Relationship Between Facility Type and Bulk Tank Milk Bacteriology, Udder Health, Udder Hygiene, and Milk Production on Vermont Organic Dairy Farms

Journal:	*Journal of Dairy Science*
Manuscript ID	Draft
Article Type:	Research
Date Submitted by the Author:	n/a

Complete List of Authors:	Jeffrey, Caitlin; University of Vermont, Department of Animal and Veterinary Sciences Andrews, Tucker; University of Vermont, Department of Plant and Soil Science Godden, Sandra; University of Minneosta, VPM Neher, Deborah; University of Vermont College of Agriculture and Life Sciences, Dept Plant and Soil Science Barlow, John; University of Vermont, Department of Animal Science

Key Words:	Mastitis, organic dairy cattle, bedded pack, milk quality

The STROBE-Vet statement checklist.

	Item	STROBE-Vet recommendation	Page #
Title and Abstract	1	(a) Indicate that the study was an observational study and, if applicable, use a common study design term	2
		(b) Indicate why the study was conducted, the design, the results, the limitations, and the relevance of the findings	2-3
Background / rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	(a) State specific objectives, including any primary or secondary prespecified hypotheses or their absence	6
		(b) Ensure that the level of organization[a] is clear for each objective and hypothesis	6
Study design	4	Present key elements of study design early in the paper	2
Setting	5	(a) Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
		(b) If applicable, include information at each level of organization	NA
Participants [b]	6	(a) Describe the eligibility criteria for the owners/managers and for the animals, at each relevant level of organization	7-8
		(b) Describe the sources and methods of selection for the owners/managers and for the animals, at each relevant level of organization	7-8
		(c) Describe the method of follow-up	8
		(d) For matched studies, describe matching criteria and the number of matched individuals per subject (e.g., number of controls per case)	NA
Variables	7	(a) Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. If applicable, give diagnostic criteria	9-12
		(b) Describe the level of organization at which each variable was measured	9
		(c) For hypothesis-driven studies, the putative causal-structure among variables should be described (a diagram is strongly encouraged)	4-5

Data sources / measurement	8*	(a) For each variable of interest, give sources of data and details of methods of assessment (measurement). If applicable, describe comparability of assessment methods among groups and over time	9-12
		(b) If a questionnaire was used to collect data, describe its development, validation, and administration	9-10
		(c) Describe whether or not individuals involved in data collection were blinded, when applicable	NA
		(d) Describe any efforts to assess the accuracy of the data (including methods used for “data cleaning” in primary research, or methods used for validating secondary data)	13
Bias	9	Describe any efforts to address potential sources of bias due to confounding, selection, or information bias	32
Study size	10	(a) Describe how the study size was arrived at for each relevant level of organization	8
		(b) Describe how non-independence of measurements was incorporated into sample-size considerations, if applicable	NA
		(c) If a formal sample-size calculation was used, describe the parameters, assumptions, and methods that were used, including a justification for the effect size selected	NA
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	14
Statistical methods	12	(a) Describe all statistical methods for each objective, at a level of detail sufficient for a knowledgeable reader to replicate the methods. Include a description of the approaches to variable selection, control of confounding, and methods used to control for non-independence of observations	13-15
		(b) Describe the rationale for examining subgroups and interactions and the methods used	NA
		(c) Explain how missing data were addressed	17-18
		(d) If applicable, describe the analytical approach to loss to follow-up, matching, complex sampling, and multiplicity of analyses	NA
		(e) Describe any methods used to assess the robustness of the analyses (e.g., sensitivity analyses or quantitative bias assessment)	NA
Participants	13*	(a) Report the numbers of owners/managers and animals at each stage of study and at each relevant level of organization - e.g., numbers eligible, included in the study, completing follow-up, and analyzed	7-9

		(b) Give reasons for non-participation at each stage and at each relevant level of organization	7-9
		(c) Consider use of a flow diagram and/or a diagram of the organizational structure	NA
Descriptive data on exposures and potential confounders	14*	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders by group and level of organization, if applicable	16, 42-43, table S1-S5
		(b) Indicate number of participants with missing data for each variable of interest and at all relevant levels of organization	17-18
		(c) Summarize follow-up time (e.g., average and total amount), if appropriate to the study design	NA
Outcome data	15*	(a) Report outcomes as appropriate for the study design and summarize at all relevant levels of organization	17-21, 42-48
		(b) For proportions and rates, report the numerator and denominator	NA
		(c) For continuous outcomes, report the number of observations and a measure of variability	17, 43
Main results	16	(a) Give unadjusted estimates and, if applicable, adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders and interactions were adjusted. Report all relevant parameters that were part of the model	43-48, 17-21
		(b) Report category boundaries when continuous variables were categorized	42
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done, such as sensitivity/robustness analysis and analysis of subgroups	NA
Key results	18	Summarize key results with reference to study objectives	21-22
Strengths and Limitations	19	Discuss strengths and limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	21-22, 26, 32
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	21-34
Generalizability	21	Discuss the generalizability (external validity) of the study results	32
~~Funding~~ Transparency	22	(a) Funding- Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based (b) Conflicts of interest-Describe any conflicts of interest, or lack thereof, for each author	(a) 35 (b) 35

		(c) Describe the authors' roles- Provision of an authors' declaration of transparency is recommended (d) Ethical approval- Include information on ethical approval for use of animal and human subjects (e) Quality standards-Describe any quality standards used in the conduct of the research	(c) NA (d) 10 (IRB), 11 (IACUC) (e) 6

[a] Level of organization recognizes that observational studies in veterinary research often deal with repeated measures (within an animal or herd) or animals that are maintained in groups (such as pens and herds); thus, the observations are not statistically independent. This non-independence has profound implications for the design, analysis, and results of these studies.
[b] The word "participant" is used in the STROBE statement. However, for the veterinary version, it is understood that "participant" should be addressed for both the animal owner/manager and for the animals themselves.
*Give such information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Interpretive summary

Previous studies reported bedded packs improve cow welfare and comfort and have advantages for manure management, soil health, and water quality. Consensus is lacking on whether bulk tank milk quality, udder health, udder hygiene and milk production are compromised on bedded packs. In an observational study measuring these outcomes during the non-grazing season on 21 organic dairies in Vermont, bedded packs were similar to tiestalls and freestalls. We conclude that bedded packs are a viable option for dairy cattle housing during the non-grazing season in the Northeastern US.

Running head:

Milk quality and udder hygiene on VT organic dairies

Relationship Between Facility Type and Bulk Tank Milk Bacteriology, Udder Health, Udder Hygiene, and Milk Production on Vermont Organic Dairy Farms

Caitlin E. Jeffrey,[1] Tucker Andrews[2], Sandra M. Godden[3], Deborah A. Neher[2], John W. Barlow[1]

[1] Department of Animal and Veterinary Sciences, University of Vermont, Burlington, VT 05405

[2] Department of Plant and Soil Science, University of Vermont, Burlington, VT 05405

[3] Department of Veterinary Population Medicine, College of Veterinary Medicine, University of Minnesota, St. Paul, MN 55108.

Corresponding author: John Barlow

Department of Animal and Veterinary Sciences,

202 Terrill Building,
University of Vermont,
Burlington, VT 05405
Phone: 802-656-1395
Email: john.barlow@uvm.edu

Abstract

The primary objective of this cross-sectional observational study on organic dairies was to determine whether bulk tank milk quality, udder health, udder hygiene and milk production outcomes were associated with facility type. A secondary objective was to identify other management-related risk factors associated with bulk tank milk quality, udder health, udder hygiene, and milk production on organic dairy herds in Vermont. We aimed to collect bulk tank milk samples, udder hygiene scores, and complete a questionnaire on mastitis risk and bedding management practices on 40 farms, in order to compare herds using the two most common housing systems (freestalls, tiestalls) with those using a bedded pack, for organic dairy cattle in the state during the non-grazing season. The study was completed on 21 farms (5 bedded packs, 6 freestalls, 10 tiestalls) before interruption due to the COVID-19 pandemic. Data captured from Dairy Herd Improvement Association records from the test closest to the date of the farm visit included average somatic cell score (SCS), standardized 150-day milk (pounds), % cows with current high SCS (SCS ≥4.0), % cows with newly elevated SCS (previous SCS <4.0 to current ≥4.0), and % cows with chronically elevated SCS (SCS ≥4.0 last two tests). Multivariable linear regression models were performed to describe outcomes by facility type, but suffered from limited statistical power due to small group sample sizes. Final results from unconditional comparisons showed that farms using each of the three facility types did not differ in metrics captured from Dairy Herd Improvement Association test data (cow-level udder health measures, milk production), bulk tank milk somatic cell count (BTSCC) and aerobic culture data, or udder hygiene scores. Subsequently, a secondary analysis was conducted using univariate linear regression to identify associations between herd management factors and outcomes for all 21 farms combined. Although not all differences found were statistically significant, numeric differences that may be biologically important are reported showing farms with deeper bedding had a lower BTSCC, lower newly elevated SCS, lower elevated current SCS, lower average SCS, and better udder hygiene metrics. Farms with lower mean udder hygiene scores had numerically lower chronically elevated SCS, lower elevated current SCS, and lower average SCS. The current study provides insight on factors affecting bulk tank milk quality, udder health and hygiene measures on organic dairy farms in Vermont. Because outcomes for bedded packs were comparable to more frequently used indoor housing systems (tiestalls and freestalls), we conclude that bedded pack facilities are a viable option for confinement during the non-grazing season for pasture-based herds interested in a loose-housing system in the Northeastern US.

Keywords: Mastitis, organic dairy cattle, housing, bedded pack, milk quality

Introduction

Mastitis due to environmental pathogens, such as those commonly found in bedding material, has now become the "most common and costly form of mastitis in modern dairy herds" that have implemented standard mastitis control practices limiting the effect of contagious pathogens (Klaas and Zadoks, 2018). Teats of dairy cattle may be in direct contact with bedding materials for 40 to 60% of the day, making this an important potential source of exposure to opportunistic environmental mastitis pathogens (Tucker and Weary, 2004; Cook et al., 2005; Hogan and Smith, 2012). Work exploring how bedding materials relate to a cow's risk of contracting mastitis has understandably focused on the most frequently used bedding materials and housing systems in the dairy industry. Currently, the most common type of dairy cattle housing for organic farms in Vermont is a tiestall barn, with freestall barns a distant second (Andrews et al., 2021). As consumer opinion about confinement housing of dairy cattle evolves and influences dairy policy, both the dairy industry and consumers are looking to move away from traditional housing systems which restrict cow movement (Barkema et al., 2015). Many smaller-scale organic dairy farmers in Vermont with aging facilities, and especially tiestall barns, may be looking to adopt a bedded pack system on their farms as a form of loose-housing (Andrews et al., 2021). These loose-housing structures are perceived to integrate well into pasture-based farm systems, and state and federal agencies in the U.S. are providing financial incentives for dairies to build these structures as part of manure management practices which improve water quality and contribute to soil conservation (USDA; Andrews et al., 2021).

As interest in bedded packs grows, it is important to better understand milk quality, udder health and hygiene on farms using these housing alternatives. Understanding mastitis risk for cattle housed on bedded packs is especially important for organic dairy farmers, as they have limited effective options for treating intramammary infections (Ruegg, 2009). As mastitis-causing bacteria may thrive in the conditions found in composting bedded packs (Black et al., 2014), previous work studying mastitis risk and bedding would suggest bedded packs could pose a relatively higher risk for intramammary infections. Loose-housed cows continually add manure to the bedded pack, contributing both pathogenic bacteria (non-*aureus* staphylococci, Wuytak et.

al., 2020; *E. coli*, *Klebsiella* spp., and *Enterobacter* spp., Eberhart, 1984; streptococci, Zadoks et al., 2005) and nutrients to the organic bedding material. Organic bedding material is more likely to have a higher bacteria count than inorganic bedding, such as sand, (Hogan et al., 1989; Rowbotham and Ruegg, 2016b), as it supplies nutrients and moisture which encourages bacterial growth. This could lead to higher concentrations of bacteria on teat skin for cows on bedded packs, because: 1) organic bedding is inherently associated with a higher number of bacteria on teat ends (Fairchild et al., 1982; Rowbotham and Ruegg, 2016b), and 2) a higher concentration of bacteria in bedding is related to a higher concentration of bacteria on teat ends (Hogan and Smith, 1997; Zdanowicz et al., 2004; Rowbotham and Ruegg, 2016b). This higher concentration of bacteria on teat ends may put the mammary gland at an increased risk of infection, although limited evidence exists for this relationship (Neave et al., 1966; Pankey, 1989; Rowbotham and Ruegg, 2016a).

Previous work describing mastitis risk and cow hygiene on bedded pack systems includes descriptive studies of actively-managed composting bedded packs (Barberg et al., 2007b; Black et al., 2013; Fávero et al., 2015; Eckelkamp et al., 2016b; Albino et al., 2018; Heins et al., 2019). However, research comparing milk quality and cow hygiene between bedded pack systems and more traditional housing types has so far been limited to freestalls with sand, which is an uncommon housing type for organic farms in Vermont (Andrews et al. 2021. These include a study comparing actively-managed composting bedded packs (CBP) and sand-bedded freestalls for farms with a history of low bulk tank somatic cell counts (Eckelkamp et al., 2016a), work describing hygiene and bulk tank milk somatic cell count (BTSCC) for sand-bedded freestalls and CBP (Adkins et al., 2022), and a comparison of CBP and two types of freestall barns (Lobeck et al., 2011). It is unclear whether the herds included in these prior studies were conventionally-managed or organic dairies. To the best of our knowledge, no studies describe and compare bulk tank milk quality, udder health and hygiene on bedded pack farms and tiestall barns of similar size and management style.

To better inform organic dairy producers in the Northeastern US, who may be interested in using a bedded pack barn for housing their cattle during the non-grazing season, we conducted a cross-sectional, observational study on organic dairies in Vermont. This study aimed to quantify bulk tank milk bacteriology, udder health and udder hygiene measures for the two most common indoor housing systems (freestalls, tiestalls) and farms using a bedded pack for organic farms in Vermont. The objectives of this project were to identify whether bulk tank milk quality, udder health and hygiene outcomes differed by facility type, with a view to determining if bedded pack systems are a viable option for indoor housing of lactating cows in VT during the non-grazing season. We hypothesized that udder health, hygiene, and bulk tank milk bacteriology of bedded pack herds is inferior to that of more traditional housing types, as has been suggested by some previous research (Peeler et al., 2000; Fregonesi and Leaver, 2001; Barberg et al., 2007b; Lobeck et al., 2011). A secondary objective was to identify other (non-facility) management-related risk factors associated with bulk tank milk quality, udder health, udder hygiene, and milk production for organic VT dairy herds.

Materials and Methods

STROBE-VET (Strengthening the Reporting of Observational Studies in Epidemiology–Veterinary Extension) statement guidelines were followed in the reporting of this study (O'Connor et al., 2016).

Herd enrollment and selection

The source population for this study was the 145 farms that responded to a survey sent to all certified organic dairy farms producing cow milk in Vermont in Winter 2018-2019 (all farms, n = 177). Certified organic dairy farms in the United States are required to allow their cows daily access to pasture during the grazing season, and cows must obtain 30% of their dry matter intake from grazing (Rinehart and Baier, 2011). During the non-grazing season (typically November-May in Vermont), organic farms house cows in a variety of indoor facility types. The Winter 2018-2019 survey aimed to quantify the frequency and diversity of indoor housing and bedding types used by organic dairy farmers in the state when cows were not on pasture (Andrews et al., 2021). Dairy farms were eligible for enrollment in the current study if they: 1) responded to the initial survey in the Winter 2018-2019, 2) indicated they met the enrollment criteria of testing with the Dairy Herd Improvement Association (DHIA) at least monthly, 3) milked between 35 and 120 cows, and 4) indicated they would be interested in further participation. Eligible farms were contacted from this source population in Spring 2019 if they responded that they were using one of four categories of bedding/housing combinations for their indoor housing system: 1) freestall barn bedded with sand, 2) freestall barn bedded with shavings or sawdust, 3) tiestall barn bedded with shavings or sawdust, or 4) an enclosed loose housing facility deeply bedded with organic material (hereafter, “bedded pack”). The first three housing and bedding combinations are the most frequently used by organic dairies in Vermont to house cows during the non-grazing season, and were compared to bedded packs as they were the housing type of interest for this project.

A convenience sample of farms was enrolled in Spring 2019 from a list of eligible farms (grouped by housing/bedding combination) using the phone number or email address provided in the 2018-2019 survey response. Our aim was to enroll 40 farms for the current study, with 10 farms from each of the four housing/bedding categories described above. Prior to obtaining the 2018-2019 survey results, based on preliminary data collected by the University of Vermont Center for Sustainable Agriculture Extension group, the study was designed anticipating that it would be possible to enroll 10 organic Vermont dairies using a bedded pack system as their primary indoor housing system. However, out of the 17 farms from the 2018-2019 survey which indicated at least some use of a bedded pack system, one farm was not interested in any further participation, five did not use DHIA testing, and six only used a bedded pack system as a secondary housing system in conjunction with a tiestall barn, or cows were only on the pack a few hours a day. Because the number of farms using bedded packs was fewer than anticipated, the eligibility requirements were relaxed to include one farm where cows spend the majority (two-thirds) of their time in a bedded pack, with the remaining time in a tiestall with wood shavings. Additionally, two bedded pack farms were included that had limited DHIA information: one farm did not utilize cow-level testing, and cow-level data for a second farm was limited due to their seasonal lactation schedule. This study was intended to study cows while they were in their indoor housing system, so all herds visits were completed before any grazing had begun for the season.

Of the intended 40 herds to be recruited in the study, 21 herds (1 freestall bedded with sand, 5 freestalls bedded with wood shavings/sawdust, 10 tiestalls bedded with wood shavings/sawdust, 5 bedded packs) agreed to participate and farm visits were completed April-May 2019. All herds sampled during this period were housing their cows as they would in the non-grazing season. Farm visits were suspended in mid-May 2019 as farms began turning their cows out to pasture for the grazing season, with the intention of resuming in April 2020 to complete the remaining 19 herds. Due to COVID-19 pandemic activity restrictions, the decision was made to not resume the study, and the final analysis included the 21 herds sampled in 2019. As there was only one farm sampled using a freestall facility bedded with sand, the initial plan to group farms by the four housing/bedding combinations specified was abandoned in favor of grouping farms by the three facility types used. The single sand freestall was combined with freestalls bedded with wood shavings/sawdust (FS; n = 6), there were 10 tiestalls bedded with wood shavings/sawdust (TS), and 5 bedded packs (BP).

Questionnaire administration, sampling, and udder hygiene scoring

At each farm visit, a questionnaire was administered to collect information about housing and bedding management, as well as other practices on the farm that could impact mastitis risk (Supplemental Data). The study questionnaire was largely adapted from a previously published survey (Stiglbauer et al., 2013), with additional questions specific to the current study. The questionnaire was reviewed by a social scientist experienced in gathering qualitative data and tested before use with herd managers at the University of Vermont teaching dairy. Questions about mastitis risk explored producer concerns about bedding/mastitis risk; mastitis control, identification and record keeping; milking facilities, procedures, and hygiene practices; information about diet, vitamin and mineral supplementation, and water source; typical calving and periparturient practices; and fly control. Questions about housing and bedding management included describing type of housing system used for both lactating and dry cows; classification and description of any bedding material used; and bedding management practices for each housing type used. The questionnaire also collected some basic herd information (production numbers; number of lactating, dry, and youngstock; breed; record-keeping systems). Farms using bedded pack systems were asked additional questions to gather detailed information about bedded pack construction, management, monitoring practices, and perceptions comparing bedded packs to any previously used systems. Completion of the questionnaire required 45 minutes on average, ranging from about 30 minutes to 1.5 hours. The questionnaire and interview protocols were registered with the University of Vermont Institutional Review Board (IRB certification 19-0057). The questionnaire was created and administered on a tablet using KoboCollect software (KoboCollect, 2019).

At each farm visit, a bulk tank milk sample and bedding samples were collected. The bulk tank milk sample was collected directly from the top of the bulk tank using a 250-mL sterile single-use vial (Blue Dippas™, Dynalon Products, England) after at least 5 minutes of agitation. Samples were kept on ice in a cooler during transport until they were processed fresh for SCC measurement or were frozen and stored at −20°C in the laboratory, before being sent to a diagnostic lab for microbiological analysis. An on-farm observation sheet was completed, which collected information about the bulk tank, cow identification, a subjective assessment of air quality, and any outdoor exercise area (Supplemental Data). Additionally, measurements of the housing facilities were recorded for freestalls and tiestalls where appropriate (stall sizes, pen sizes, bedding depth, stocking density, trainer use), as well as observations about bedded packs when applicable (temperature, depth, pen size, and stocking density in m^2 per animal). If multiple pens were present (e.g., freestall barn), used bedding samples were collected from the pen containing the largest group of lactating cows, or from the highest producing group of animals if there were multiple pens of equal size. Bedding depth of freestalls and tiestalls was included as a producer reported value in the questionnaire. Bedding depth of bedded pack facilities was measured where the pack met a cement knee wall. Udder hygiene scoring was completed by the same researcher at all farms for a minimum of 30 randomly selected cows.

Udder hygiene scores were taken from cows housed in the same pens from which used bedding samples were collected. A four-point udder hygiene scoring system was used, where 1 = free of dirt, 2 = slightly dirty (2–10% of surface area), 3 = moderately covered with dirt (10–30% of surface area), and 4 = covered with caked on-dirt (>30% of surface area) (Schreiner and Ruegg, 2002). Animal use for this project was approved by the University of Vermont Institutional Animal Care and Use Committee (IACUC; protocol #PROTO202000089).

Herd-level udder health measurements

Herd-level DHIA test results for the test day closest in time to the farm visit (either preceding or following day of farm visit, whichever was shorter) were captured from the record processing center working with each herd (Lancaster DHIA, Manheim, PA; Dairy One Co-Op. Inc., Ithaca, NY). Information captured included test date, number of lactating cows, standardized 150-day milk production (STD 150-day milk), and test-day average cow-level somatic cell score (SCS). The following udder health measures were also captured from DHIA records: proportion of cows with an SCC ≥200,000 cells/mL on most recent test day (“elevSCS”), where elevated SCS was defined as a somatic cell score of ≥4.0; the proportion of cows with a newly elevated SCS (“newSCS”), which was defined as a SCS changing from <4.0 to ≥4.0 over the last 2 tests; and the proportion of cows with a chronically elevated SCS (“chronSCS”), which was defined as having a SCS ≥4.0 on the last two tests (Schukken et al., 2003).

Bulk tank milk culture and bulk tank somatic cell count measures

An aliquot of the bulk tank milk sample was stored at -4°C until it could be transported to the laboratory of a dairy processing plant (St. Alban’s Cooperative/Dairy Farmers of America, St. Albans, VT) within 48 hours of collection for determination of the bulk tank somatic cell count (BTSCC).

Frozen bulk tank milk samples were shipped on ice to the Laboratory for Udder Health (University of Minnesota Veterinary Diagnostic Laboratory, St. Paul) for analysis. Methodology for bulk tank milk cultures at the Laboratory of Udder Health are described elsewhere (Patel et al., 2019). Briefly, thawed, room-temperature bulk tank milk and a 10-fold dilution of each bulk tank milk sample were plated onto MacConkey, Factor (gram-positive selective agar; University of Minnesota), and Focus (selective for SSLO bacteria; University of Minnesota) media plates and incubated for two days at 37°C. Any lactose-fermenting colonies on MacConkey medium were counted and reported as coliform bacteria. Any β-hemolytic colonies on Focus medium were counted and identified to the species level using a MALDI Biotyper (suspect *Streptococcus agalactiae*). All remaining colonies on Focus medium that were not identified as *Strep. agalactiae* were counted and recorded as streptococci or strep-like organisms (SSLO). Hemolytic colonies on Factor medium were counted and identified to the species level using a MALDI Biotyper (suspect *Staph. aureus*). Any hemolytic colonies with a confidence score ≥2.0 for *Staph. aureus* were counted and reported as such. Remaining colonies of staphylococci on Factor media (based on colony morphology, catalase reaction, or Gram stain) were counted and reported as *Staph.* spp. Bulk tank samples were also cultured for *Mycoplasma* spp. (0.1 mL milk was swabbed across a Mycoplasma agar plate, then placed in a 7% CO2 incubator at 37°C for 7 days, after which they were examined for *Mycoplasma* spp. by a trained microbiology technician). For each bulk tank milk sample, total colony-forming units (cfu) per mL were calculated for coliform organisms, *Staph.* spp., streptococci and strep-like organisms (SSLO), *Staph. aureus*, *Strep. agalactiae*, and *Mycoplasma* spp. The lower threshold of detection for bacteria in this bulk tank milk culture protocol was 5 cfu/mL, and the upper threshold was 62,500 cfu/mL.

Data management and analysis

Bulk tank milk culture results, BTSCC, DHIA test results, farm-level udder hygiene outcomes, questionnaire data, and farm observations were entered into an Excel database (Microsoft Corp., Redmond, WA). Udder hygiene scores for individual cows were used to calculate two farm-level udder hygiene measures: 1) mean udder hygiene score, and 2) proportion of cows with dirty udders (udder hygiene score ≥3), which were incorporated into the database. This Excel database was then imported into the R Statistical Programming Environment (R Development Core Team, 2023) for data cleaning, checking, and statistical analysis. The distribution of outcome variables was assessed to check for normality using a Shapiro-Wilk test with significance set at $P \leq 0.05$, visual assessment of distribution and residuals, skewness, and comparison of the median and mean values. Raw bulk tank somatic cell count (BTSCC) data was $\log_{10}$ transformed for analyses. Descriptive statistics were calculated to evaluate the distribution of data, data integrity, and to identify missing data. Descriptive statistics generated included description of general herd characteristics and farm traits, lactating cow housing/facilities, lactating cow bedding material/bedding management practices, milking hygiene procedures, and mastitis control practices for all 21 herds included in the study.

Objective 1. Evaluation of relationships between housing system and measures of milk quality, udder health, udder hygiene and milk production. As most measures of aerobic culture data were not normally distributed even after log transformation, a Kruskal-Wallis test was used to compare cfu counts between the three facility types. Statistical significance was declared at $P \leq 0.05$.

Independent farm-level predictors from the herd-management questionnaire offered to the multivariable models are described in Table 1. Continuous variables underwent correlation analysis to identify predictor variables that were highly correlated (correlation coefficient ≥0.60), and unconditional associations among categorical variables were evaluated using a Pearson's chi-squared or Fischer's Exact test as appropriate ($P \leq 0.05$). An ANOVA was used to check for correlation between numeric continuous variables and categorical variables ($P \leq 0.05$). When a categorical variable had multiple groups with a small number of observations in each, groups were combined when biologically reasonable to have all categories of predictor variables contain at least five observations. If any predictor had only one observation in a group and there was no way to combine groups in a logical way, it was excluded from further analysis (but listed in descriptive statistic tables, Supplemental Tables S1-S4).

Univariate linear regression was performed in R using the "lme4" package to investigate the unconditional relationship between the six udder health and production outcomes (BTSCC, avg. SCS, newSCS, elevSCS, chronSCS, STD 150-day milk) and two hygiene outcomes (mean hygiene score, proportion of dirty udders) for each farm and the previously-described herd-level independent variables. The two udder hygiene metrics (proportion dirty udders and average udder hygiene score) were used as both predictor variables (in models for other outcome variables) and outcome variables in models of their own. Any explanatory variable that was unconditionally associated with 1 or more of the outcomes of interest at $P < 0.20$ was then offered into a multivariable model investigating the relationship between the udder health and production or hygiene outcome and the herd-level predictor variables. If any predictor variables were found to be correlated with each other at the previously described cut-offs, the one with the more highly significant relationship from univariate analysis was offered to the multivariable model when appropriate. The two udder hygiene metrics were highly correlated (derived from the same data), so whichever one had a smaller *P*-value from the univariate analysis was chosen for inclusion in the model-building process. Facility type was forced into these multivariable models, as it was the primary explanatory predictor of interest. A backward stepwise variable selection process was then used, with the least significant variables being removed one by one until all remaining predictors had $P \leq 0.10$. Final models were selected based on lowest Akaike information criteria, and an *F*-test to compare the final model to the model with facility type as the only predictor. The multivariable modelling approach described above aimed to investigate the conditional relationship between facility type and the eight outcomes of interest while controlling for different farm management practices, housing characteristics, milking procedures and mastitis control practices.

Objective 2. Identify other (non-facility) management-related risk factors associated with bulk tank milk quality, udder health, and milk production in organic dairy herds. After grouping all 21 farms together, we used linear regression to explore associations between the independent predictors described in Table 1 and the six udder health and production outcomes (BTSCC, avg. SCS, newSCS, elevSCS, chronSCS, STD 150-day milk) and two hygiene outcomes (mean hygiene score, proportion of dirty udders). Unconditional relationships between the eight outcome variables and independent predictors are reported for a significance level of $P \leq 0.20$, and only for predictor variables with group sizes of at least n = 5.

Power analysis

A priori sample size calculations were not performed, as group size was determined by the number of organic dairy herds housing lactating cows on bedded pack systems in our region.

Results

Description of study herds

Of the 21 herds enrolled, 5 used a bedded pack system, 1 used a freestall bedded with sand, 5 used a freestall bedded with shavings/sawdust, and 10 used a tiestall bedded with shavings/sawdust (Supplemental Table S1). Of the 5 BP farms, two bedded with shavings/sawdust and cultivated 2 times a day to promote aerobic composting, 1 bedded with straw and woodchips and cultivated 2 times/week, and 2 bedded mainly with straw, adding woodchips as needed, and did not cultivate the pack at all. The predominant breeds on all farms were Holstein (n = 8 farms), Jersey (n = 10), and mixed Holstein-Jersey crosses/other (n = 3). The median (mean; range) number of lactating cows was 68 (64.9; 32-99). The median annual rolling herd average milk production for the farms was 6,367 (6,424; 4,082-9,618) kg. Nineteen of the 21 farms tested with DHIA monthly while their cows were in milk, 1 farm tested 5-8 times/year, and 1 tested every other month. On average, DHIA data was captured from a test day 4 days before the farm visit (range: -28 days to +33). Detailed descriptions further characterizing study farm management practices and housing characteristics for lactating animals (e.g., laying surface, ventilation, stocking density), and details about bedding material and bedding management practices for lactating animals (e.g., bedding depth, frequency of adding new bedding, manure removal) are provided in Supplemental Tables S1 and S2, respectively. Detailed descriptions of routine milking procedures and mastitis control practices are provided in Supplemental Tables S3 and S4, respectively.

Description of bulk tank milk quality, udder health measures, milk production, and udder hygiene scores

The aerobic culture results for the four bacterial groups measured for bulk tank milk did not differ among facility types (Table 2). None of the 21 bulk tank milk samples were positive for *Strep. agalactiae* or *Mycoplasma* spp. Sixteen of the 21 samples were negative for coliforms on aerobic culture, while 5 farms had a coliform count of 5 cfu/mL. *Staph. aureus* was found in the bulk tank milk from 13/21 herds, with a median (range) cfu/mL of 50 (15-320) when present.

BTSCC, % cows with newly elevated SCS, % cows with chronically elevated SCS, % cows with elevated SCS, avg. SCS, and STD 150-day milk production did not differ by facility type (Table 3).

The overall mean (95% CI) of herd-level udder hygiene scores for all 21 farms was 2.32 (2.16-2.49). The mean hygiene score was 2.2 (1.91-2.44) for bedded pack farms (n = 5), 2.5 (2.24-2.76) for tiestall farms (n = 10), and 2.15 (1.93-2.37) for freestall farms (n = 6). Mean udder hygiene score did not differ by facility type. The overall mean proportion of cows with dirty udders in a herd (udder hygiene score ≥3) was 40% (31-48). The mean proportion of cows with dirty udders (95% CI) was 32% (18-46) for bedded pack farms, 49% (35-62) for tiestall farms, and 32% (20-44) for freestall farms. The proportion of cows with dirty udders did not differ by facility type.

Objective 1. Analysis of relationship between facility type and measures of bulk tank milk quality, udder health, milk production, and udder hygiene scores

Final multivariable models are summarized in Table 4. All 21 farms were able to be included in the models for BTSCC, average hygiene score, and proportion of dirty udders. For the models exploring newSCS, chronSCS, and elevSCS, two bedded pack farms did not have available DHIA data (n = 19; group sizes: FS =6, TS = 10, BP = 3). One bedded pack farm did not have average cow-level SCS data (n = 20; group sizes: FS = 6, TS = 10, BP = 4). For STD 150-day milk, one bedded pack farm and two tiestall farms were missing DHIA data (n = 18; group sizes: FS = 6, TS = 8, BP = 4). Farms with missing data for a particular outcome were excluded for the analyses of that outcome.

Bulk tank milk quality outcomes

There was no difference in cfu count between the three facility types for any of the four bacterial groups measured using a nonparametric unconditional comparison (Table 2). Multiple attempts were made using multivariable analysis to compare the four aerobic culture outcomes for bulk tank milk, but all modeling approaches suffered from over-parametrization even when data was log transformed and were not pursued further.

Variables that were associated at P <0.20 with BTSCC in univariate analysis included predominant breed, if herds ever performed culture of mastitic milk, glove use, and herd size. The final multivariable included facility type (forced) and herd size. Facility type was not associated with BTSCC in the final model (Table 4).

Udder health outcomes

Herd size category, use of bedding amendment, air quality as assessed by researcher, glove use at milking, and clinical mastitis record keeping practices were offered to a multivariable model for newSCS. The final multivariable model included facility type (forced), bedding amendment use, air quality, glove use, and mastitis record keeping practices. Facility type was not associated with newSCS in the final model (Table 4).

Variables that were associated at P <0.20 with chronSCS in univariate analysis included feeding additional supplemental selenium, use of a bedding amendment, clipping/flaming udder hair, and proportion of dirty udders. The final multivariable model included all four variables from univariate analysis, as well as facility type (forced). Facility type was not found to be a significant predictor of the outcome chronSCS (Table 4).

Bedding amendment use and mean hygiene were offered to a multivariable model for elevSCS. Facility type (forced), bedding amendment, and mean hygiene were retained in the final multivariable model. Facility type was not associated with elevSCS in the final model (Table 4).

Feeding additional supplemental selenium, use of bedding amendment, OMRI-listed intramammary product at dry-off, injectable selenium and vitamin E product, and mean hygiene were offered to a multivariable model for herd average SCS. The final multivariable model for avg. SCS included facility type (forced), use of bedding amendment, dry product, injectable selenium, and mean hygiene score. Facility type was not found to be a significant predictor of avg. SCS (Table 4).

Milk production outcome

Variables that were associated at $P < 0.20$ with STD 150-day milk included use of injectable selenium and vitamin E product, whether producers cultured high SCC cows, and herd size group. All three variables and facility type (forced) remained in the final multivariable model (Table 4). Facility type was not associated with STD 150-day milk in the final model (Table 4).

Udder hygiene outcomes

Air quality assessed by researcher was offered to the multivariable model for proportion of dirty udders. The final multivariable model included only facility type (forced), which was not associated with proportion of dirty udders.

Variables that were associated at P <0.20 with average hygiene score included whether the producer ever cultured quarter milk samples and whether they checked for cases of clinical mastitis by both examining the udder and forestripping. The final multivariable model included facility type (forced), and how the producer checked for clinical mastitis. Facility type was not associated with the outcome of mean udder hygiene (Table 4).

Objective 2. Analysis of farm management factors (non-facility) associated with bulk tank milk quality, udder health, milk production, and udder hygiene scores for all farms combined

Selected results of univariate linear regression models identifying management factors beyond facility type which were unconditionally associated with bulk tank milk quality, udder health, milk production and hygiene outcomes for all farms combined (n = 21) at P <0.20 are presented in Table 5. We report the results of these univariate regression models as they may be biologically important, even though many failed to reach threshold for declaring statistical significance at $P \leq 0.05$, possibly due to small sample size.

The depth of bedding in stalls for freestall and tiestall herds was unconditionally associated with multiple udder health outcomes. As the depth of bedding in freestall and tiestall herds increased, multiple udder health measures improved, including lower avg. SCS, BTSCC, elevSCS, and newSCS. Similarly, comparing farms where cows were on deep bedding (i.e., grouping all herds reporting deeply-bedded stalls plus bedded pack herds) to herds that had stalls with a smaller amount of bedding on top of a mattress or concrete, farms with deep bedding had a numerically lower BTSCC.

Udder hygiene measures were associated with several udder health outcomes. Higher mean hygiene scores and proportion of udders scored ≥3 were associated with higher chronSCS, elevSCS, and average SCS. A few specific management practices were also found to be unconditionally associated with udder health outcomes: consistent glove use was associated with lower newSCS and BTSCC, clipping or flaming udders was associated with fewer chronSCS, and both parenteral supplementation of vit. E/selenium and use of an OMRI-listed intramammary product at dry-off were associated with lower average SCS and higher STD 150-day milk.

Both udder hygiene outcomes were unconditionally associated with the same predictors, most of which were related to the depth of bedding for cows. For herds using a bedded pack, deeper bedding was associated with lower average hygiene scores and lower proportion of dirty udders. Farms with cows housed on some type of deep bedding (i.e., grouping all herds reporting deeply-bedded stalls plus bedded pack herds) had numerically lower average udder hygiene scores and proportion dirty udders compared to cows on stalls with bedding over a mattress or concrete surface. For the fifteen farms reporting bedding depth in stalls, increased bedding depth was associated with lower mean udder hygiene score and a numerically lower proportion of dirty udders.

Discussion

This work presents the results of our observational study exploring the relationship between facility type and udder health and hygiene metrics, BTM quality (SCC and microbiology), and milk production on organic dairy farms in Vermont. The current study is to the authors' knowledge the first direct comparison of milk quality, udder health and udder hygiene on bedded pack farms to both tiestall and freestall herds of similar size and management styles, for a population of entirely small to midsize organic dairy farms. The major objective was to identify if milk quality, udder health and hygiene outcomes were associated with facility type, thereby exploring if bedded pack systems are a viable option for housing in Vermont during the non-grazing season compared to the two most common indoor housing systems in the state (freestalls, tiestalls). This study is also the first to describe udder health and hygiene on bedded packs in the Northeastern US, which is significant as the performance of these systems can be greatly influenced by climatic factors. As BTM bacteriology, udder health and hygiene metrics, and milk yield did not differ for BP herds compared to TS and FS herds, there was insufficient evidence to reject our hypothesis that these metrics would vary by facility type. We conclude that bedded pack systems can be considered a viable loose-housing option for organic dairy cattle during the non-grazing season in the Northeastern US.

Objective 1: Comparison of bulk tank milk quality, udder health, milk production, and udder hygiene measures by facility type

Previous work describing bulk tank milk aerobic culture data for farms using a bedded pack system has primarily been limited to descriptive studies enrolling only composting bedded pack herds (Barberg et al., 2007b; Shane et al., 2010), with only one study directly comparing bacterial counts between composting bedded packs and freestall barns (Lobeck et al., 2012). The current study is the first the authors are aware of directly comparing bacterial counts of bulk tank milk between bedded packs (both composting and static) and tiestall barns, and the first one to describe a population of exclusively organic dairies. The six farms included in Lobeck et al. (2012) used mainly wood sawdust as bedding material (with one using wheat straw by-product) as did the 12 farms in Barberg et al. (2007). This is similar to the current study, where three of five bedded packs used a combination of woodchips/shavings and straw/hay, and two used exclusively sawdust/shavings. The six farms included in Shane et al. (2010) bedded with a variety of “alternative” organic materials, including straw by-products, soybean stubble, and oat hulls. In contrast to previous work, which evaluated milk culture results across the summer months (Barberg et al., 2007b) and year-round (Lobeck et al., 2012), the current study focused solely on sampling during the period when animals are primarily housed inside in Vermont. We were most interested in studying bulk tank milk bacteriology for these organic herds during the non-grazing season, as this is when these pastured-based farms need to house their animals inside. All herds included had excellent bulk tank milk quality; most (19/21) fell into the “low BTSCC” category as defined by Jayarao et al. 2004 with the remaining 2 in the “medium BTSCC” category.

The *Staph.* spp. count for the five bedded pack farms included in this study (median: 40 cfu/mL, range: 0-130) was comparable to previous work describing bulk tank milk quality for CBP in Minnesota during the winter months. Lobeck et al. 2012 found a mean of 26.1 cfu/mL (95% CI: 2-443) and Shane et al. (2010) found a range of 0-108 cfu/mL for *Staph.* spp. from BTM collected just over the winter months from six composting bedded pack farms. “*Staph.* spp.” is comprised of a diverse group of different species, with 23 (Condas et al., 2017) or 25 (De Visscher et al., 2017) different species isolated from intramammary infections in dairy cattle. Within this highly heterogenous group, some species are considered primarily host-adapted (colonizing the skin or udder), while others are primarily found in the cow’s environment (reviewed in De Buck et al., 2021). Certain species have been associated with stall surfaces, air, and unused sawdust bedding material (Piessens et al., 2011), some with different facility types (Condas et al., 2017), and others with environmental contamination and poor teat hygiene at milking time (De Visscher et al., 2016; De Visscher et al., 2017). Although the specific source and routes of transmission for many *Staph.* spp. are still being elucidated, the importance of postmilking teat-dip to control this group of bacteria has been established (Hogan et al., 1987), while the efficacy of pre-dipping to control *Staph*. spp. other than *S. aureus* remains controversial (Pankey, 1989). In general, the use of pre- and post- milking teat dip decreases contamination of bulk tank milk both by commensal skin organisms and environmental contamination at milking time (Pankey et al., 1985; Pankey et al., 1987; Quirk et al., 2012). All but one farm in the current study would fall into the "low" category for *Staph.* spp. counts in the BTM (Jayarao et al., 2004), which is consistent with all 21 herds using both pre- and post-dip consistently at milking time.

Streptococci and strep-like organisms (SSLO) counts in BTM for bedded packs in the current study were much lower than those from Minnesota composting bedded packs in the winter. Shane et al. 2010 reported a range of SSLO counts of 98-48,400 cfu/mL for six farms, and Lobeck et al. 2012 reported a mean of 911 cfu/mL (95% CI: 138-6,011). The median SSLO counts for bedded pack farms included in the current study was 35 cfu/mL (range: 10-80). Work from Barberg et al. (2007) describing milk quality on composting bedded packs in Minnesota noted that 6 of 12 farms sampled had "high" levels of SSLO. SSLO count did not differ between tiestalls, freestalls, and bedded packs in the current study. The overall SSLO count for all 21 farms included in the current study (median: 45 cfu/mL, range: 10-1250) was lower than that for the overall *Strep.* count for all three facility types studied in Lobeck et al. 2012 (445 cfu/mL, 95% CI: 116-1704). As the overall SSLO counts for all farm types included in the Minnesota studies are higher than that found for all 21 farms in the current study, better milking and bedding hygiene amongst herds included in the current study may best explain this difference in BTM pathogen profiles (Jayarao and Wolfgang, 2003).

All farms had low levels of coliforms in bulk tank milk (median: 0 cfu/mL, range: 0-5), indicating excellent hygiene practices at milking time (Jayarao and Wolfgang, 2003). Coliform counts did not differ between the three facility types. Bedded pack farms in the current study had very low coliform counts in BTM (median: 0 cfu/mL, range: 0-5), similar to those found for three compost bedded pack farms in a Brazilian study (2.8 cfu/mL; Fávero et al. 2015). These low coliform counts are in contrast with previous work describing BTM quality for this kind of facility in the United States. Coliform counts for bedded packs in Minnesota in the winter ranged from 15-1,128 cfu/mL (Shane et al., 2010), and the six bedded packs included in Lobeck et al. 2012. had a mean of 63.7 cfu/mL (95% CI: 6-735). However, direct comparison of coliform counts between studies may be potentially problematic due to variation in duration of freezer storage (Schukken et al., 1989). Although sampled during summer months, Barberg et al. 2007 found that 5 of 12 bedded packs sampled had “high” levels of coliforms in BTM, contributing to their conclusion that “special attention to cow preparation procedures at milking time are a must for achieving satisfactory milk quality when cows are housed in compost dairy barns.”

Prevalence of *Staph. aureus* was similar between the five VT bedded pack farms in the current study (median: 0 cfu/mL, range: 0-30) and the six bedded packs described in Lobeck et al. 2012 (6.2 cfu/mL, 95% CI: 1.3-30.1). Farm-level prevalence of *Staph. aureus* was also fairly low for bedded packs studied in Shane et al. 2010 (3 of 6 farms BTM negative) and Barberg et al. 2007 (only 1 of 12 farms with a “high” level of *Staph. aureus*). Overall, the population of all 21 farms in the current study had a higher amount of *Staph. aureus* in BTM than the 18 Minnesota farms described in Shane et al. 2010 (median: 30 cfu/mL, range: 0-320; vs. 17.3 cfu/mL, 95% CI: 3.3-91.2). Although it is not clear how many herds included in previous work on bedded packs were certified organic, the higher prevalence of *Staph. aureus* amongst organic farms in the current study is consistent with work comparing organic and conventional dairy systems (Pol and Ruegg, 2007).

Analysis of a single bulk tank milk sample from a farm is a simple, convenient, and relatively inexpensive way to capture a snapshot of current milk quality and animal health on a farm, and can be a highly specific (albeit poorly sensitive) screening test for major contagious mastitis pathogens (*Staph. aureus* and *Strep. agalactiae;* Godkin and Leslie 1993. Our bulk tank sampling strategy (collecting a single sample) differed from previous work describing the bacteriology of milk from bedded pack farms, where four or five consecutive bulk tank milk pickups were collected and then pooled for analysis (Barberg et al., 2007b; Shane et al., 2010; Lobeck et al., 2012). We acknowledge that analysis of a single BTM sample in the current study comes with limitations. Bacterial groups traditionally considered to be primarily environmental in origin (non-*ag. Strep., Staph* spp., coliforms), may enter BTM from cows with an intramammary infection, but also may originate from non-specific contamination (teat and udder skin, bedding, manure, or other environmental sources; Elmoslemany et al., 2009. Furthermore, a single bulk tank sample does not give insight into long-term, consistent patterns of a particular farm's milk quality as is possible from repeated BTM samplings (Jayarao and Wolfgang, 2003). With the financial constraints of research on commercial dairy farms, the limitations inherent in performing analysis of a single bulk tank milk sample from each farm were a trade-off for the ability to get a picture of milk quality on a larger number of farms included in the study.

Udder health outcomes included in the current study (percent cows with elevSCS, percent cows with chronSCS, percent cows with newSCS, BTSCC, and average SCS) did not differ significantly between facility types. Although some previous work has found BTSCC to be elevated for CBP farms (425,000 cells/mL over all four seasons, Black et. al 2013; 325,000 cells/mL during summer, Barberg et. al 2007b), other groups have also found udder health and milk quality measures on bedded pack farms are similar to farms using more traditional facility types. Specifically, subclinical mastitis prevalence levels did not differ between compost bedded packs and two types of freestall housing in Minnesota and South Dakota, where the percent of cows in a herd with an SCC on test day ≥200,000 cells/mL was 33.4, 26.8, and 26.8% for compost bedded packs, cross-ventilated freestalls, and naturally-vented freestalls (Lobeck et al., 2011). Eckelkamp et. al 2016a ound no significant difference in subclinical mastitis prevalence in CBP vs. sand-bedded freestalls in Kentucky with a history of low BTSCC (21.8 and 19.4%, respectively), as well as no difference in BTSCC between the two facility types (229,582 and 205,131 cells/mL, respectively). Subclinical mastitis prevalence was 27.7% for 12 CBP farms in Minnesota (Barberg et. al 2007b) which may be more representative of the general population of bedded pack farms in that state as there were no inclusion criteria around maintaining a low SCC previous to the start of the study. The prevalence of subclinical mastitis for herds in the current study (26% for bedded packs) is similar to previous work in the US. In contrast, Fávero et. al (2015) found a much higher prevalence of subclinical mastitis (43.8%) and percent new infections (20.9%) for three bedded pack farms in Brazil than our study (26 and 7% respectively, for the three bedded packs with available data).

STD 150-day milk production did not differ between facility type in the current study. This aligns with previous research which found no significant differences in various production metrics of cows housed on bedded packs vs. in freestall barns (Lobeck et al., 2011; Eckelkamp et al., 2016a; Costa et al., 2018). Varying production metrics for cows housed on bedded packs have been reported previously (kg/cow/day, fat-corrected milk/cow/day, average L/cow/day, ME-305, rolling herd average, energy-corrected milk), preventing direct comparisons of milk production between the bedded packs in the current study and other work. Additionally, many variables play a role in determining milk production (nutrition, breed, seasonality, DIM), so teasing out the effect of facility type alone on production in an observational study is difficult. However, as Leso et. al (2020) oint out, the “results in the literature indicate that high levels of milk production are possible in CBP.” As bedded packs potentially improve cow comfort, one may even expect greater milk production than in more traditional housing systems (Calamari et al., 2009; Ruud et al., 2010).

Our finding no difference in the two udder hygiene measures between the three facility types is in accordance with previous work, which found that cow hygiene on bedded pack systems is comparable to traditional facility types in the Upper Midwestern U.S., Southeastern U.S., and Brazil (Barberg et al., 2007b; Shane et al., 2010; Black et al., 2013; Eckelkamp et al., 2016b; a; Costa et al., 2018; Adkins et al., 2022; Andrade et al., 2022). Black (2013) and Eckelkamp (2016a) reported that increased pack moisture allows wet bedding material and manure to adhere more easily to animals, meaning that cow hygiene is highly dependent on conditions of the bedded pack. This sentiment was echoed by the bedded pack producers in the current study, who shared that keeping their cows clean during periods of wet or humid weather could be a challenge. However, all bedded packs in the current study had an average udder hygiene score of less than 2.5, and the farm with the lowest mean average udder hygiene score overall was a bedded pack farm. Although Cook (2002) as pointed out the challenges of comparing dairy cattle hygiene between different facility types, we chose to focus on gathering observations of udder hygiene. The relationship between udder hygiene and health is well-studied, and was a tractable observation to make during non-grazing season farm visits where individual animals were often roaming freely in a pen, or confined in a tiestall barn.

Objective 2: Analysis of farm management factors (non-facility) associated with bulk tank milk quality, udder health, milk production, and udder hygiene scores for all farms combined

As results from the multivariable models exploring the relationship between facility type and outcomes of interest suffered from limited statistical power due to small sample sizes, the focus of the discussion will be on trends that emerged from the univariate analysis which combined all 21 farms.

One finding emerging from this work is that farms with deeper bedding had more favorable udder hygiene metrics (deeper bedding begets cleaner cows). When comparing farms that housed cows with a deep bedding system (deeply-bedded stalls or a bedded pack) to those that housed cows on stalls with a smaller amount of bedding (over a mattress or concrete surface), the deeply-bedded systems tended to have better hygiene scores. This agrees with previous observational field studies of freestall barns, including: Cook et al. 2016 prevalence of dirty udders was 13% lower for farms using deep bedding vs. stalls with mats), de Vries et al. 2015 deep-bedding vs. mat/mattress reduced the likelihood of a cow having a dirty hindquarter by half), and Robles et al. 2020 farms with mattress-based stalls had a higher prevalence of cows with dirty upper legs/flanks vs. those using a deep bedding system, often inorganic sand). In contrast, an experimental study looking at the effect of bedding depth in tiestalls over 28-day periods found no difference between leg, flank, and udder hygiene of cows using deeply-bedded stalls (14 cm) and the control treatment (2-3 cm; Wolfe et al., 2018.

Beyond comparing udder hygiene of cows housed on a deep-bedding system to cows that were not, there was a linear association between bedding depth (depth of bedded pack, depth of bedding in freestalls and tiestalls) and hygiene score. As the measured height of bedding got deeper (height of bedded pack, or amount of bedding material in stall), cows tended to have cleaner udders. To the best of our knowledge, work exploring this direct relationship between measured bedding depth and hygiene is limited to a single study by de Vries et al. 2015, who found no relationship between prevalence of dirty hindquarters and three different freestall bedding height groups (<0.56 cm, 0.56–1.75 cm, >1.75 cm). In our study, this relationship between bedding depth and udder hygiene was especially strong for bedded packs, despite the limited sample size of five herds. To the best of our knowledge, this specific association has not previously been explored for bedded pack herds. There is clearly opportunity for future research looking at this relationship between increased amount of bedding used in deep-bedded systems (or more deeply-bedded stalls) and the benefit of improved udder hygiene and milk quality.

Multiple measures of udder health in this study were associated with udder hygiene, in accordance with the well-supported tenet that better cow hygiene is associated with better milk quality (cleaner cows beget better milk). The association between hygiene and udder health has been well-documented, both at the cow level (for IMI presence: de Pinho et al. 2012 for SCS/SCC: Reneau et al. 2005 Dohmen et al. 2010 and Sant'anna et al. 2011 for both SCS and IMI: Schreiner and Ruegg, 2003 and at the herd-level (BTSCC: Barkema et al. 1998 new IMI rate: Cook et al. 2002; average herd SCC, incidence clinical mastitis, and % new high SCC: Dohmen et al. 2010. Of particular relevance to the current work, a study carried out on three bedded pack farms in Brazil found the odds of a new case of subclinical mastitis (SCC ≥200,000 cells/mL) and of a cow having subclinical mastitis on test day increased 32% and 16% for each one-unit increase in leg cleanliness score, respectively (Fávero et al., 2015). Curiously, although leg cleanliness score was associated with both mastitis outcomes on Brazilian bedded packs, udder hygiene score was not.

A third interesting finding to emerge from the univariate regression results is that farms using deeper bedding had better milk quality outcomes (deeper bedding begets better milk). Although there is an established recommendation of 15 cm for deep bedding of freestalls (Bickert, 2000; Cook, 2002) this depth appears to be based on optimizing cow comfort in deep-bedded freestalls with no reference to udder hygiene or health. There is very limited work exploring ideal bedding material depth for tiestall barns (Tucker and Weary, 2004; Tucker et al., 2009), and this is again solely focused on the important concern of cow comfort. As is the experience of the authors, and is stated elsewhere in a literature review by McPherson (2020), "very little research has investigated the effect of bedding depth on cow cleanliness" or considerations around udder health outcomes. It is likely that the effect seen in the current work of deeper bedding and better udder health outcomes is mediated through the presumed causal pathway of (1) deeper bedding leading to improved hygiene, and (2) improved hygiene resulting in better udder health. Even still, the opportunity exists for research exploring optimal stall bedding depths of different organic materials in tiestall barns with a focus on mastitis and udder health outcomes. It may be that recommending a particular depth of bedding to use for different types of organic material would not prove feasible, as the ideal amount would vary with many factors particular to a producer's barn and bedding source (type of stall surface, presence/type of stall mat used, type of organic material, particle size, compressibility, percent dry matter, etc.).

Recent previous work has exclusively focused on describing bedded packs that are actively managed for aerobic composting (Leso et al., 2020). Leso et al. contrasted composting bedded packs managed with daily cultivation with conventional static bedded packs, such as straw yards, noting the reduced cow cleanliness and increased risk of mastitis associated with the latter. While bedded pack systems are not common for housing lactating cows in Vermont, both composting and static systems are used (Andrews et al., 2021). This infrequent use of bedded packs in our state created a challenge for enrolling ten herds using this kind of system in our observational study. Despite this limitation, by including bedded pack farms managed in a variety of ways, the current work sheds light on a broader spectrum of options used within this loose-housing system. Our current study shows that farms can achieve excellent milk quality using either a static or aerobically composting bedded pack system for indoor housing, e.g., three of the five bedded pack farms had a BTSCC ≤99,000 cells/mL, and the remaining two were ≤160,000 cells/mL. Furthermore, the lowest BTSCC in the study (54,000 cells/mL) was a static bedded pack farm using woodchips and straw. This low BTSCC was not just from selectively dumping milk from high-SCC cows; this farm also had the lowest overall % cows with elevated SCS (8.6%; data not shown).

As for any observational study, there is the potential for bias to have influenced the observed results. Most importantly, participating herds were not a random sample of organic farms in the state, possibly resulting in selection bias. Participating herds were a convenience sample of a subset who responded to our initial survey in Winter 2018-2019. In 2021, there were 147 organic dairy farms in Vermont selling milk, with an average herd size of 87 cows making 6,627 kg milk/cow/year (USDA, 2022) Herds in the current study were slightly smaller, averaging 65 cows per farm, but with higher-producing cows (7,828 kg milk/cow/year, estimated from captured DHIA records). The potential exists that producers who volunteered to participate in the current study are systematically more progressive or somehow different in their management practices than the general population of organic farms in Vermont. Additionally, cross-sectional studies are unable to demonstrate causality for associations presented between management practices and outcomes. However, these limitations are inherent to every observational study, and all attempts were made to control for potential confounding with the multivariable models presented.

One limitation of the current study is the small number of farms in each facility type. As state agencies had been promoting the use of bedded pack systems for years in Vermont, we had anticipated it would be feasible to enroll 10 farms using this system to house their lactating animals. This turned out not to be the case; the Winter 2018-2019 survey showed that many dairy farms were instead using these systems for non-lactating animals (heifers, dry cows; Andrews et al. 2021). Furthermore, the COVID-19 pandemic precluded resumption of the study in Spring 2020, limiting the number of farms included to herds sampled in 2019, and not all farms had DHIA data for every outcome of interest. A related limitation is that well-established mastitis control practices (i.e., teat-dipping, forestripping, using separate towels for individual cows) were widely adapted by participating herds, so we were unable to analyze associations between certain practices and BTM quality, udder health, and hygiene. A large body of work exists showing consistent udder health benefits from using these and other practices, so lack of association between these fundamental mastitis control practices and desirable outcomes in the current study should not be taken as evidence that they provide no benefit. The potential exists for future studies with a larger number of farms enrolled to further characterize milk quality and udder health on bedded pack systems in the Northeastern US. Studies enrolling a larger number of bedded pack farms by covering a larger geographic area may have sufficient power to identify particular management factors which are beneficial on bedded packs specifically.

Bedded pack systems have a number of advantages for producers considering updating their facilities, including a smaller initial investment when compared to a new freestall or tiestall barn (Barberg et al., 2007a; Janni et al., 2007; Black et al., 2013), although the cost year-over-year for bedding is substantial (Shane et al., 2010). Bedded packs are designed for cow comfort (Barberg et al., 2007b; Bewley et al., 2012), and prevalence of lameness, foot, and leg injuries in these systems has been found to be less than tiestall and freestall barns (Barberg et al., 2007b; Lobeck et al., 2011; Burgstaller et al., 2016). Lastly, manure management and environmental stewardship is a top concern for both dairy producers and the general public (Holly et al., 2018). Anecdotally, the five BP producers enrolled in the study were pleased with their systems of manure management, viewing their used bedding material and manure as a valuable soil amendment and an integral part of their nutrient management plan. Bedded pack systems decrease the amount of liquid manure waste when compared to conventional barns, and the used bedding with manure is more easily composted before use as a soil amendment. As composted bedded pack material is drier before it is spread on fields, it poses less of a risk for run-off into waterways, increases soil infiltration of nutrients, and creates flexibility around timing of manure application to fields (Rushmann). With no obvious disadvantages for udder health or hygiene when properly managed on farms with excellent milking hygiene practices already in place, bedded packs may be an especially good housing option for small, pasture-based farms in the Northeastern US.

Conclusion

Bedded pack systems did not differ significantly in their milk quality, udder health, udder hygiene measures, or milk production, as compared to the more commonly used indoor housing systems (freestall or tiestall) for organic cows in Vermont. Bedded packs can therefore be considered as a viable option for pasture-based herds looking for a loose-housing system. Findings from the secondary analysis of results found evidence of the well-supported tenets that better cow hygiene is associated with better milk quality, and farms with deeper bedding had more favorable udder hygiene metrics. Additionally, farms using deeper bedding had better milk quality outcomes, which may likely be mediated through improved hygiene resulting in better udder health outcomes.

Acknowledgements

This project was funded by the USDA NIFA OREI project 2018-51300-28561. We would like to thank all the organic dairy producers who agreed to participate in this study, for giving us their time and allowing us to collect samples from their farms. We would also like to thank Jennifer Timmerman and the Laboratory for Udder Health at Veterinary Diagnostic Lab (University of Minnesota), as well as the laboratory staff at St. Alban's Cooperative/Dairy Farmers of America, for their advice and analyses of bulk tank milk samples collected in the study. The authors have not stated any conflicts of interest.

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Tables

Table 1. Predictors offered to multivariable models for each of the eight different outcomes of interest along with facility type (forced)

Predictor	Level of parameter, if categorical:
Farm demographics/lactating cow housing	
Facility type	Bedded pack; Freestall; Tiestall
Predominant breed	Holstein; Jersey/Other
Herd size (lactating cows)	
Herd size group (lactating cows)	30-55; 56-69; 70-100
Subjective assessment of air quality (producer)	Excellent; Good; Fair/Poor
Subjective assessment of air quality (researcher)	Good; Fair
Age of facility (years)	
Feed supplemental vit. E and selenium	Yes; No
Lactating bedding management practices	
Lying surface for cows[1] (deeply-bedded vs. not)	Deeply-bedded stalls or bedded pack; Stalls with bedding on a mattress or concrete surface
If use shavings/sawdust/woodchips for bedding material:	
Moisture-content	Kiln-dried; Fresh/raw
Bedding amendment (e.g., hydrated lime) used on surface	Yes; No
If facility is freestall or tiestall:	
Freq. adding new bedding to stalls (times per week)	
Freq. scraping stalls (times per week)	
Depth bedding in stalls (cm)	
Mastitis control and milking hygiene practices	
Clip/flame udder hair	Yes; No
Keep record of clinical mastitis events	Always; Sometimes/Temp.; Never
Routinely culture mastitic milk	Always/Sometimes; Never
Routinely culture high somatic cell count cows	Always/Sometimes; Never
Ever perform culture of mastitic cows	Yes; Never culture
Use intramammary product at dry-off (OMRI-listed)	Yes; No
Parenteral supplementation with vit. E and selenium	All lactating cows regularly/ Occasionally as needed; No
Glove use at milking	All milkers consistently; Inconsistently/No
Check for clinical mastitis by noticing abnormal cow/abnormal udder and forestripping	Yes; No
Type of milking system used[3]	Parlor; Tiestall
Farm-level udder hygiene metrics	
Average udder hygiene score	
Prop. dirty udders (%; udder hygiene score ≥ 3)	

[1] If freestall or tiestall, producer asked if used deeply-bedded stalls

[2] OMRI: Organic Materials Review Institute

[3] One freestall farm used an automated milking system

Table 2. Objective 1: Descriptive and univariable results for bulk tank milk aerobic culture outcomes by facility type [median (range)]. *P*-value is for Kruskal-Wallis test by facility type grouping

Bacteria group (cfu/mL)	Overall (n = 21)	Bedded packs (n = 5)	Tiestalls (n = 10)	Freestalls (n = 6)	*P*-value
Staph. spp.	65 (0-665)	40 (0-130)	85 (15-665)	67.5 (5-125)	0.62
Strep. and strep-like orgs.	45 (10-1250)	35 (10-80)	167.5 (20-1250)	32.5 (25-260)	0.10
Staph. aureus	30 (0-320)	0 (0-30)	47.5 (0-320)	42.5 (0-100)	0.19
Coliforms	0 (0-5)	0 (0-5)	0 (0-5)	0 (0-5)	0.82

Table 3. Objective 1: Descriptive results for milk quality, udder health and production outcomes by facility type [mean (95%CI)]

Outcome	Overall	Bedded packs	Tiestalls	Freestalls
BTSCC (log_{10}cells/mL)	n = 21	n = 5	n = 10	n = 6
	5.13 (5.06-5.20)	5.00 (4.84-5.17)	5.14 (5.05-5.23)	5.21 (5.09-5.33)
% newly elevated SCS[1]	n = 19	n = 3	n = 10	n = 6
	5.7 (4.2-7.3)	7.0 (2.8-11.2)	5.4 (3.0-7.8)	5.6 (3.0-8.3)
% chronically elevated SCS[1]	n = 19	n = 3	n = 10	n = 6
	13.6 (11.2-16.1)	14.5 (5.4-23.7)	14.3 (11.9-16.7)	12.0 (6.7-17.3)
% SCS ≥ 4.0 current test[1]	n = 19	n = 3	n = 10	n = 6
	24.9 (21.6-28.3)	26.0 (12.6-39.3)	25.4 (22.1-28.6)	23.7 (16.9-30.5)
Avg. SCS[2]	n = 20	n = 4	n = 10	n = 6
	2.44 (2.26-2.62)	2.38 (1.84-2.91)	2.45 (2.31-2.59)	2.50 (2.00-2.93)
Standardized 150-day milk (pounds)[3]	n = 18	n = 4	n = 8	n = 6
	50.0 (45.7-54.3)	46.9 (39.8-53.9)	49.4 (43.1-55.7)	53.0 (43.5-62.5)

[1] DHIA data not available for 2 bedded pack farms

[2] DHIA data not available for 1 bedded pack farm

[3] DHIA data not available for 1 bedded pack farms and 2 tiestall farms

Table 4. Objective 1: Final multivariable models describing the relationship between facility type (forced) and milk quality, udder health, production, and udder hygiene outcomes

Outcome	Explanatory variable	Group (sample size)	Coefficient estimate (SE)	*P*-value
BTSCC ($\log_{10}$cells/mL)				
	Intercept		4.8 (0.15)	
	Facility type (forced)	Freestall (n = 6)	0.19 (0.09)	0.05
		Tiestall (n = 10)	0.16 (0.08)	0.07
		Bedded pack (n = 5)	Ref.	Ref.
	Herd size	All herds (n = 21)	0.003 (0.002)	0.15
% newly elevated SCS				
	Intercept		-1.6 (2.5)	
	Facility type (forced)	Freestall (n = 6)	2.3 (2.2)	0.33
		Tiestall (n = 10)	0.43 (1.9)	0.82
		Bedded pack (n = 3)	Ref.	Ref.
	Use bedding amendment	Yes (n = 5)	3.9 (1.8)	0.05
		No (n = 14)	Ref.	Ref.
	Subjective assessment air quality (researcher)	Good (n = 14)	3.6 (1.5)	0.04
		Fair (n = 5)	Ref.	Ref.
	Glove use at milking[1]	Never/Inconsistently (n = 9)	2.0 (1.3)	0.17
		Always (n = 9)	Ref.	Ref.
	Clinical mastitis events record keeping	Never kept records (n = 6)	4.4 (1.8)	0.03
		Sometimes/Temporarily kept records (n = 6)	1.1 (1.6)	0.52
		Always kept records (n = 7)	Ref.	Ref.
% chronically elevated SCS				
	Intercept		5.3 (3.6)	
	Facility type (forced)	Freestall (n = 6)	1.5 (4.6)	0.75
		Tiestall (n = 10)	-0.08 (3.5)	0.98
		Bedded pack (n = 3)	Ref.	Ref.
	Feed supplemental vit. E and selenium[2]	Yes (n = 11)	2.1 (2.8)	0.48
		No (n = 7)	Ref.	Ref.

	Use bedding amendment	Yes (n = 5)	5.7 (3.4)	0.12
		No (n = 14)	Ref.	Ref.
	Clip/flame udder hair	Yes (n = 5)	-6.3 (3.1)	0.07
		No (n = 14)	Ref.	Ref.
	% udder hygiene scores ≥3	Herds with available data (n = 19)	17.0 (6.1)	0.02
% SCS ≥ 4.0 current test				
	Intercept		0.85 (10.6)	
	Facility type (forced)	Freestall (n = 6)	1.8 (5.7)	0.75
		Tiestall (n = 10)	-2.4 (5.3)	0.66
		Bedded pack (n = 3)	Ref.	Ref.
	Use bedding amendment	Yes (n = 5)	8.0 (4.2)	0.07
		No (n = 14)	Ref.	Ref.
	Mean hygiene	Herds with available data (n = 19)	9.8 (4.7)	0.06
Avg. SCS				20
	Intercept		0.93 (0.44)	
	Facility type (forced)	Freestall (n = 6)	0.38 (0.21)	0.09
		Tiestall (n = 10)	0.03 (0.19)	0.86
		Bedded pack (n = 4)	Ref.	Ref.
	Use intramammary product at dry-off (OMRI-listed)	Yes (n = 5)	-0.30 (0.16)	0.08
		No (n = 15)	Ref.	Ref.
	Use bedding amendment	Yes (n = 5)	0.52 (0.16)	0.007
		No (n = 15)	Ref.	Ref.
	Parenteral supplementation vit. E/selenium	Regularly or occasionally (n = 9)	-0.36 (0.14)	0.02
		No supplementation (n = 11)	Ref.	Ref.
	Mean hygiene	Herds with available data (n = 20)	0.64 (0.19)	0.005
Standardized 150-day milk (pounds)				18
	Intercept		41.2 (6.1)	
	Facility type (forced)	Freestall (n = 6)	-0.06 (7.0)	0.99
		Tiestall (n = 8)	-1.7 (6.6)	0.80
		Bedded pack (n = 4)	Ref.	Ref.
	Parenteral supplementation vit. E/selenium	Regularly or occasionally (n = 7)	7.0 (5.2)	0.20

	No supplementation (n = 11)	Ref.	Ref.
Culture high SCC cows	Always/Sometimes (n = 8)	9.3 (5.9)	0.14
	Never (n = 10)	Ref.	Ref.
Herd size grp. (lact. cows)	70-100 (n = 8)	-0.18 (7.3)	0.98
	56-69 (n = 5)	10.3 (6.2)	0.12
	30-55 (n = 5)	Ref.	Ref.
% udder hygiene scores ≥3			
Intercept		0.32 (0.08)	
Facility type (forced)	Freestall (n = 6)	0.002 (0.11)	0.99
	Tiestall (n = 10)	0.17 (0.10)	0.12
	Bedded pack (n = 5)	Ref.	Ref.
Avg. udder hygiene score			
Intercept		2.3 (0.17)	
Facility type (forced)	Freestall (n = 6)	-0.04 (0.21)	0.84
	Tiestall (n = 10)	0.33 (0.19)	0.11
	Bedded pack (n = 5)	Ref.	Ref.
Check for clinical mastitis by noticing abnormal cow/abnormal udder and forestripping	Yes (n = 8)	-0.25 (0.16)	0.14
	No (n = 13)	Ref.	Ref.

[1] One farm used automatic milking system

[2] One farm unable to provide response

Table 5. Objective 2: Selected models of univariate analysis identifying (non-facility type) factors unconditionally associated with milk quality, udder health, production, and udder hygiene outcomes at *P* <0.20

Outcome	Explanatory Variable	Group (sample size)	Coefficient estimate (SE)	*P*-value	Intercept
BTSCC (log_{10}cells/mL)					
Model 1	Lying surface	Mattress or concrete (n = 13)	0.12 (0.07)	0.12	5.1
		Deep bedding (n = 8)	Ref.	Ref.	
Model 2	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-0.02 (0.01)	0.11	5.2
Model 3	Glove use at milking[2]	Never/Inconsistently (n = 9)	0.10 (0.07)	0.19	5.1
		Always (n = 11)	Ref.	Ref.	
% newly elevated SCS[3]					
Model 4	Glove use at milking	Never/Inconsistently (n = 9)	2.83 (1.7)	0.11	4.3
		Always (n = 9)	Ref.	Ref.	
Model 5	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-0.62 (0.24)	0.02	8.3
% chronically elevated SCS[3]					
Model 6	Clip/flame udder hair	Yes (n = 5)	-4.31 (2.9)	0.16	14.8
		No (n = 14)	Ref.	Ref.	
Model 7	% udder hygiene scores ≥3	Herds with available data (n = 19)	12.7 (6.1)	0.05	8.6
Model 8	Avg. udder hygiene score	Herds with available data (n = 19)	6.39 (3.1)	0.05	-1.2
% SCS ≥ 4.0 current test[3]					
Model 9	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-1.2 (0.42)	0.01	30
Model 10	% udder hygiene scores ≥3	Herds with available data (n = 19)	13.6 (8.5)	0.13	19.6
Model 11	Avg. udder hygiene score	Herds with available data (n = 19)	7.7 (4.3)	0.09	7.1
Average SCS[4]					
Model 12	Parenteral supplementation vit. E and selenium	Regularly or occasionally (n = 9)	-0.27 (0.18)	0.15	2.6
		No supplementation (n = 11)	Ref.	Ref.	
Model 13	Use intramammary product at dry-off (OMRI-listed)	Yes (n = 5)	-0.29 (0.21)	0.18	2.5
		No (n = 15)	Ref.	Ref.	
Model 14	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-0.05 (0.03)	0.10	2.6

Model 15	% udder hygiene scores ≥3	Herds with available data (n = 20)	0.75 (0.45)	0.12	2.1
Model 16	Avg. udder hygiene score	Herds with available data (n = 20)	0.39 (0.23)	0.11	1.5
Standardized 150-day milk (pounds)[5]					
Model 17	Parenteral supplementation vit. E and selenium	Regularly or occasionally (n = 7)	9.0 (4.5)	0.06	46.5
		No supplementation (n = 11)	Ref.	Ref.	
Model 18	Herd size	Herds with available data (n = 18)	0.26 (0.14)	0.07	33.1
% udder hygiene scores ≥3					
Model 19	Depth of bedded pack (m)	Bedded pack herds (n = 5)	-0.5 (0.06)	0.004	0.97
Model 20	Lying surface	Mattress or concrete (n = 13)	0.17 (0.08)	0.06	0.30
		Deep bedding (n = 8)	Ref.	Ref.	
Model 21	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-0.02 (0.02)	0.13	0.54
Avg. udder hygiene score					
Model 22	Depth of bedded pack (m)	Bedded pack herds (n = 5)	-0.96 (0.15)	0.008	3.4
Model 23	Lying surface	Mattress or concrete (n = 13)	0.33 (0.16)	0.06	2.1
		Deep bedding (n = 8)	Ref.	Ref.	
Model 24	Depth of bedding in stalls (cm)[1]	Tiestalls and freestalls (n = 15)	-0.06 (0.03)	0.07	2.6

[1] Stall bedding depth for freestalls and tiestalls bedded with wood shavings or sawdust

[2] One farm used automatic milking system

[3] DHIA data available for n = 19 herds.

[4] DHIA data available for n = 20 herds.

[5] DHIA data available for n = 18 herds.

University of Vermont Organic Dairy Bedding Management Study – On-farm observation sheet

Pre-interview Orientation:

Where are the dry cows and heifers and unused bedding:

Where are the lactating cows? (If needed: Which pen contains the largest group, if multiple, which contains the high producing cows?)

Where is the unused bedded stored for lactating cows?

Where is the bulk tank and can you turn on the agitator?

How many hours since the cows were last bedded?___________________

How many milkings are in the tank?_________________

Number of cows whose milk is in the tank?_______________

University of Vermont Organic Dairy Bedding Management Study – On-farm observation sheet

On-farm Observation Sheet

1. *ALL FARMS*

a. Bulk tank milk sample collection *(Agitate the milk for at least 5 minutes before taking a sample)*

i. Temperature of milk in tank from tank thermometer: ________________

ii. Temperature of milk in tank from infrared (surface reading): ____________

iii. Temperature of milk in tank from lab thermometer: __________________

iv. Record the date and time that the sample was taken

Date ________________________

Time _______________________

b. How are individual cows identified?

□ Ear tags
□ Neck collars
□ Tattoos
□ No obviously visible identification
□ Other (describe): ____

c. Type of ventilation for lactating cow barn: (Check one)

□ Natural
  □ Sidewall curtains present
  □ Open ridge vent present
□ Tunnel ventilated (mechanical ventilation)
□ Cross ventilated (mechanical ventilation)
□ Other (describe): ____

d. Is the ventilation: (Check one)

□ Good: Constant air flow, no hanging odors
□ Fair: Some odors, but not overpowering
□ Poor: No air flow, strong hanging odors

University of Vermont Organic Dairy Bedding Management Study – On-farm observation sheet

2. *Both FREE and TIE stall, lactating cows:*

a. Stall width: ________ inches

b. Stall body length (from neck rail or brisket board to back curb): ________ inches

c. Total stall length (including head space to back curb): _______inches
d. Are all the stalls uniform in size?

□ Yes □ No □ Other (describe): _________________

e. Gutter behind cow or just alleyway?

□ Gutter □ Alleyway only □ Other (describe): _________________

f. Does the stall have a brisket board or brisket locator?

□ Yes □ No

3. FREE STALL, lactating cows: *sample from pen containing largest group of lactating cows, or if multiple pens of equal size sample from high producing group.*

a. Total number of pens for lactating cows: _________

b. How many rows of stalls are in a pen?

□ 2 rows/pen □ 3 rows/pen □ Other (describe): ________________

c. Number of stalls per sampled pen: _______

d. Number of cows in sampled pen: ____________

e. Stocking density in cows/stalls (can be calculated after): _____________________

4. TIE STALL, lactating cows:

a. Number of stalls in barn: ___________

b. Number of stalls used for lactating cows: __________

c. Trainers present?

□ Yes □ No

University of Vermont Organic Dairy Bedding Management Study – On-farm observation sheet

5. ***LOOSE HOUSING/BEDDED PACK, lactating cows:*** *if multiple pens and pens are different sizes or designs, describe the largest lactating group or high group if equal*

   a. Number of pens for lactating cows: ___________

   b. Size of pen: ______ square feet

   c. CURRENT number of cows per pen: ______

   d. Square feet per cow (can be calculated after): ____________

   e. Current estimated depth of pack: ________

   f. Temperature of pack: ___________

6. ***Outdoor turn-out area, lactating****: sample similar to loose bedding; if no material on concrete surface, no sample necessary*

   a. Number of outdoor pens: ___________

   b. Size of pen: ______ square feet

   c. CURRENT number of cows in pen: ______

   d. Square feet per cow (can be calculated after): ____________

   e. Describe base (surface) material (e.g. concrete, no surface):

   ____

   ____

   ____

   f. Describe surface of turn-out pen (depth of manure present, how wet/muddy):

   ____

   ____

   ____

   g. **TAKE PICTURE OF EXERCISE YARD FOR LACTATING/DRY COWS WITH TABLET**

Survey on bedding and mastitis risk

Date completed

yyyy-mm-dd hh:mm

1. Farm Name

2. Farm owner

Mobile number of owner

3. Farm manager (if not owner)

Mobile number of manager

4. Farm Address: Street/road number

Farm address: City

Farm address: State

Farm address: Zipcode

Farm address: Email

5. Herd Vet: Name

Herd vet: Email

Herd vet: Phone

____

6.a) How big of a problem is mastitis in general on your farm?

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6.b) Do you have any cows in your herd that you aren't actively TREATING, but that you're currently managing for chronic mastitis?

If yes, please describe. If answer to 6b was "Yes," complete 6c through 6.f.iv. If "No," skip to 6h.

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6.c) How do you identify these cows that may have chronic mastitis?

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6.d) How many cows are you currently managing with chronic mastitis, as a percent of your milking herd?

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6.e) Do you ever culture these cows?

If yes, please describe what pathogens have been identified.

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6.f.i) How do you manage these cows with chronic mastitis?

Depending on their answer to 6.f.i, the interviewer may need to ask questions 6.f.ii through 6.f.iv or may skip to 6.g.

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6.f.ii.) If not specifically addressed in 6.f.i: Are these cows housed differently than the rest of the herd?

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6.f.iii.) If not specifically addressed in 6.f.i: Are these cows milked in a different way than the rest of the herd?

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6.f.iv.) If not specifically addressed in 6.f.i: Is the milk from these cows handled in a different way than the rest of the herd?

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6.g) What do you do on your farm generally to reduce a cow's risk of getting mastitis?

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6.h) How do you manage bedding on your farm to reduce a cow's risk of mastitis?

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6.i) Is a milk quality premium paid by your milk cooperative a motivator for your milking hygiene and mastitis control practices?

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7.a) How do you recognize or identify a cow with a case of CLINICAL mastitis?

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7.b.i) How do you recognize or identify a cow with a case of SUBCLINICAL mastitis?

Some ways you might identify subclinical mastitis include CMT test, other cowside somatic cell count test, or monthly DHIA somatic cell count scores. Do you use any of these to recognize subclinical mastitis?

Some ways you might identify subclinical mastitis include CMT test, other cowside somatic cell count test, or monthly DHIA somatic cell count scores. Do you use any of these to recognize subclinical mastitis?

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7.c.i) Do you keep a record of clinical mastitis events on farm? (check one)

- Always
- Sometimes
- Temporarily until milk is good
- Never

7.c.ii) If records are kept, how do you record clinical mastitis events? (check one)

- Software (e.g. on-farm record keeping program)
- Paper
- Other (describe on written survey)

7.c.iii) If mastitis treatment records are kept, what details do you record about a clinical mastitis event? (E.g. cow, quarter, date, treatment given, culture result if available, days treated, other) (Describe on written survey)

7.d) Number of people recognizing or identifying a case of mastitis on the farm:

7.e) Do you routinely perform bacteriological culture of mastitic milk? (check one)

- Never
- Always
- Sometimes

7.f) Do you routinely perform bacteriological culture of high somatic cell count cows? (check one)

- Never
- Always
- Sometimes

7.g) Do you routinely perform bacteriological culture of fresh cows? (check one)

- Never
- Always
- Sometimes
- Only if there's an issue/cause for concern

7.h) Do you routinely perform bacteriological culture of cows before dry-off? (check one)

- Never
- Always
- Sometimes
- Only if there's an issue/cause for concern

7.i) If you culture milk from mastitic cows, where is this done? (check one)

- Reference lab (state, university, or private tester such as DHIA)
- Local vet clinic
- On-farm culture
- Never culture milk from mastitic cows
- Other (describe on written survey)

8.a) Milking schedule for the majority of the herd (check one)

- 2X
- 3X
- Other (describe on written survey)

8.b.i) Milking system (check one)

- ◯ Robot (Automated milking system)
- ◯ Parlor
- ◯ Tie stall

8.b.ii) If milked in a parlor, what kind? (check one, if combination of multiple types describe in "Other")

- ◯ Rotary
- ◯ Parallel
- ◯ Herringbone
- ◯ Swing
- ◯ Other (describe on written survey)

8.b.iii) If milked in a parlor, are milking units routinely washed/sprayed off between uses? (check one)

- ◯ Yes, routinely between milking individual cows
- ◯ Yes, routinely between milking individual pens or groups
- ◯ Occasionally, if the milking unit gets very dirty (e.g. splattered with manure)
- ◯ No, only at the completion of milking

8.b.vi) If milked in a parlor, do you SPRAY the deck during milking? (check one)

- ◯ After every turn of cows that comes through each side
- ◯ As needed throughout milking if it gets very dirty
- ◯ Only at the completion of milking
- ◯ Never spray the deck, even after milking

8.b.v) If you SPRAY the deck during milking, do you ever do it when cows are still present, either entering or exiting a side? (check one)

- ◯ Yes
- ◯ No
- ◯ Occasionally

8.b.vi) If milked in a parlor, does anyone SCRAPE the deck during milking? (choose one)

- ◯ After every turn of cows that comes through each side
- ◯ As needed throughout milking if it gets very dirty
- ◯ Only at the completion of milking
- ◯ Never scrape the deck, even after milking

8.d.i) Do you pre-dip teats with a chemical disinfectant before milking? (check one)

- ◯ Yes
- ◯ No

8.d.ii) If yes, type of pre-dip disinfectant solution (check one)

- ◯ Iodine
- ◯ Chlorhexidine
- ◯ Hydrogen peroxide
- ◯ Other (described on written survey)

8.d.iii) Please provide the name of the pre-dip product used:

____

8.e.i) Do you post-dip teats with a chemical disinfectant after milking? (check one)

- ◯ Yes
- ◯ No

8.e.ii) If yes, type of post-dip disinfectant solution (check one)

- ◯ Iodine
- ◯ Chlorhexidine
- ◯ Hydrogen peroxide
- ◯ Other (described on written survey)

8.e.iii) Please provide the name of the post-dip product used:

____

8.f) Do milkers routinely fore strip teats as a part of udder prep (also called "starting a cow")? (Check one)

- ◯ Yes
- ◯ No

8.g.i) Are udders routinely wiped dry with any kind of towel prior to attaching the milking unit? (Check one)

- ◯ Yes
- ◯ No

8.g.ii) If yes, do you use paper (disposable) or cloth (reusable) towels? (Check one)

- ◯ Paper
- ◯ Cloth

8.g.iii) If yes, how many COWS are wiped with each towel? (check one)

- One
- Two
- More than two
- Depends how dirty the udder is

8.g.iv) If one towel per cow, how many TEATS do you routinely wipe with each towel? (check one)

- One
- More than one
- Depends how dirty each teat is

8.g.v) If you use cloth towels, describe how they are laundered (washed) and dried? (check one)

- Yes, washed and dried
- Washed and used damp
- Other (describe on written survey)

8.h.i) Do you clip or flame udders one or more times per lactation? (check one)

- Yes
- No

8.h.ii) If yes, how often on average do you clip or flame a cow's udder each year?

____

8.i.i) Do you have any cows with docked tails? (check one)

- Yes
- No

8.i.ii) If yes, what percent of your adult cows would you estimate have docked tails? (% cows)

____

8.j.i) Do you trim switches on tails? (check one)

- Yes
- No

8.j.ii) If yes, how frequently do you trim switches each year?

____

8.k) Do milkers wear gloves (e.g. nitrile gloves) during milking? (check one)

- ◯ Yes, all milkers, consistently
- ◯ Yes, some milkers, but not all, or inconsistent use
- ◯ No, no one on our farm wears gloves during milking
- ◯ Other (describe on written survey)

9.a.i) Do you routinely use vaccines for mastitis control (e.g. J-5, J-VAC, or ENDOVAC-Bovi)? (check one)

- ◯ Yes
- ◯ No

9.a.ii) If yes, product name?

____

9.b.i) Do you dry cows off between lactations? (check one)

- ◯ Yes
- ◯ No

9.b.ii) If yes, how many days on average are they dry? (number of days)

____

9.c.i) Do you use any sort of intramammary product at dry-off? (check one)

- ◯ Yes
- ◯ No

9.c.ii) If yes, product name?

____

9.d.i) Do ever have cases of mastitis in your dry cows? (check one)

- ◯ Yes
- ◯ No

9.d.ii) If yes, how many cases on average per year? (# cases/year)

____

10.a.i) What do you primarily feed your lactating cows during the winter? (check any that apply)

- ☐ Total mixed ration
- ☐ Component fed
- ☐ Dried forage, not ensiled
- ☐ Ensiled forage
- ☐ Other (describe on written survey)

10.b.i) Do you work with a nutritionist or other consultant to analyze your ration? (check one)

- ◯ Yes
- ◯ No

10.b.ii) If yes, how often?

____

10.c.i) Do you feed any supplemental minerals with your ration containing vitamin E and selenium? (check one)

- ◯ Yes
- ◯ No
- ◯ Unsure
- ◯ Other (describe on written survey)

10.c.ii) If yes, product name or name of mill if product name not known?

____

10.d.i) Do you regularly supplement DRY COWS with an injectable vitamin supplement containing selenium and vitamin E, such as MuSe or Multimin?

- ◯ Yes
- ◯ No
- ◯ As needed, if animal is sick
- ◯ Other (describe on written survey)

10.d.ii) If yes, product name used:

____

10.d.iii) If yes, AMOUNT given to each animal:

____

10.d.vi) If yes, FREQUENCY supplement is given to each animal:

____

10.e.i) Do you regularly supplement CALVES with an injectable vitamin supplement containing selenium and vitamin E, such as BoSe or Multimin?

- ◯ Yes
- ◯ No
- ◯ As needed, if animal is sick
- ◯ Other (describe on written survey)

10.e.ii) If yes, product name used:

____

10.e.iii) If yes, AMOUNT given to each animal:

10.e.vi) If yes, FREQUENCY given to each animal:

10.f) How do lactating animals get water when they are inside your WINTER housing system? (check one)

- ◯ Individual water bowls
- ◯ Troughs
- ◯ Other (describe on written survey)

10.g) What is the source of drinking water in the WINTER for lactating cows? (check one)

- ◯ Well
- ◯ Municipal
- ◯ Surface
- ◯ Other (describe on written survey)

10.h.i) Do you ever test the water for lactating cows for levels of bacteria, nitrates, or other trace elements? (check one)

- ◯ Yes
- ◯ No

10.h.ii) If yes, how often?

11.a.i) Do employ any fly control measures for lactating cows during the summer months? (check one)

- ◯ Yes
- ◯ No

11.a.ii) If yes, what kind? (check any that apply)

- ☐ Fly tape
- ☐ Predator wasps
- ☐ Fly traps
- ☐ Dust/paint/spray cows with fly repellent
- ☐ Other (describe on written survey)

11.a.iii) If you use a fly-repellent that is applied directly to cows, please list all the product(s) you use:

11.b) Do you feel like you have an issue with flies inside the barn during the winter months? (check one)

- ◯ Yes
- ◯ No

11.c) Where do cows typically have their calves? (check any that apply)

- ☐ Designated calving pen for ONE cow at a time
- ☐ Designated calving pen with MULTIPLE cows at a time
- ☐ On the same pack with other cows, where she normally lives
- ☐ In her stall
- ☐ Pasture
- ☐ Other (describe on written survey)

11.d.i) Typically, do calves nurse on their dams before they are removed? (check one)

- ◯ Yes
- ◯ No

11.d.ii) If yes, how long on average? (check one)

- ◯ Few minutes
- ◯ Few hours
- ◯ Few days
- ◯ Other (describe on written survey)

11.e) Do you feed waste from mastitic cows or high cell count cows to calves? (check one)

- ◯ Yes, PASTEURIZED waste milk from high cell count cows and mastitic cows
- ◯ Yes, PASTEURIZED but only from high cell count cows
- ◯ Yes, UNPASTEURIZED waste milk from high cell count cows and mastitic cows
- ◯ Yes, UNPASTEURIZED but only from high cell count cows
- ◯ No waste milk from mastitic or high cell count cows is fed to calves
- ◯ Other (describe on written survey)

11.f) What are pre-weaned calves fed? (check all that apply)

- ☐ Milk replacer
- ☐ Whole, saleable milk from bulk tank or individual cow
- ☐ Use a nurse cow
- ☐ Unpasteurized waste milk (non-saleable milk) from mastitic or high cell count cows
- ☐ Pasteurized waste milk (non-saleable milk) from mastitic or high cell count cows
- ☐ Other (describe on written survey)

11.g) If you use a nurse cow to feed calves, do you know the mastitis status of this cow?

- Yes, nurse cow is a problem mastitis cow
- Yes, she does not have mastitis best to my knowledge
- No, do not know the mastitis status of the nurse cow
- Other (describe on written survey)

12.a.i) Where are LACTATING cows housed during the WINTER on your farm? Please indicate every type of housing you use for them in winter. If it's a combination, please estimate the percent of time on average over a 24-hour period they spend in each housing component (RECORD ON WRITTEN SURVEY).

- [ ] Free stall
- [ ] Tie stall
- [ ] Loose housing: PACK WITH BEDDING
- [ ] Loose housing: DRY LOT/PAD NO BEDDING

12.a.ii) Where are DRY cows housed during the WINTER on your farm? Please indicate every type of housing you use in winter. If it's a combination, please estimate the percent of time on average over a 24-hour period they spend in each housing component (RECORD % ON WRITTEN SURVEY).

- [ ] Free stall
- [ ] Tie stall
- [ ] Loose housing: PACK WITH BEDDING
- [ ] Loose housing: DRY LOT/PAD NO BEDDING

12.b.i) Do lactating and dry cows have access to outside paddock or exercise yard during the winter? (Check one)

- Yes
- No

12.b.ii) If Yes, on average, what is the number of hours outside per day:

____

12.b.iii) Describe their outdoor turn-out space:

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12.b.iv) Do you ever clean your outdoor turn-out space?

- Yes
- No
- Other (describe on written survey)

12.b.v) If you clean your outdoor turn-out space, how often do you do it?

____

12.b.vi) Please take a picture of their outdoor turn-out space:

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12.c) When was your current winter housing system constructed?

12.d) Describe the quality of the ventilation of your winter housing using the following scale:

- Excellent
- Good
- Fair
- Poor

13.a.i) Lactating: Estimated depth of the bedding:

13.b.i) Lactating: Frequency of scraping manure from back of stall surface:

13.c.i) Do you have a gutter behind the cows, or just an evenly-graded alleyway?

- Gutter
- No gutter, evenly-graded alleyway
- Other (describe on written survey)

13.d.i) Lactating: If you have an evenly-graded alleyway behind the cows, how do you clean it?

- Continuous automated scraper
- Skid steer or other similar equipment
- Slatted floors
- Flush system
- By hand
- Other (describe on written survey)

13.e.i) Lactating: If you have a gutter behind the cows, how often do you run the gutter cleaner?

13.f.i) Lactating: Frequency of adding new bedding material to the stalls:

13.g.i) Lactating: If you use DEEP BEDDING in a free or tie stall, has the bedding ever been completely dug out and removed, then replaced (e.g. removing the entire back third of bedding from free stalls)? (Check one)

- Regularly
- Infrequently
- Never
- Not applicable, don't deep bed in the free or tie stall

13.h.i) Lactating: If deep bedding removed on a regular schedule, how frequently does this occur?

13.i.i) Lactating: If deep bedding removed on a regular schedule OR infrequently, when was the date last completed?

13.j.i) Do you have mattresses in your stalls?

- Yes
- No

13.a.ii) Dry: Estimated depth of the bedding:

13.b.ii) Dry: Frequency of scraping manure from back of stall surface:

13.c.ii) Dry: Do you have a gutter behind the cows, or just an evenly-graded alleyway?

- Gutter
- No gutter, evenly-graded alleyway
- Other (describe on written survey)

13.d.ii) Dry: If you have an evenly-graded alleyway behind the cows, how do you clean it?

- Continuous automated scraper
- Skid steer or other similar equipment
- Slatted floors
- Flush system
- By hand
- Other (describe on written survey)

13.e.ii) Dry: If you have a gutter behind the cows, how often do you run the gutter cleaner?

13.f.ii) Dry: Frequency of adding new bedding material to the stalls:

13.g.ii) Dry: If you use DEEP BEDDING in a free or tie stall, has the bedding ever been completely dug out and removed, then replaced (e.g. removing the entire back third of bedding from free stalls)? (Check one)

- ○ Regularly
- ○ Infrequently
- ○ Never
- ○ Not applicable, don't deep bed in the free or tie stall

13.h.ii) Dry: If deep bedding removed on a regular schedule, how frequently does this occur?

____

13.i.ii) Dry: If deep bedding removed on a regular schedule OR infrequently, when was the date last completed?

____

13.j.ii) Do you have mattresses in your stalls?

- ○ Yes
- ○ No

14.a.i) Lactating: How would you describe your loose housing system bedding? (check one)

- ○ Bedded pack barn WITHOUT mechanical aeration or surface tilling
- ○ Bedded pack barn WITH mechanical aeration or surface tilling
- ○ Bedded pack barn with other (describe on written survey)

14.b.i) Lactating: Average number of cows on the pack at any given time:

____

14.c.i) Lactating: If the pack is aerated or tilled, how deep below the surface is it aerated/tilled?

____

14.d.i) Lactating: If the pack is aerated or tilled, how frequently is it aerated/tilled?

____

14.e.i) Lactating: How often is the pack completely removed/dug out while cows are still housed on it?

____

14.f.i) Lactating: How long, if ever, is the barn empty of pack and not used to house cows in a given year?

____

14.g.i) Lactating: Do you monitor the pack for temperature?

- ○ Yes
- ○ No

14.h.i) Lactating: If you monitor the pack for temperature, how do you do this and how often? (Describe on written survey)

____

14.i.i) Lactating: Do you monitor the pack for moisture level?

- Yes
- No

14.j.i) Lactating: If you monitor the pack for moisture level, how do you do this and how often? (Describe on written survey)

____

14.k.i) Lactating: Do you monitor the pack for density (how compacted the bedding material is)?

- Yes
- No

14.l.i) Lactating: If you monitor the pack for density, how do you do this and how often? (Describe on written survey)

____

14.m.i) Lactating: Any other factors you monitor for the pack? How do you do this and how often? (Describe on written survey)

____

14.n.i) Lactating: Can you estimate the amount (mass) of bedding material added to the pack on average throughout the winter, per unit time? (e.g. two 500 lb. round bales added every day,10 yards wood chips every other week) (Describe on written survey)

____

14.o.i) Lactating: Does the rate at which you add material to the pack vary throughout the season? If so, how? (Describe on written survey)

____

14.p.i) Lactating: Are cows fed directly ON the pack (i.e., no feeding alley)?

- Yes
- No

14.q.i) Lactating: Can you describe how you initially build your pack after completely removing the previous pack and starting over?

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14.r.i) Lactating: If you changed to a bedded pack from another housing style, do you feel that cow hygiene was affected? If so, how?

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14.s.i) Lactating: If you changed to a bedded pack from another housing style, do you feel that mastitis incidence was affected? If so, how?

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14.t.i) Lactating: Anything else about your pack management and construction you feel we should know that we didn't cover?

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14.a.ii) Dry: How would you describe your loose housing system bedding? (check one)

- Bedded pack barn WITHOUT mechanical aeration or surface tilling
- Bedded pack barn WITH mechanical aeration or surface tilling
- Bedded pack barn with other (describe on written survey)

14.b.ii) Dry: Average number of cows on the pack at any given time:

14.c.ii) Dry: If the pack is aerated or tilled, how deep below the surface is it aerated/tilled?

14.d.ii) Dry: If the pack is aerated or tilled, how frequently is it aerated/tilled?

14.e.ii) Dry: How often is the pack completely removed/dug out while cows are still housed on it?

14.f.ii) Dry: How long, if ever, is the barn empty of pack and not used to house cows in a given year?

14.g.ii) Dry: Do you monitor the pack for temperature?

- Yes
- No

14.h.ii) Dry: If you monitor the pack for temperature, how do you do this and how often? (Describe on written survey)

14.i.ii) Dry: Do you monitor the pack for moisture level?

- Yes
- No

14.j.ii) Dry: If you monitor the pack for moisture level, how do you do this and how often? (Describe on written survey)

14.k.ii) Dry: Do you monitor the pack for density (how compacted the bedding material is)?

- Yes
- No

14.l.ii) Dry: If you monitor the pack for density, how do you do this and how often? (Describe on written survey)

____

14.m.ii) Dry: Any other factors you monitor for the pack? How do you do this and how often? (Describe on written survey)

____

14.n.ii) Dry: Can you estimate the amount (mass) of bedding material added to the pack on average throughout the winter, per unit time? (e.g. two 500 lb. round bales added every day,10 yards wood chips every other week) (Describe on written survey)

____

14.o.ii) Dry: Does the rate at which you add material to the pack vary throughout the season? If so, how? (Describe on written survey)

____

14.p.ii) Dry: Are cows fed directly on the pack (i.e., no feeding alley)?

- Yes
- No

14.q.ii) Dry: Can you describe how you initially build your pack after completely removing the previous pack and starting over?

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14.r.ii) Dry: If you changed to a bedded pack from another housing style, do you feel that cow hygiene was affected? If so, how?

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14.s.ii) Dry: If you changed to a bedded pack from another housing style, do you feel that mastitis incidence was affected? If so, how?

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14.t.ii) Dry: Anything else about your pack management and construction you feel we should know that we didn't cover?

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15.a.i) How long has the current WINTER bedding system been in use for LACTATING cows?

____

15.a.ii) How long has the current WINTER bedding system been in use for DRY cows?

____

15.b.i) Type of bedding material used for LACTATING cows (Check any that apply)

- [ ] New sand
- [ ] Reclaimed (recycled) sand
- [ ] Manure solids (Biosolids)
- [ ] Shavings
- [ ] Sawdust
- [ ] Woodchips
- [ ] Straw
- [ ] Hay
- [ ] Other (describe on written survey)

15.b.ii) Type of bedding material used for DRY cows (Check any that apply)

- [ ] New sand
- [ ] Reclaimed (recycled) sand
- [ ] Manure solids (Biosolids)
- [ ] Shavings
- [ ] Sawdust
- [ ] Woodchips
- [ ] Straw
- [ ] Hay
- [ ] Other (describe on written survey)

15.b.iii) If you chose more than one material for LACTATING cows, describe a typical snapshot of the composition of bedding by estimating the percentage made up by each material:

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15.b.vi) If you chose more than one material for DRY cows, describe a typical snapshot of the composition of bedding by estimating the percentage made up by each material:

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15.c.i) What kind of sand is it that you use? (check one)

- Silica sand
- River sand
- Don't know

15.c.ii) If new sand, is it washed before you purchase it? (check one)

- Yes
- No
- Don't know

15.c.iii) If using reclaimed sand, how is it recycled/recaptured? (check one)

- Passive sand separator lanes
- Mechanical separator
- Other (describe on written survey)

15.c.iv) If using reclaimed sand, time in storage from recapturing the sand to reusing in stalls:

____

15.c.v) If using sand, how is it stored? (check one)

- In the open
- Under cover

15.c.vi) If using reclaimed sand, check which of the following is true: (check one)

- We use reclaimed sand 12 months per year
- We use reclaimed sand most of the year, but in the coldest months we will purchase and use new dry clean sand.

15.d.i) How would you classify the manure solids you use? (check one)

- Raw (green)
- Composted
- Digested
- Other (describe)

15.d.ii) Are the manure solids pressed before use? (check one)

- Yes
- No

15.d.iii) Are the manure solids mechanically dried (with a dryer) before use? (check one)

- Yes
- No

15.d.iv) If digested solids, what is the temperature is the methane digester (if known)?

15.d.v) If digested solids, what is the flow rate or material through the digester (if known)?

15.d.vi) If using manure solids, estimate typical time in storage from recapturing the solids to reusing in stalls:

15.e.i) Do you use straw or hay for bedding? (choose one)

- Straw
- Hay
- Both
- Other (describe on written survey)

15.e.ii) Is the straw/hay purchased or produced on farm? (check one)

- Purchased
- Produced
- Both
- Other (describe on written survey)

15.e.iii) If you bed with hay, dry or ensiled? (check one)

- Dry hay (e.g. round bales)
- Ensiled hay (e.g. wrapped round bales)
- Both
- Other (describe on written survey)

15.e.iv) Storage location of straw and hay used for bedding? (check one)

- Stored under cover
- Stored outside not under cover
- Both
- Other (describe on written survey)

15.f.i) Are the shavings/chips/sawdust you used kiln dried or "fresh?" (check one)

- Kiln dried
- Fresh/raw
- Both
- Other (describe on written survey)

15.f.ii) Storage location of woodchips/shavings/sawdust used for bedding? (check one)

- Stored under cover
- Stored outside not under cover
- Both
- Other (describe on written survey)

15.g.i) Do you use a bedding conditioner (e.g. hydrated lime) in your stalls or on your pack?

- Yes
- No

15.g.ii) If you use a bedding conditioner, what's the name of the product?

15.g.iii) What's the AMOUNT of conditioner applied (eg ounces per stall, amount per sq ft pack)?

15.g.vi) What's the FREQUENCY of conditioner applied (eg times/week, times/month)?

15.h) Anything you'd like to tell us about your bedding management practices or materials used that weren't included in the above questions?

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16.a) What is/are the breeds of dairy cattle on your farm? (describe all breeds on written survey):

16.b) What is the rolling herd average calculated for your farm? If not on milk test, what is the average milk production per cow, in pounds of milk per cow per year? (Describe on written survey, indicate measure)

16.c.i) What are the number of lactating cows currently on your farm?

16.c.ii) What are the number of dry cows currently on your farm?

16.c.iii) What is the number of youngstock currently on your farm?

16.d) Are these numbers exact (calculated from software or paper records) or approximate (estimated)?

- Exact
- Approximate

16.e.i) What is the average age of lactating cows in your herd, in years?

____

16.e.ii) How this answer was generated? (check one)

- ☐ Milk testing results
- ☐ On-farm software
- ☐ Estimated
- ☐ Other (describe on written survey)

16.f) How many years has this farm been certified organic?

____

16.g) How many years have you owned or managed ANY dairy farm?

____

16.h) How many years have you owned or managed an ORGANIC dairy farm?

____

16.i) If you have an on-farm electronic record keeping system, what is it? (Check one)

- ○ DairyComp 305 (or Scout)
- ○ DairyPlan
- ○ DHI-Plus
- ○ PCDART
- ○ Does not have an on-farm electronic record keeping system
- ○ Other (describe on written survey)

16.j) Do you sell raw milk direct to consumers?

- ○ No
- ○ Yes, limited sales (87.5 or fewer gallons per week) of unpasteurized milk direct to consumers, VT tier 1
- ○ Yes, registered with VT Agency of Ag for sales as tier 2 producer (> 87.5 gallons per week and allowed to deliver)

16.k) Are you a registered milk handler processing milk or other dairy products on your farm? (e.g. producing pasteurized fluid milk, cheese, yogurt, ice cream or other dairy products on the same premises)

- ○ Yes
- ○ No
- ○ Not sure

16.l) Do you, your family, or your employees consume raw milk from this farm?

- Yes
- No
- Not sure

16.m) Are you currently considering leaving dairy farming within the next 2 years?

- Yes
- No
- Not sure

16.m.i) If yes, could you describe your plan for leaving dairy farming within the next 2 years?

17.a.i) Can you share your DHIA herd number with us (this should begin with 13)?

17.a.ii) Can you share your RAC (access code) number with us (4 digits)?

It can be found by opening herd management software and exploring (File – HerdDownload setup)

17.b) How many times per year do you participate in DHIA testing (eg monthly/12 times per year, less frequently, more frequently, OR don't use DHIA testing service)?

17.c) What is the DHIA lab you test through (DHIA Lab name and state)?

Answer may be VT-DHIA, Lancaster DHIA, or Dairy One

Supplemental Table S1. Description of farm traits and lactating cow housing for 21 Vermont organic dairy herds participating in the study.

		Categorical descriptors		Continuous descriptors		
Parameter	Level of parameter	Number	Percentage	Mean	SD	Range
Facility type	Bedded pack	5	23.8			
	Freestall	6	28.6			
	Tiestall	10	47.6			
Bedding type	Bedded pack	5	23.8			
	Sand	1	4.8			
	Wood	15	71.4			
Facility and bedding combination used	Bedded pack	5	23.8			
	Freestall with sand	1	4.8			
	Freestall with wood	5	23.8			
	Tiestall with wood	10	47.6			
County	Addison	2	9.5			
	Caledonia	1	4.8			
	Chittenden	2	9.5			
	Franklin	4	19			
	Lamoille	1	4.8			
	Orange	5	23.8			
	Orleans	4	19			
	Washington	1	4.8			
	Windham	1	4.8			
Predominant breed	Holstein	8	38.1			
	Jersey	10	47.6			
	Other	3	14.3			
Herd size category (no. cows)	30 to 55	6	28.6	64.9	17.1	32-99
	56 to 69	6	28.6			
	70 to 100	9	42.8			
Rolling herd average (pounds)		20		14,163	3,096	(9,000-21,204)

Feed a supplemental source of vit. E and selenium for lactating or dry cows	Yes	12	60			
	No	8	40			
	Was not sure	1				
Air quality (producer-assessed)	Poor/Fair	6	28.6			
	Good	8	38.1			
	Excellent	7	33.3			
Age of housing facility for lactating cows (years)				47	42	2-200
Laying surface	Deep bedded	8	38.1			
	Mattress or concrete	13	61.9			
If facility is freestall:						
Freestall stocking density[1]		6		1.16	0.38	0.84-1.76
If facility is tiestall:						
Trainers in tiestall	Yes	3	30			
	No	7	70			
If facility is bedded pack:						
Cows fed on bedded pack	Yes	3	60			
	No	2	40			
Number of cows on bedded pack		5		52.2	17.1	35-80
Resting area per cow on bedded pack (m^2/cow)		5		8.1	1.7	6.3-10.2
Bedding pack stocking density (percent)[2]		5		1.09	0.23	0.84-1.39

[1] Current number of lactating cows divided by number stalls available in freestall

[2] Stocking density as percentage of ideal stocking density (suggested 9.29 meters sq/cow Holsteins, 7.9 for Jerseys; University of Minnesota; https://extension.umn.edu/dairy-milking-cows/compost-bedded-pack-barns-dairy-cows): i.e., (no. cows x 9.29 m^2)/(no. cows x calculated cow density); a stocking density for a farm of 1.00 would exactly match the suggested stocking density for a bedded pack.

Supplemental Table S2. Description of lactating bedding management for 21 Vermont organic dairy herds participating in the study.

Parameter	Level of parameter	Categorical descriptors		Continuous descriptors		
		Number	Percentage	Mean	SD	Range
If use wood products in bedding:[1]						
If use shavings/sawdust/woodchips for bedding material, moisture-content?	Kiln-dried	8	40			
	Fresh or raw	12	60			
If shavings/sawdust not used immediately, where is it stored?[2]	Outside uncovered	1	5.6			
	Under cover	17	94.4			
If use fiber in bedding:						
What type is it?	Both straw and hay	2	66.7			
	Hay	1	33.3			
Where is it sourced from?	Grown on-farm	1	33.3			
	Purchased	2	66.7			
Is it wrapped or dry?	Wrapped round bales	1	33.3			
	Dry round bales	2	66.7			
Where is it stored?	Outside uncovered	1	33.3			
	Under cover	1	33.3			
	Both	1	33.3			
Bedding conditioner used?	Yes	5				
	No	16				
If facility is freestall or tiestall:						
Frequency of adding new bedding to stalls (times per week)		16		12.2	10	1-28
		16		27.6	13.6	14-56
Depth of bedding in stalls (cm)[3]		15		4.5	3.5	1.3-12.7
How is alleyway cleaned (freestall)?[4]	Continuous automated scraper	2	33.3			
	Skid steer	4	66.7			
Frequency of running gutter cleaner (tiestall)[5]	Once daily	3	30			

	Twice daily	7	70			
If facility is bedded pack:						
Frequency of tilling pack (times per week)[6]		0 (n = 2)				
		3.5 (n = 1				
		14 (n = 2)				
Depth of tilling pack (cm), if tilled:[7]		10.2 (n = 1)				
		23.3 (n = 1)				
		30.5 (n = 1)				
"Attentiveness to bedded pack" score[8]	n = 5 (0.7, 0.9, 0.9, 1.0, 1.0)			0.9	0.12	0.7-1.0
Depth of bedded pack (m)		0.9 (n = 1)				
		1.2 (n = 2)				
		1.5 (n = 1)				
		1.7 (n = 1)				

[1] n = 1 farm used new sand, so was the only one of the 21 farms not using a wood product at all

[2] n = 2 bedded pack farms used fresh woodchips immediately on delivery

[3] n = 15; n =1 deep-bedded sand producer unable to estimate bedding depth in stalls

[4] n = 6 freestalls

[5] n = 10 tiestalls

[6] n = 5 bedded packs

[7] n = 3 bedded packs that tilled surface

[8] Variable created by combining 4 categorical variables from survey into 1 numeric scale (0-1.0). Assigned 0.8 if answered “yes” to "add new bedding to pack daily," and additional 0.1 added if answered “yes” to any of following: monitor pack for temperature, monitor pack for moisture, monitor pack for density.

Supplemental Table S3. Description of mastitis control practices for 21 Vermont organic dairy herds participating in the study.

Parameter	Level of parameter	Number	Percentage
If answer to question, "How do you detect a case of CLINICAL mastitis?" included some sort of clinical sign (abnormal cow/abnormal udder) AND forestripping (check for abnormal milk)	Yes	8	38.1
	No	13	61.9
Clip or flame udders one or more times per lactation	No	16	76.2
	Yes	5	23.8
Trim switches on tails	No	2	9.5
	Yes	19	90.5
Do you keep a record of clinical mastitis events?	Always	8	38.1
	Sometimes	4	19
	Temporarily	3	14.3
	Never	6	28.6
If you do keep a record of clinical mastitis events, how is this done?	Written (paper, whiteboard)	11	26.7
	Software	4	73.3
Routinely perform bacteriological culture of mastitic milk	Always	4	19
	Sometimes	9	42.9
	Never	8	38.1
Routinely perform bacteriological culture of high somatic cell count cows	Always	3	14.3
	Sometimes	6	28.6
	Never	12	57.1
Routinely perform bacteriological culture of fresh cows	Always	0	0
	Sometimes	0	0
	Never	17	81
	Only if there is an issue noticed	4	19
Routinely perform bacteriological culture of cows before dry-off	Always	0	0
	Sometimes	0	0
	Never	17	81
	Only if there is an issue noticed	4	19
Where are cultures from mastitic cows performed?	On-farm or local veterinarian	9	42.9

	Reference lab	5	23.8
	Never culture	7	33.3
Routinely use vaccines for mastitis control	No	17	81
	Yes	4	19
Use any sort of intramammary product at dry-off	No	15	71.4
	Yes	6	28.6
Regular parenteral supplementation of dry cows with selenium and vitamin E	All lactating cows regularly	5	23.8
	Occasionally as needed (sick cow)	5	23.8
	No	11	52.4

Supplemental Table S4. Description of milking hygiene practices for 21 Vermont organic dairy herds participating in the study.

Parameter	Level of parameter	Number	Percentage
Do milkers wear gloves during milking?	Yes, all milkers consistently	11	55
	No, no one does	4	20
	Some milkers or inconsistent use	5	25
Frequency of milking cows	2 times per day	20	95.2
	Automated milking system (AMS)	1	4.8
Type of milking system used (if not AMS)	Parlor	7	35
	Tiestall	13	65
If milk in a parlor:			
Parlor type	Herringbone	3	42.8
	Step-up	2	28.6
	Swing	2	28.6
Are milking units routinely washed/sprayed off between uses?	Yes, routinely between milking individual cows; or occasionally, if the milking unit gets very dirty	5	71.4
	No, only at the completion of milking	2	28.6
Pre-dip teats with a chemical disinfectant	Yes	21	100
Type of pre-dip used	Iodine-based	18	85.7
	Hydrogen peroxide-based	3	41.3
Post-dip teats with a chemical disinfectant	Yes	21	100
Type of post-dip used	Iodine-based	20	95.2
	Chlorhexidine-based	1	4.8
Routinely forestrip as a part of udder prep	Yes	18	85.7
	No	3	14.3
Udders routinely wiped dry with any kind of towel prior to attaching the milking unit	Yes	20	95.2

	No (automated milking system)	1	4.8
If wipe udders dry:			
Paper or cloth towels?	Cloth	3	15
	Paper	17	85
How many cows are wiped with each towel?	One	16	80
	Two; or depends how dirty the udder is	4	20