Increased costs and reduced availability of common bedding materials such as straw and sawdust have prompted dairy producers to search for alternative bedding sources. Sand can be considered the ideal bedding source for dairy cows; it offers improved cow comfort especially due to better cushion and traction and it is inorganic which provides minimal nutritive support to mastitis pathogens. However, not all producers consider sand a feasible alternative for their operation. Inherent properties of sand can make it difficult to handle in some manure systems. Recent improvements in anaerobic digestion and solids separation technology as well as the associated environmental benefits of using digesters make them an attractive option for dairy producers. Large amounts of bedding can be obtained from mechanical separation of manure.

There is some skepticism among producers and other professionals in the dairy industry about using recycled manure solids (RMS) successfully as bedding for dairy cows. Research data on the use of RMS as bedding material for dairy cows, milk quality and animal welfare on farms using RMS, the chemical and bacteriological characteristics of RMS, and methods of obtaining RMS for bedding in the Midwest US were not available. Therefore, the objectives of our cross-sectional study were to 1) characterize RMS as a bedding material, 2) describe different methods for obtaining RMS, 3) document management practices, milk quality and animal welfare, and 4) compare characteristics of RMS obtained from different systems.

Methodology
The study included 38 dairy operations with herd sizes ranging from 130 to 3700 lactating cows. Average herd size was 1300 cows. Farms were visited once in the summer. Forty-five percent of the herds had mattresses and 55% had deep bedded stalls. Freestall dimensions - stall width, body resting length, total stall length, neck rail height, and bedding depth - were measured during the farm visit. The depth of bedding was estimated prior to the addition of fresh bedding by measuring thickness of bedding with a tape measure in stalls with mattresses. In deep-bedded stalls, bedding depth was estimated in the back third of the stall using a steel rod manually driven through the bedding material to the base of the stall and measuring the portion of the steel rod above the stall surface. Producers were provided with a questionnaire designed to gather information related to the method of obtaining manure solids as well as bedding and other management practices. Composite samples of both the unused and used bedding material were obtained from each herd for bacterial and chemical analyses.

At the time of visit, 50% or more of the cows in all lactating pens were scored for locomotion, hygiene, and hock lesions. Animals were evaluated for lameness using a 5-point locomotion scoring method. Locomotion scores (LS) were identified as 1 = normal locomotion, 2 = imperfect locomotion, 3 = lame, 4 = moderately lame, 5 = severely lame. Locomotion scoring was performed by one observer as cows were exiting the milking parlor. A representative number of cows from the beginning, middle, and end of each lactating pen were scored for locomotion to avoid biasing the results. Lameness prevalence for each lactating pen was calculated as the number of animals with LS ≥ 3 divided by the total number of animals scored in the pen. Severe lameness prevalence by pen was calculated as the number of animals with LS ≥ 4 divided by the total number of animals scored in the pen. Cows were scored for hock lesions (HL) and hygiene in the milking parlor. Hock lesions were scored on a 3-point scale with 1 = no lesion, 2 = hair loss (mild lesion), 3 = swollen hock with or without hair loss (severe lesion). Cow hygiene was assessed by the amount of dirt on the udder and lower hind legs and was based on a 5-point scale with 1 = clean and 5 = dirty. Across all farms 37,271 cows were scored for locomotion and 29,565 cows for hock lesions and hygiene to represent the average score in each pen.

On-farm herd records were collected for the entire year and used to investigate mortality, culling, milk production, and mastitis incidence. Herd clinical mastitis incidence was calculated as the number of cases per 100 cow years (36,500 days) at risk. Both the number of clinical mastitis cases and cows at risk during the year were obtained from the on-farm record system. Each reported clinical mastitis case was considered to be a new case if a 14-d period had
passed between the previous and current case of clinical mastitis. Herd turnover rate was calculated as the number of animals that left the farm (died or sold) over the course of 1 year divided by the average herd inventory (dry and lactating cows). Herd turnover rate for cows less than 60 DIM was calculated as the number of animals that died or were sold within the first 60 DIM divided by the number of animals that freshened during the year. Daily bulk tank milk information from January to December was obtained from each herd’s milk processor when accessible.

**Farm characteristics**

Thirty-eight Midwest dairy operations from Wisconsin (26), Minnesota (6), South Dakota (4), and Iowa (2) were included in this study. Anaerobic digestion preceded mechanical manure solids separation on 50% of the farms, with plug-flow digesters (14) being more common than complete-mix digesters (5). Farms without anaerobic digesters were separating raw manure for bedding (13) or purchasing manure solids from dairies with anaerobic digesters (6). All farms used mechanical screw press separators to obtain RMS, and 19 of the 38 farms were utilizing anaerobic digestion prior to mechanical separation of manure. Average herd size of farms using anaerobic digesters was 1755 cows.

On the 13 farms where anaerobic digesters were not used, producers mechanically separated raw manure and either used it without treatment or subjected the solids to mechanical drum-composting for 18 to 24 h at approximately 150°F. Nine herds used separated raw manure solids and 4 herds used manure solids after drum-composting. Average herd size was 1025 cows for farms utilizing a drum-composting unit and 1105 cows for farms separating raw manure solids. Six herds in our study were purchasing digested manure solids from another dairy operation. In these herds, manure solids were stockpiled for a period of 1-3 weeks and used as needed by the dairy producer. In herds purchasing manure solids, herd size averaged 542 cows.

**RMS chemical and bacteriological characteristics**

Unused RMS bedding moisture was 72.4% (±6.0) with a pH of 9.16 (±0.2). It contained 1.4% (±0.2) N, 44.9% (±1.1) C, 32.7 (±5.2) C:N ratio, 0.44% (±0.19) P, 0.70% (±0.21) K, 76.5% (±2.5) NDF, 9.4% (±2.0) ash, 4.4% (±1.6) NFC, and 1.1% (±0.5) fat. Used bedding samples had an average moisture content of 50.4% (±12.6) and a pH of 9.39 (±0.2). These samples contained 71.3% (±4.1) NDF, 12.2% (±4.2) ash, 1.9% (±0.4) N, 43.0% (±2.1) C, and had a C:N ratio of 22.6 (±4.3).

Total bacterial counts in unused bedding were 4,211,927 cfu/mL and ranged from 325 to 23,373,500 cfu/mL. Proportionally, samples had 58.0% bacillus species, 37.2% environmental Streptococci species, 4.0% Staphylococcus species, and 0.9% coliforms. Separated raw manure solids contained the greatest total counts of bacteria prior to use as freestall bedding. In particular, populations of bacillus, coliforms, and environmental Streptococci were greater than those found in digested and composted manure solids. Populations of bacillus and environmental Streptococci species were similar between digested and composted solids. No difference was found in the populations of Staphylococcus species between digested, composted, and separated raw manure solids. Coliform bacteria were not detected in unused samples of composted solids.

Total bacterial population in used bedding was 13,285,010 cfu/mL and ranged between 25,100 and 73,036,500 cfu/mL. Proportionally, bedding samples had 51% bacillus species, 39.3% environmental Streptococci species, 7.4% environmental Staphylococcus species, and 2.2% coliforms. Bacterial counts among the different types of manure solids were more similar after use as freestall bedding; however, digested manure solids contained less total bacteria than composted (P < 0.001) and separated raw manure solids (P = 0.006). Coliform bacteria, not present in composted solids prior to use as bedding, were found in amounts similar to that of digested and separated raw manure solids after use as freestall bedding at approximately 145,000 cfu/mL. Environmental Streptococci were present in lower concentrations (P < 0.001) in digested manure solids (1,379,180 cfu/mL) than composted (5,614,707 cfu/mL) and separated raw (3,934,915 cfu/mL) manure solids. Digested solids also contained fewer (P < 0.05) bacillus species (1,375,599 cfu/mL) than separated raw (2,852,767 cfu/mL) manure solids. No differences were observed in counts of Staphylococcus species.

**Digester comparison**

Anaerobic digestion was being utilized by 19 of the 38 farms in this study and 6 herds were purchasing digested solids from another dairy. Plug-flow digesters were most common, with 14 of the 19 herds using this type of digester. The remaining 5 herds used complete-mix digesters. Differences between systems include percent solids of manure entering the digester, mixing of manure within the system, and most notably the design. Plug-flow digesters usually are built below grade and plugs of fresh manure enter the digester at one end and push out digested manure at the opposite end. Complete-mix digesters...
are typically silo-like tanks built above ground which use agitators to periodically mix digester contents.

Only minor differences existed between unused RMS obtained from plug-flow compared to complete-mix digesters. RMS from plug-flow digesters contained less N (1.4%) than from complete-mix digesters (1.6%; P < 0.01). This difference resulted in a greater C:N ratio (P = 0.03) for solids obtained from plug-flow digesters (31.3) compared to complete-mix (27.7) digesters. Unused RMS bedding moisture, NDF, NFC, ash, total C, P, and K content as well as pH were not different between digester types. Bacterial populations of bacillus, coliforms, environmental Streptococci, and Streptococcus species were similar between unused RMS obtained from plug-flow and complete-mix digesters.

**Animal welfare**

Stall surface was associated with lameness and hock lesion prevalence. Lameness prevalence (locomotion score ≥3 on a 1 to 5 scale) was lower in deep bedded freestalls (14.4%) than freestalls with mattresses (19.8%). It is interesting to note that lameness prevalence, even for farms using mattresses, was similar to lameness prevalences we have observed in herds with deep bedded sand stalls. Severe lameness prevalence (locomotion score ≥4) was also lower for cows housed in deep bedded freestalls (3.6%) than for cows housed in freestalls with mattresses (5.9%). Again, those prevalences are similar to what we have found in sand-based freestalls. Producers were using large quantities of solids on top of mattresses because the bedding material is readily available. In addition, the prevalence of hock lesions (hock lesion scores ≥2 on a 1 to 3 scale) and severe hock lesions (hock lesion score = 3) was lower in herds with deep bedded freestalls (49.4%; 6.4%) than in herds with mattresses (67.3%; 13.2%).

Herd turnover rates were not associated with stall surface; however, the percentage of removals due to voluntary (low production, disposition and dairy) and involuntary (death, illness, injury, and reproductive) reasons was different between deep bedded and mattress based freestalls. Voluntary removals averaged 16.1% of all herd removals in deep bedded herds, whereas in mattress herds these removals were 7.9%. Herds utilizing RMS in deep-bedded and mattress based stalls were found to have similar mortality rates. Mortality rates were 8.2% for herds with deep beds and 8.6% for herds with mattresses. Nearly half of all mortalities were found to occur prior to 60 DIM. In herds with deep beds, 47.2% of mortalities occurred prior to 60 DIM (range of 18.7 to 74.0%). Herds with mattresses reported 42.7% of deaths occurred before 60 DIM (range of 33.8 to 55.3%).

**Milk quality and udder health**

One major concern expressed by producers considering the use of manure solids for bedding is the possibility of increased somatic cell count (SCC). We found that yearly average bulk tank SCC was 275,000 cells/mL (range - 121,000 to 688,000 cells/mL). This average is not very different from the average in the region (~290,000). Eighteen percent of the herds had a yearly bulk tank SCC less than 200,000 cells/mL and 9% had more than 400,000 cells/mL. All herds used pre and post-milking teat disinfection, individual towels for drying udders, and routine dry cow therapy at dry off.

Cows in this study were on the average cleaner than any other freestall study we have conducted. The lowest percentile herds for SCC (which averaged 186,000 SCC) had an average hygiene score of 2.38 (1-to-5 scale where 1 = clean and 5 = very dirty); the highest percentile herds (average of 430,000 SCC) had an average hygiene score of 2.62. Cleaner cows are easier to prepare prior to milking and are less susceptible to mastitis. Stall maintenance and speed of moving cows to the parlor can influence cow hygiene.

Incidence rates of clinical mastitis in the current study were 66.3 and 49.0 cases per 100 cow-years for deep-bedded and mattress herds, respectively, and ranged from 9.3 to 108.7 cases per 100 cow-years in deep-bedded and 13.2 to 107.6 cases per 100 cow-years in herds with mattresses. No association was found between clinical mastitis incidence and stall surface. These relatively high results for clinical mastitis incidence suggest that udder health may be compromised when using RMS as bedding for lactating dairy cows or producers using RMS are paying closer attention and detecting clinical cases more often.

**Conclusions**

Differences in the chemical and bacteriological characteristics of digested, drum-composted, and separated raw manure solids were found prior to and after use as bedding. These differences were likely due to the processes of anaerobic digestion and drum-composting. Bacteriological differences were substantial in unused RMS but were minor after use as freestall bedding. Minor differences existed between RMS obtained from plug-flow and complete-mix digesters.

The use of RMS in deep-bedded freestalls appeared to provide cows with a more welfare friendly resting surface than the use of RMS on top of mattresses. Herds with deep beds had a lower prevalence of lameness and hock lesions compared to herds with mattresses. Additionally, the prevalence of severe
lameness and severe hock lesions in herds with deep-bedded stalls was lower than those observed in herds with mattresses. When the results are compared to previous studies with sand for bedding, we learned that lameness prevalence was similar, hock lesion prevalence was slightly higher, and cow hygiene was better in herds using RMS. Similar herd turnover rates were found between deep-bedded and mattress based herds; however, removals due to voluntary and involuntary reasons were found to be different. Death was indicated as the primary reason for herd removal both during lactation and prior to 60 DIM.

It appears that excellent cow preparation at milking time, sanitation of milking equipment, cow hygiene, adequate dry cow housing, and bedding/stall management appeared to be critical in maintaining a low SCC when using recycled manure solids for bedding and making it work. These practices are important when using any type of bedding and even more so with recycled manure solids. Overall, RMS appear to be a satisfactory bedding option for freestall dairy herds.

Acknowledgments
We thank the dairy producers who participated in this study and the extension educators and industry representatives who helped identify cooperator farms. Thanks to Jim Salfer, Kevin Janni and Jeff Reneau for their input on the project. We would also like to thank Mark Kinsel (AgriMetrica, LLC, Ellensburg, WA) for providing us with the handheld PC software used to collect locomotion, hock lesion and hygiene scores. We also thank AgSource (Menomonie, WI) and DRMS – Dairy Records Management Systems (Raleigh, NC) for access to DHIA data for some farms and the milk processors for access to daily bulk tank data. This project was funded by the University of Minnesota Rapid Agricultural Response Fund.