of stall standing index and cows lying outside freestalls were performed on all cows standing or lying in the stalls in the lactating groups. Individual assessments of 35 cows were conducted on a random sample. To sample the individual cows, the assessor began with the first cow "in sight" and then continued with every second cow for herd size of 61 to 120 cows, and with every third cow for herd size >120 cows, until the sample of 35 cows was fulfilled. In cases where lactating cows were held in different groups in the barn, a sample of cows (relative to group size) from each group were assessed up to a total sum of 35 cows.

Freestall Dimensions

Freestall dimensions (length, width, distance from rear curb to brisket board, neck rail height, and horizontal distance to neck rail from rear curb) were measured in one randomly selected stall on each farm.

Production Data and Herd Health

Data on milk production and herd health obtained from SOMRS included average milk yield per cow and year (rolling herd average obtained March 31, 2021), average herd SCC based on DHI test day results, and recorded veterinary treatments and conditions or diseases (**VTC/D**) based on reports from veterinarians and farm owners. Measures of VTC/D included incidence of veterinary-treated clinical mastitis (**VTCM**) and total number of registered disease events (all treated conditions registered by farmer or veterinarian as well as veterinary visits where no treatment was initiated). The most commonly reported events are udder, feet and leg, reproductive, and metabolic disorders (Växa, 2022). According to Swedish legislation (SFS, 2018: 1192), a veterinarian always needs to make an examination of sick animals before any treatment may be given unless there is an agreement on certain treatments between the veterinarian and the herd owner and the conditions are fulfilled. If such an agreement is in place, all disease events that result in a medical treatment are registered by the farmer.

Most farms in Sweden practice preventative trimming for each cow twice a year, encouraged by government funding. Many farms plan foot trimmings before and after the grazing period; therefore, to include as many foot trimmings as possible within the housing period, data recorded during the period from October 1, 2020, to May 31, 2021, were used. Claw health was assessed as the prevalence of claw disorders and abnormal claw conformation (the number of reports of each condition, as a proportion of total trimmings carried out). These data were taken from the reports of professional foot trimmers, who recorded according to the Nordic Claw Atlas

Table 1. Assessment of animal welfare using parts of the "Ask the cow" method (Sandgren et al., 2009)

Assessment	Description	Individual[1]	Group[2]
Rising behavior	The cow should be able to rise without difficulty and no hesitation longer than 5 s.	X[3]	
Lameness	Cow walks with arched back. Short striding with one or more limbs.	X	
Injuries	Lesions or swellings larger than half a palm of a hand. Several lesions or swellings corresponding together to the size of 1 palm of a hand.	X	
Cow with serious injuries	Lesions or swellings larger than one palm of a hand. Several lesions or swellings corresponding together to the size of 2 palms of a hand.	X	
Cow with asymmetric claws	Hind claw outwardly angled >30° (outer claw larger than inner claw).	X	
Cow with long claws	Claws >95 mm.	X	
Dirty cow	Areas of manure, together larger than the size of 3 palms of a hand.	X	
Very dirty cow	An area with manure >1/3 of udder, hindquarters, and flanks.	X	
Body condition	Indicators for very lean and very fat present in 4 regions: cavity around tail head, back- and hipbones, spine vertebrae, and loin.	X	
Stall standing index	Proportion of cows in stalls that are standing.		X
Cows lying outside stalls	Proportion of cows in stalls lying with 1 body part outside stall.		X

[1]35 randomly selected cows from groups with lactating cows.

[2]All groups with lactating cows.

[3]The X indicates whether the assessment was performed at the individual or group level.

Table 2. Records of milk production, herd health, and detailed data on claw health obtained from the Swedish Official Milk Recording Scheme (SOMRS), Växa Sverige (Stockholm) and the national claw health database, Växa Sverige (Stockholm)

Milk production	Herd health	Claw health
Milk yield	SCC	Dermatitis[1]
	VTC/D[2]	Digital dermatitis[3]
	VTCM[4]	Heel horn erosion
	Culled, total	Sole hemorrhage
	Culled, udder	Sole ulcer[5]
	Culled, leg/hooves	Remarks on hoof shape
	Culled, fertility	Interdigital hyperplasia
	Natural death/euthanized	Other remarks
		Treatments
		Infection remarks[6]
		Traumatic remarks[7]

[1]Refers to interdigital/superficial dermatitis (according to ICAR Claw Health Atlas; Egger-Danner et al., 2020).

[2]VTC/D = veterinary-treated conditions/diseases.

[3]Refers to severe digital dermatitis (M2 according to ICAR Claw Health Atlas; Kofler et al., 2020).

[4]VTCM = veterinary-treated clinical mastitis.

[5]Includes white line abscess/ulcer.

[6]Includes severe digital dermatitis, heel horn erosion, interdigital hyperplasia, wart growth (chronic hyperkeratosis/proliferation and M4) according to ICAR Claw Health Atlas (Kofler et al., 2020).

[7]Includes sole hemorrhage, sole ulcer, white line disease, double sole.

(Nordic Ruminant Lameness Research Network, 2013; Table 2).

Sampling Procedure

Each sample of bedding or manure was taken by hand with a new plastic freezer bag. Samples of unused bedding material were collected outside the dairy barn, beside the separator or from the storage area. A composite sample (~3 L) from 5 subsamples at 0- to 20-cm depth was mixed and placed in a plastic freezer bag. Samples of used bedding material were collected at the surface centrally in the rear third of freestalls, approximately where the udder is positioned when the cow is lying down, as late as possible in the period between 2 bedding occasions (i.e., just before new bedding material was added). Mixtures with feces were avoided. A composite sample (~3 L) from 10 different freestalls evenly distributed in the barn was placed in a plastic freezer bag. No samples were taken from end stalls. During the second visit, a composite sample of manure (~0.5 L) for *Treponema* analysis was collected from the alley behind the feed barrier and the cross alleys with water troughs. No fresh manure was collected, only manure that had been trampled by cows.

All bedding and manure samples were immediately placed in a cool bag with ice packs and frozen (≤−18°C) after 1 to 6 h. The frozen samples were transported to the laboratory Eurofins (Jönköping, Sweden) in cool bags with ice packs, where they were stored in a freezer until analysis. Eurofins, the official milk testing laboratory in Sweden, also determined TBC in one of the representative milk samples routinely taken by the tanker driver at each milk collection on participating farms. One sample from each farm, taken within ±14 d of each bedding material sampling occasion, was transported refrigerated to Eurofins and analyzed for TBC.

Microbial and DM Analyses

All microbial analyses and DM determinations were performed by Eurofins. Total bacterial count in bedding material and milk was analyzed using a plate count method (EN ISO 4833-1:2013; European Committee for Standardization, 2013). Bacterial growth under aerobic conditions in plate count agar incubated at 30°C for 3 d was quantitatively determined as number of colony-forming units (cfu) per gram of bedding material and per milliliter of bulk tank milk (detection limit ≥10 bacteria per gram or per milliliter).

Samples of unused bedding material, used bedding material, and manure for analysis of *Treponema* spp. were prepared by Eurofins with RNAlater (1 mL of sample + 5 mL of RNAlater) and then frozen (−20°C) and sent in cool boxes to the Swedish University of Agricultural Sciences (Uppsala, Sweden), where they were kept at −20°C until DNA extraction. Bacterial DNA was extracted from the samples using the QIAamp PowerFecal Pro DNA Kit (Qiagen, Hilden, Germany). All samples were pretreated by centrifugation at 20,000 × *g* for 10 min at room temperature and removal of the supernatant. Extraction of DNA was then performed according to the manufacturer's instructions. The DNA obtained was stored at −20°C before use for multiplex quantitative PCR analysis for presence of 3 species of *Treponema*: *T. phagedenis*, *T. pedis*, and *T. medium* (Frosth et al., 2023). The detection limit for positive samples was set at copy number ≥10.

Dry matter content was determined (at Eurofins) by oven-drying at 103°C for 5 h (method 2009/152/EU mod.; European Commission, 2009).

Economic Evaluation of Bedding Costs

Responses to financial questions in the interviews were used to perform an economic evaluation of the production cost of RMS versus purchase cost of WSS. Data on investment costs, rental costs, electricity consumption, working hours, maintenance, and WSS costs for each farm were gathered. In the calculations, 7-year depreciation and 5% interest were assumed. Data on the prices of electricity and WSS were from winter 2021.

Data and Statistical Analysis

During the indoor period, 1 RMS farm changed bedding material between the 2 visits, causing missing data. In addition, 3 more RMS farms had incomplete reports to SOMRS. Some samples of unused bedding material were collected from smaller piles of bedding material in front of the freestalls and were excluded from the analysis. Hence, in the analysis of unused bedding material, 26 samples from 16 RMS farms and 11 samples from 11 WSS farms were used.

Statistical calculations were performed using Minitab 21, version 21.3.1 for Windows (2022). The differences between the 2 groups of farms were tested for each variable separately. Log-transformed TBC values were used ($\log_{10}$ cfu/g in bedding material, $\log_{10}$ cfu/mL in bulk tank milk). For normally distributed variables, ANOVA was used to determine statistically significant differences. Normality was assessed with the Andersson-Darling normality test. For non-normally distributed variables, Friedman's or Kruskal-Wallis non-parametric tests were used. For herd size and claw health parameters, balanced ANOVA was used, with bedding material (RMS or WSS) as fixed factor and paired farms (pairID; 1–17) as the random factor. Mixed effects models were applied for all other variables, with bedding material (RMS or WSS) as fixed factor and paired farms (pairID) as the random factor. For DM and TBC values in used bedding material, mixed effects models were used with bedding material (RMS or WSS) and sampling occasion (1 or 2) as fixed factor, paired farms (pairID) as the random factor, and the interactions bedding material × pairID and bedding material × sampling occasion tested. For TBC in unused bedding material, a mixed effects model was used with bedding material (RMS or WSS) and sampling occasion (1 or 2) as fixed factor and paired farms (pairID) as the random factor; pairID was nested within bedding material and the interaction bedding material × sampling occasion tested. The DM in unused bedding material was analyzed with Kruskal-Wallis test and TBC in milk with Friedman's test. In herds with samples from 2 occasions, the average value from the 2 occasions was used. Statistical significance was considered at $P \leq 0.05$.

RESULTS

Description of Surveyed Herds

The median herd size (mean; range) of RMS farms, 358 cows (434; 75–1,308), was larger (P = 0.018; n = 17) than that of WSS farms, 249 cows (265; 74–611). All herds consisted of Swedish Holstein or Swedish Red cows, or both. Average milk yield per cow and year was 11,019 kg (SD 1,590; n = 13) of ECM on RMS farms and 11,443 kg of ECM (SD 1,174; n = 17) on WSS farms (P = 0.41). Nine of the RMS farms were organically managed, whereas only 3 of the WSS farms were organic.

The RMS farms had on average 3.9 (range 1–8) years of experience of using RMS bedding. Of these farms, 12 owned a separator, 2 leased a separator continuously during the year, 2 leased a separator occasionally (once a year and every 3 mo, respectively), and 1 bought RMS from another farm. Two farms separated digested manure and composted the RMS in a drum composter before use.

The dairy barns fell into 3 different groups concerning building type, depending on whether the barn was insulated or uninsulated and with mechanical or natural ventilation (Table 3). Six of the largest farms housed dairy cows in more than one building, sometimes with different types of buildings, freestalls, walking surfaces, and milking systems. Among the RMS farms, 1 had only deep-bedded freestalls, 3 had both deep-bedded freestalls and mattresses or mats, and all the others had only freestalls with mattresses or mats with a thin layer of bedding material.

We found no significant difference in freestall dimensions between farms using RMS or WSS (Table 4). Stall length (from wall to rear curb) ranged from 220 to 300 cm on RMS farms and from 225 to 310 cm on WSS farms. Most farms in both groups had stall width >120 cm, with minimum widths of 110 and 114 cm for RMS and WSS barns, respectively. The average length from rear curb to brisket board was >180 cm for both groups of barns, and the average neck rail height was about 116 cm.

Table 3. Detailed data on housing system characteristics on participating farms using either recycled manure solids (RMS) or wood shavings/sawdust (WSS) as bedding

Housing characteristic	RMS (n = 17)	WSS (n = 17)
Type of building for dairy cows		
Insulated, mechanical ventilation	2	2
Insulated, natural ventilation	10[1]	13[2]
Uninsulated, natural ventilation	8[1]	4[2]
Surface or bedding in freestalls		
Mattress or mat	16[3]	17
Deep bed	4[3]	0
Flooring in alleys		
Only slatted or solid concrete	9	10
Rubber flooring all over	8	7
Type of milking system		
Milking parlor (herringbone, parallel)	7[4]	6
Rotary milking parlor	5	4[5]
Automatic milking system (AMS)	6[4]	9[5]

[1]Three farms had both insulated and uninsulated dairy barns with natural ventilation.
[2]Two farms had both insulated and uninsulated dairy barns with natural ventilation.
[3]Three farms had both freestalls with mattress or mat and deep beds.
[4]One farm had both milking parlor and AMS.
[5]Two farms had both rotary milking parlor and AMS.

Table 4. Summary of measured freestall dimensions in dairy barns with recycled manure solids (RMS) and wood shavings/sawdust (WSS) as bedding[1]

	RMS				WSS					
Freestall dimensions	n	Mean	SD	Q1/Q3	n	Mean	SD	Q1/Q3	*P*-value	LSD
Length, wall to rear curb, cm	15	258.1	25.1		17	264.7	27.5		0.49	19.1
Width, cm	15	119.7		115.0/125.0	17	118.9		116.0/125.0	0.40	
Brisket board distance from rear curb, cm	11	183.1	6.2		11	182.1	6.2		0.79	9.3
Neck rail height, cm	15	115.7	6.0		16	116.8	8.1		0.68	5.3
Neck rail distance, horizontal from rear curb, cm	15	166.0	21.8		17	171.1	17.9		0.41	13.9
Rear curb height, cm	16	23.8	6.2		17	22.4	3.5		0.27	3.2

[1]SD analyzed with ANOVA. First and third quartiles (Q1, Q3) analyzed with Kruskal-Wallis test.

Production and Handling of Bedding Material

Solid-liquid separation on RMS farms was done with a screw-press separator in all cases. Of the 2 farms that produced RMS from digested manure, one had a mesophilic biogas reactor and the other a thermophilic reactor. Both farms composted the RMS in a vertical rotary drum composter, which, according to the manufacturer, keeps the material at a temperature of 70°C for at least 60 min of the retention time.

Handling of RMS before use in the freestalls differed between farms. Ten farms moved the RMS into stalls in the barn immediately after production. Four farms stored the RMS in piles for up to 2 wk (1 farm stored it outside for 3–7 d, 2 farms stored it outside under a roof for <2 wk and 3–4 d, respectively, and 1 farm stored it indoors for 0–5 d). In all, 3 farms stored the RMS for 2 wk or longer, of which one farm produced RMS once a year (Aug.–Sep.) and another farm produced RMS 3 times a year. Both stored the RMS outdoors covered with plastic sheets. The third farm had close collaboration with a farm using RMS and bought RMS every second week and stored it in a container with a roof. Seven of the farms added a larger amount of fresh bedding in the front of the stalls and pulled it back in the stall during cleaning. The other farms added the fresh bedding straight into the stalls. The frequency of moving RMS into the barn or stalls and cleaning the stalls and the amount of bedding used on RMS farms are shown in Table 5.

Handling of WSS differed between the farms (Table 5). Five farms bought WSS in bulk directly from the wood processing industry and stored it for 1 week to 1 month indoors or under a roof. The other farms used WSS of different brands bought in bales with plastic wrapping. Most of the farms using WSS added a larger amount of fresh bedding in the front of the freestalls and pulled it back during cleaning. Only 4 farms added fresh bedding directly into the stalls.

Lime was regularly distributed over the rear part of the freestalls on 6 of the RMS farms and 1 of the WSS farms. Other additives to improve stall hygiene were used by 1 RMS farm and 4 WSS farms.

DM Content of Bedding Materials

According to the interview responses, the goal of RMS farmers was to produce RMS with a DM content of 33% to 42% (median 35%, n = 10). The DM content on farms in samples of unused RMS collected from storage outside the dairy barns was 25.1% to 37.1% (median 32.7%; n = 16), whereas that in unused WSS was 75.2% to 91.7% (median 90.6%; n = 11; $P < 0.001$). Used bedding mate-

Table 5. Information obtained in interviews about bedding routines in dairy barns using recycled manure solids (RMS) and wood shavings/sawdust (WSS) in freestalls

	RMS (n = 17)			WSS (n = 17)			
Item	Median	Minimum	Maximum	Median	Minimum	Maximum	*P*-value[1]
Frequency of adding fresh bedding in stalls, no./wk	2.0	0.3	21.0	1.0	0.3	14.0	0.617
Frequency of cleaning stalls, no./d	2.0	1.5	4.5	2.0	1.0	3.0	0.157
Bedding thickness in rear part of stalls, cm							
Mattress or mat[2]	1.5	0.8	6.5	1.0	0.8	3.0	0.078
Deep bed[3]	12.3	11.0	20.0				
Bedding amount, L/stall and day							
Mattress or mat[2]	11.4	4.0	25.0	7.8	3.3	70.0	0.664
Deep bed[3]	16.1	14.0	59.0				

[1]Friedman's or Kruskal-Wallis test.

[2]RMS (n = 15) and WSS (n = 17).

[3]RMS (n = 4).

rial from the freestalls had an average DM content of 56.9% (SD 9.8; n = 33) on RMS farms and 76.7% (SD 5.0, n = 34) on WSS farms ($P < 0.001$; LSD = 4.3). No interactions were detected.

Total Bacterial Count in Bedding and Milk

Total number of bacteria in unused bedding material was significantly higher ($P < 0.001$; LSD = 0.71) in RMS (8.50 $\log_{10}$ cfu/g, SD 0.45; n = 26) than in WSS (4.74 $\log_{10}$ cfu/g, SD 1.27; n = 11). The TBC in used bedding material was also significantly higher ($P < 0.001$; LSD = 0.30) in RMS (9.75 $\log_{10}$ cfu/g; SD 0.21; n = 33) than in WSS (8.63 $\log_{10}$ cfu/g, SD 0.40; n = 34). No interactions were detected. Some RMS farms had deep-bedded freestalls. We found no significant difference ($P = 0.375$) in TBC in samples of used RMS between deep-bedded freestalls (9.89 $\log_{10}$ cfu/g; SD 0.40; n = 7) and freestalls with mattresses or mats (9.72 $\log_{10}$ cfu/g; SD 0.21; n = 26). For bulk tank milk the difference was not significant ($P = 0.207$), with median TBC in bulk tank milk of 4.07 $\log_{10}$ cfu/mL (range 3.45–5.16; n = 17) on RMS farms and 3.89 $\log_{10}$ cfu/mL (range 3.28–4.73; n = 16) on WSS farms.

Animal Welfare

No significant differences between RMS and WSS herds were detectable for any of the animal-based measures used in animal welfare assessments (Table 6). The average prevalence of cows with injuries was 19.8% for RMS and 22.9% for WSS herds, with hock lesions as the most common injury, 17.1% and 20.7% for RMS and WSS, respectively. The median prevalence of dirty cows was 6.0% for RMS herds and 9.0% for WSS herds. Even if the 3 farms where cows were observed in groups with deep-bedded freestalls were excluded from the analyses, no significant differences were found. For hock lesions the average prevalences were 18.7% and 20.7% for RMS and WSS, respectively ($P = 0.815$), and for dirty cows the median prevalences were 6.0% and 9.0% for RMS and WSS, respectively ($P = 0.949$).

Herd Health

We detected no significant differences in herd health data from SOMRS between RMS and WSS herds (Table 7). However, numerically, the number of VTC/D per 100 cows was slightly higher for RMS herds (27.3) than for WSS herds (20.8), as was the incidence of VTCM (10.7 and 6.8 per 100 cows, respectively) and of cows culled for udder reasons (9.5 and 7.4 per 100 cows, respectively).

Claw health was assessed as the prevalence of disorders and abnormal claw conformation recorded at trimmings during the 8-mo observation period. The number of trimmings per cow during the observation time period was on average 1.6 (range 0.94–2.2; SD 0.42; n = 16) for RMS herds and 1.7 (range 0.85–2.5; SD 0.41; n = 16) for WSS herds, without significant difference ($P = 0.363$; LSD = 0.297). The RMS herds had significantly lower prevalences of total claw disorders ($P = 0.037$), dermatitis ($P = 0.044$), and sole ulcers ($P = 0.007$) than WSS herds (Table 8).

According to the national claw health database, DD was present in all RMS herds. During the 8-mo observation period, the median prevalence of DD was 3.1%

Table 6. Results of animal welfare assessments in participating dairy herds using recycled manure solids (RMS) and wood shavings/sawdust (WSS) as bedding; percentages of studied cows[1]

Item	RMS[2] (n = 16)				WSS (n = 17)					
	Mean	Median	SD	Q1/Q3	Mean	Median	SD	Q1/Q3	P-value	LSD
Random sample of individual cows (35 cows)										
Cows having difficulties rising	0.0	0.0		0.0/0.0	1.6	0.0		0.0/0.0	0.065	
Cows that are lame	8.9	6.0	7.6		8.5	9.0	6.4		0.800	3.5
Cows with body injuries	19.8	17.0		9.5/25.2	22.9	17.0		9.0/34.0	0.625	
Cows with serious body injuries	1.3	0.0		0.0/0.0	2.8	0.0		0.0/4.5	0.183	
Cows with hock lesions	17.1	15.7	9.0		20.7	17.1	7.0		0.470	10.2
Cows with asymmetric claws	2.9	3.0		0.0/10.5	7.1	3.0		0.0/5.5	0.251	
Cows with overgrown claws	1.3	0.0		0.0/3.0	0.6	0.0		0.0/0.0	0.236	
Cows that are dirty	8.1	6.0		0.8/11.0	10.1	9.0		4.5/11.0	0.422	
Cows that are very dirty	0.0	0.0		0.0/0.0	1.4	0.0		0.0/0.0	0.164	
Cows that are lean	1.9	0.0		0.0/3.0	2.1	0.0		0.0/3.0	0.935	
Cows that are obese	3.7	3.0		0.0/6.0	2.4	0.0		0.0/4.5	0.295	
Recorded at group level										
Cows standing in freestalls	10.9	11.0	6.9		11.9	8.0	8.8		0.651	4.3
Cows lying outside freestalls	5.3	2.5		0.0/8.5	7.4	5.0		0.0/8.0	0.771	

[1]SD analyzed with ANOVA. First and third quartiles (Q1, Q3) analyzed with Kruskal-Wallis test.

[2]On 3 farms, the cows studied were in housing with deep-bedded freestalls.

Table 7. Somatic cell count, number of diseases, treatments, culled cows, and natural deaths/euthanized cows per average herd size during the indoor period (Oct. 1, 2020–Mar. 31, 2021) in participating dairy herds using recycled manure solids (RMS) or wood shavings/sawdust (WSS) as bedding[1]

	RMS (n = 14)				WSS (n = 17)					
Item[2]	Mean	Median	SD	Q1/Q3	Mean	Median	SD	Q1/Q3	*P*-value	LSD
SCC, 1,000 cells/mL	265.2	243.8		188.3/304.8	239.5	229.2		187.1/281.6	0.55	
VTC/D	27.3	30.8	16.4		20.8	18.5	11.6		0.20	10.3
VTCM	10.7	10.0	8.6		6.8	5.2	5.0		0.13	5.1
Culled, total	39.9	39.4		35.1/44.0	38.5	36.7		33.6/41.0	0.63	
Culled, udder	9.5	8.8	4.5		7.4	6.7	5.2		0.25	3.5
Culled, leg/hooves	3.0	2.1	2.9		2.9	3.8	2.3		0.92	1.2
Culled, fertility	11.0	9.6	7.1		8.5	7.0	4.9		0.26	4.4
Natural death or euthanized	6.6	4.6	5.9	2.4/9.9	6.5	6.0	2.7	4.4/8.6	0.45	

[1]Data obtained from the Swedish Official Milk Recording Scheme (SOMRS), Växa Sverige (Stockholm). SD analyzed with ANOVA. First and third quartiles (Q1, Q3) analyzed with Kruskal-Wallis test.

[2]Data are percentages, except SCC. VTC/D = veterinary-treated conditions/diseases; VTCM = veterinary-treated clinical mastitis.

for RMS herds and 4.5% for WSS herds (Table 8). We found prevalence above 10% in 2 of the RMS herds and 5 of the WSS herds. A PCR analysis of unused RMS (n = 16), used RMS from the rear part of stalls (n = 16), and manure from alleys (n = 15) did not reveal any trace of the targeted *Treponema* species (*T. phagedenis*, *T. pedis*, *T. medium*). However, on 1 WSS farm (unused WSS n = 8, used bedding n = 17, manure n = 17), the used WSS tested positive for *T. phagedenis* (copy number 13).

Economic Evaluation of Bedding Costs

Mean cost of bedding was 0.13 USD per stall and day (SD 0.10; n = 17) on RMS farms and 0.19 USD per stall and day (SD 0.11; n = 17) on farms using WSS (winter 2021 prices in Sweden; Figure 1). This difference was not significant ($P = 0.094$, LSD = 0.074), but large variation in the values occurred, with lower costs of RMS bedding for larger dairy herds. The breakdown of yearly total costs on RMS farms that had invested in a separator was, on average, 55% depreciation (SD 15), 10% interest (SD 3), 5% electricity (SD 4), 20% maintenance (SD 10), and 8% working time (SD 4). The rental cost was 92% (SD 4) for the farms that rented a separator.

DISCUSSION

Interest in using RMS as bedding material for dairy cows is increasing in Sweden. For inclusion in this study, RMS farms had to have used an RMS system for at least 1

Table 8. Prevalence of claw disorders and abnormal claw shape as proportion of total number of trimmings made during the extended observation period (Oct. 1, 2020–May 31, 2021) in participating dairy herds using recycled manure solids (RMS) or wood shavings/sawdust (WSS) as bedding, based on records made by professional claw trimmers according to the Nordic Claw Atlas (Nordic Ruminant Lameness Research Network, 2013)[1]

	RMS (n = 16)				WSS (n = 16)					
Disorder, prevalence as % of trimmings made	Mean	Median	SD	Q1/Q3	Mean	Median	SD	Q1/Q3	*P*-value	LSD
Total remarks	25.9	23.3	13.2		38.0	35.1	22.0		0.037	11.3
Infection remarks[2]	14.4	12.6	8.3		23.8	16.4	21.0		0.066	10.1
Traumatic remarks[3]	11.8	10.9	8.1		17.7	17.5	11.5		0.078	6.7
Dermatitis[4]	6.9	5.7	4.8		16.2	9.6	17.9		0.044	9.0
Digital dermatitis[5]	4.9	3.1	4.3		6.9	4.5	6.5		0.357	4.0
Heel horn erosion	3.3	1.6	5.6		7.8	4.3	9.5		0.063	4.8
Sole hemorrhage	7.0	5.3	6.7		12.5	7.9	12.4		0.132	7.4
Sole ulcer[6]	2.0	2.0	1.2		4.0	3.6	2.4		0.007	1.3
Abnormal claw shape	2.9	2.4		0.1/5.6	5.2	1.2		0.2/5.0	0.317	
Interdigital hyperplasia	5.1	3.9	3.7		4.4	3.1	4.5		0.593	2.8
Other remarks	4.8	3.3	3.4		5.2	4.6	3.3		0.637	1.8

[1]SD analyzed with ANOVA. First and third quartiles (Q1, Q3) analyzed with Friedman's test.

[2]Dermatitis, digital dermatitis, heel horn erosion, interdigital hyperplasia, wart growth (chronic hyperkeratosis/proliferation and M4 according to ICAR Claw Health Atlas; Kofler et al., 2020).

[3]Sole hemorrhage, sole ulcer, white line disease, double sole.

[4]Refers to interdigital/superficial dermatitis (according to ICAR Claw Health Atlas; Egger-Danner et al., 2020).

[5]Refers to severe digital dermatitis (M2 according to ICAR Claw Health Atlas; Kofler et al., 2020).

[6]Including white line abscess/ulcer.

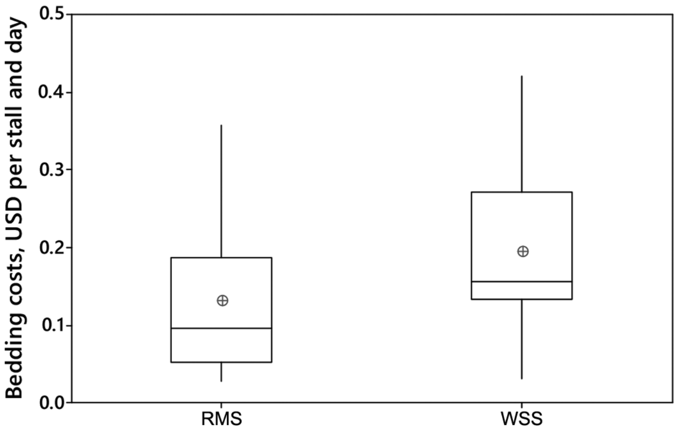

Figure 1. Calculated production costs (winter 2021 prices) of recycled manure solids (RMS, n = 15 farms) and purchase cost of wood shavings/sawdust (WSS, n = 17 farms). Box plots illustrate the median, quartiles, minimum, and maximum values, circles indicate the mean value.

year and had to be connected to the SOMRS. In Sweden, about 70% of the dairy herds are connected to SOMRS (Växa, 2021b). This limited the number of RMS farms in the study to 17 herds, but these were geographically well distributed over large parts of Sweden. In total, the farms using WSS were well matched with RMS farms as regards dairy buildings and milking systems. Herds in the study had somewhat higher milk yield per cow and year than the average in Sweden in 2020 (10,679 kg of ECM; Växa, 2021b). Larger herds and organic farms were more likely to have changed to use RMS: the RMS herds in the study had on average 434 cows, compared with the Swedish average of 104 cows, and about 50% of the RMS farms were organic, compared with only 18% of dairy farms in Sweden in 2021 (Swedish Board of Agriculture, 2023). However, the housing systems on conventional and organic dairy farms in Sweden are similar, with mandatory grazing for both during the summer period. According to statistics from SOMRS (Växa, 2022), no significant difference in VTC/D exists between conventional and organic dairy herds in Sweden. In addition, udder health, use of antibiotics, and medical treatment are rather similar in organic and conventional Swedish dairy herds, although organic herds have been shown to have higher SCC and lower incidences of mastitis treatments (Olmos Antillón et al., 2020), which could have affected the present results. Also, the registered cases of CM are those that the farmer deemed severe enough to contact a veterinarian. This threshold may vary between farmers, and cases of mild CM may be underreported in organic herds. Weather conditions and environmental conditions in the dairy barns could have affected the properties of bedding and observations. As the farms were paired and matched for region in Sweden and each pair of farms, RMS and WSS, were visited the same day, the risk of bias was limited.

The DM content of unused RMS bedding was on average 32%, which is within the range reported in previous studies (Husfeldt et al., 2012; Frondelius et al., 2020; Robles et al., 2020). Once applied in the freestalls RMS bedding dried out, as also observed by Lendelová et al. (2016) and Robles et al. (2020), whereas WSS absorbed water. However, used RMS bedding still had a lower DM content than WSS. Wet bedding can affect the lying behavior negatively via shorter lying time and decreased numbers of lying bouts (Reich et al., 2010; Schütz et al., 2019). According to Adamski et al. (2011), cows show a preference for freestalls with RMS compared with straw, sand, or sawdust. However, a study by Leach et al. (2022) comparing sawdust and RMS on mattresses, RMS in deep beds, and sand in deep beds found shorter total daily lying time with RMS on mattresses and in deep beds than with sawdust on mattresses. The number of lying bouts per day in that study was greater on sawdust than any other treatment, whereas lying bouts were 2.6 min longer on deep RMS and 9.3 min longer on sand than on sawdust (Leach et al., 2022). In the present study, no differences were found in the proportion of cows standing in the freestalls, indicating difference in their hesitance about lying in stalls with RMS or WSS.

No differences in cow cleanliness were found, which is consistent with findings in previous studies. Compared with other organic bedding materials, RMS do not cause differences in cow cleanliness (Lombard et al., 2010; Fréchette et al., 2022b) or udder hygiene (Patel et al., 2019). Type of freestall can affect the results. However, a negative association between cow cleanliness and RMS on mattresses compared with RMS in deep-bedded freestalls, recycled sand, or new sand, has been reported, although with no differences between the different bedding materials in deep-bedded freestalls (Esser et al., 2019). In contrast, Frondelius et al. (2020) observed improved cow cleanliness for RMS on mattresses compared with peat. Cow hygiene is associated with udder cleanliness and can affect SCC (Sant'Anna and Paranhos da Costa, 2011) and bulk milk bacterial count (Robles et al., 2021).

Average SCC in bulk tank milk from RMS farms was numerically higher than the Swedish average of 249,000 cells/mL (Växa, 2021a) but did not differ significantly from the WSS group average, which was numerically lower. The amount of TBC found in unused RMS was in the upper range of what Timms (2008b) registered in samples from newly produced RMS, but within the same range as found by Feiken and van Laarhoven (2012). Method of how RMS is obtained could affect the amount of bacteria (Husfeldt et al., 2012; Godden et al., 2023).

Husfeldt et al. (2012) found greater TBC in raw manure solids than in digested or composted manure solids. In used bedding material from the freestalls, RMS still had significantly greater TBC than WSS. The amounts of TBC found in used RMS and WSS were at similar levels to those found in previous studies (Feiken and van Laarhoven, 2012; Bradley et al., 2018). Type of freestall can affect the bacterial count in used bedding, with larger numbers of some bacteria, for example *Klebsiella* and *Bacillus cereus*, in deep-bedded freestalls than in shallow-bedded freestalls (Magnusson et al., 2007; Sorter et al., 2014). In the present study, 4 RMS farms used deep-bedded freestalls. However, we found no significant differences of TBC in used bedding material from deep-bedded stalls versus stalls with mattresses bedded with RMS. Despite the significant difference in TBC between used RMS bedding and WSS, no significant difference in TBC was detectable between bulk tank milk from RMS and WSS herds. Similarly, Bradley et al. (2018) found no difference in TBC in bulk tank milk from farms with RMS versus sawdust bedding.

The data on herd health showed no significant difference in VTCM or in number of cows culled due to udder disease between the RMS and WSS farms, but LSD are quite large, and including a larger number of dairy farms in the data set might have revealed significant differences. It is also important to consider that VTCM may not always reflect actual udder health of the herd but, rather, herd health strategy and willingness to medically treat CM cases of lower severity. In this study no comparison was made of the incidence of mastitis that did not require veterinary visits. However, the significant difference in TBC between used RMS bedding and WSS indicates an increased risk of impaired hygiene, udder health, and milk quality that farmers using RMS must consider.

Major differences in production, storage, and handling of RMS bedding exist between the farms studied, which very likely influenced DM and bacteria content in the unused bedding. All farms used a screw press, which gives lower DM than a roller press (Fournel et al., 2019a). Unused and used RMS from digested manure are both reported to have lower TBC than RMS produced from fresh manure (Husfeldt et al., 2012). Composting RMS in a drum composter also increases the DM content (Husfeldt et al., 2012), decreases TBC, and alters the microbiota (Fournel et al., 2019b; Godden et al., 2023). In the present study, only 2 farms separated digested manure and composted the RMS in a drum composter. Most farms moved the RMS bedding into the barn immediately after production, but 7 farms stored it outside under a roof, covered in plastic, in a container, or indoors, for a period varying from 1 day up to 1 year. Type of storage (anaerobic under plastic or aerobic in piles) and storage duration probably affected the bacterial count in unused RMS. Stall bedding regimen also varied on RMS farms, with new RMS bedding added from 3 times per day to once every 3 weeks and with the freestalls cleaned between 1 and 4 to 5 times per day. After 24 to 48 h in stalls, the number of bacteria in bedding material is high (Hogan and Smith, 1997). To reduce bacterial growth in the bedding, new bedding needs to be added frequently (Magnusson et al., 2007; Sherwin et al., 2021). Further studies are needed to determine the effects of production, storage, and management of RMS bedding on the bacterial counts in unused and used RMS.

The prevalence of hock lesions is affected by freestall design, characteristics of mats or mattresses, bedding material, and bedding amount (Rutherford et al., 2008; Kester et al., 2014; Ekman et al., 2018). Dimensions of the freestalls did not differ between RMS and WSS farms in our study. The animal welfare regulations in Sweden (SJVFS, 2019: 18) guarantee minimum size for welfare achievements. Studies examining the associations between RMS bedding and hock lesions report contradictory results, depending on the materials compared and the experimental setup (Lombard et al., 2010; Frondelius et al., 2020). Frondelius et al. (2020) found fewer hock lesions when using RMS compared with peat, whereas Ekman et al. (2018) found that peat caused fewer hock lesions than straw or sawdust. No significant difference in prevalence of hock lesions between RMS bedding and WSS was detectable in the present study. However, due to the sample size and the variation between herds, LSD is quite high. The amount of bedding used per freestall and bedding thickness on mats or mattresses in the rear part of stalls was similar for all farms. In groups where hock lesions were assessed, 3 RMS farms used deep-bedded freestalls, which are reported to decrease prevalence of hock lesions (Husfeldt and Endres, 2012). Even so, no differences in the prevalence of hock lesions were found between RMS and WSS farms in this study.

Type of flooring, freestall design, stall comfort, floor hygiene, and claw cleanliness are major factors affecting lameness and claw health (Norring et al., 2008; Cook and Nordlund, 2009; Bergsten et al., 2015b). In the present study, the proportions of concrete flooring (slatted or solid) or rubber flooring were similar on RMS and WSS farms, as were freestall dimensions. Furthermore, the average number of trimmings per cow during the observation time period was equal for both bedding types. In Sweden, a welfare reimbursement stimulates all dairy herds to trim each cow twice yearly by a professional claw trimmer. Hence, it is likely that the difference in bedding has contributed to a difference in the risk of claw disorders between these 2 groups of farms, although the significantly lower prevalence of total claw disorders, dermatitis, and sole ulcer with RMS bedding could derive from multiple factors. A sole ulcer is a result of too much loading and counter-pressure on the sensitive corium in the rear part of the sole (Shearer and van Amstel, 2017). One possible explanation for the difference seen in our study could be the bedding comfort in the stalls. Four RMS farms had deep-bedded stalls, which is a considerably softer base preferred by cows. Thicker and more persistent bedding on mats and mattresses, and in particular in deep beds, gives better lying comfort and increased lying time (Cook and Nordlund, 2009), and the associated reduction in standing time would reduce weight stress on the claws. Another possible explanation could be drier alleys in the RMS herds, considering that RMS is a bedding material with greater ability to absorb water. Another possible explanation could be that the RMS group included a greater proportion of farms with organic production systems, which have been shown to improve claw health and lameness (Bergsten et al. 2015a; Sjöström et al., 2018). Further studies are needed to confirm any positive effect on claw health of using RMS bedding compared with other bedding types, and to thoroughly investigate possible causes.

The effect of bedding material and bedding frequency on infectious disorders, especially DD, is unclear. The literature indicates advantages with bedding materials with high absorption capacity, contributing to a dry environment for the hooves (de Jong et al., 2021). Klitgaard et al. (2017) detected *Treponema* spp. only in the slurry from herds with reported DD and concluded that slurry is not a primary reservoir of infection. However, if a *Treponema* species causing DD is present in a herd, it could be spread via recycling of RMS bedding. Li et al. (2021) detected *Treponema* in a small number of samples of recycled sand bedding and compost bedding (including sawdust, rice straw, and manure solids). In the present study, DD was found to be present in all except 2 WSS herds, but PCR analysis of unused RMS, used RMS and WSS, and manure from alleys for 3 species of *Treponema* gave only 1 positive result (*T. phagedenis* slightly over the detection limit in used bedding from 1 WSS farm). However, other *Treponema* species have been detected in previous studies (Krull et al., 2014; Zinicola et al., 2015), and the proportions of different *Treponema* species can change as DD lesions develop (Zinicola et al., 2015). We found no increased risk of DD with RMS bedding, but further investigations are needed, including detection of more *Treponema* species, to confirm this.

We found large variation in bedding costs for RMS, depending on the ratio between separator investment or rental cost and amount of RMS produced. According to a previous assessment by Green et al. (2014), RMS bedding can be economically attractive when the herd is large enough to cover the capital costs of equipment. The 4 largest herds (>700 milking cows) in this study had very low bedding costs (0.02–0.06 USD per freestall and day), which could be one of the reasons why more of the larger farms in this study used RMS. The variation in bedding costs for WSS was also quite large, caused by differences in price between buying in bulk directly from the wood industry and buying commercial baled products. Electricity consumption comprised on average only 5% of the total production costs for RMS, so production was not very sensitive to variations in electricity price. However, the lower DM of RMS than of WSS means that the cost of handling RMS in the barn could be higher (investment and maintenance cost of bedding machines, working time), but this was not investigated here.

CONCLUSIONS

Although the small number of farms and the observational nature of this study prevented any determination of causal associations between bedding type and outcome measures, the following conclusions can be drawn. Total bacterial count was significantly higher in unused and used RMS bedding than in WSS, but no significant differences were found in total bacterial count or SCC in bulk tank milk from RMS and WSS farms. Animal welfare did not differ significantly between RMS and WSS farms, but the prevalences of total claw disorders, dermatitis, and sole ulcers were significantly lower in RMS herds, indicating improved claw health. The PCR analyses of *Treponema* spp. revealed no presence in unused RMS material, although all RMS herds had records of DD. Thus, RMS bedding is a potential alternative bedding material for dairy cows in Sweden. The cost of RMS bedding varied widely, depending on the amount produced, with RMS being a profitable alternative for large dairy herds. However, the high level of total bacteria in the material requires attention to bedding and milking routines as well as regular monitoring of herd health.

NOTES

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Nonstandard abbreviations used: AMS = automatic milking system; CM = clinical mastitis; DD = digital dermatitis; Q1 = first quartile; Q3 = third quartile; RMS = recycled manure solids; SOMRS = Swedish Official Milk Recording Scheme; TBC = total bacteria count; VTC/D = veterinary treatments and conditions or diseases; VTCM = veterinary-treated clinical mastitis; WSS = wood shavings/sawdust.

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