# USING MANURE SOLIDS AS BEDDING

Final Report

Prepared by

**CORNELL WASTE MANAGEMENT INSTITUTE**
Ithaca, NY

Ellen Harrison
Jean Bonhotal
Mary Schwarz

Prepared for

**THE NEW YORK STATE**
**ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**
Albany, NY

Tom Fiesinger

Senior Project Manager

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**ABSTRACT**

Six farms using different types of dried manure solid (DMS) strategies, including a farm that had side-by-side pens using sand and DMS, participated in a study to assess the impact on herd health of using DMS as bedding on dairy farms in the Northeast. Samples of unused and used bedding were taken over the course of a year and analyzed for bacterial content and physical properties. Mastitis and somatic cell count (SCC) records were analyzed in relation to those properties. Sand bedding started out "cleaner" than DMS bedding, but once in the stalls, the bacterial load of several organisms was highest in sand. In addition, DMS with the least bacterial numbers in the unused tended to have the highest bacterial numbers in the used bedding. A comparison of bacterial concentrations in unused and used air-dried DMS versus composted DMS did not show composted to be consistently lower and calls into question the value of composting DMS prior to bedding. Bacteria in the unused bedding had little to no effect on bacteria in the used indicating that bacterial levels in used bedding are more dependent on bacterial levels in the manure of the cows using the stalls and how well the stalls are scraped, rather than the cleanliness of the bedding before it is place in the stalls. Levels of *Streptococcus*, *Klebsiella* and gram negative and positive bacteria were significantly higher on the teat ends of cows bedded on DMS versus those bedded on sand, but SCC and mastitis for those cows did not differ between bedding materials. Although mastitis differed among farm/bedding strategies, bacteria levels and properties of bedding had no effect on mastitis incidence. Lactation number, stage of lactation and SCC were the significant variables. Decreased levels of *Klebsiella* in the used bedding increased the odds of having an abnormal SCC for one FBS, and decreased moisture and fine particles in the used bedding increased the odds of having an abnormal SCC for a different FBS. For all others, abnormal cell counts were affected only by season, lactation number and milk production. Concern that continued use of DMS will increase SCC was not borne out using linear regression of 10 years worth of linear score data. Although 2 of 6 farms showed an increase in linear score while using DMS, it was not different from the change in linear score prior to using DMS. Lameness was higher in cows bedded on sand compared to DMS. Economic analysis a savings of between 1 and 26 cents per hundred weight of milk produced through the use of manure solids as bedding on five farms. This study suggests that properly managed DMS can provide an economic benefit without compromising herd health.

Key words: dried manure solids, dairy farms, mastitis, linear score, SCC, compost, dairy manure solids

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Tim Pajda, Farm Manager

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## SUMMARY

This document summarizes the results of a study conducted by Cornell Waste Management Institute (CWMI) that was funded by the New York State Energy Research and Development Authority, the New York Farm Viability Institute, Cornell Cooperative Extension and the College of Agriculture and Life Sciences at Cornell. This research was conducted to assess the impact of using dried manure solids (DMS) as bedding on herd health on dairy farms in the Northeast.

Six farms using different types of DMS bedding strategies participated in this study, including a farm that used sand and two DMS strategies side-by-side. Samples of unused and used bedding were taken over the course of a year and analyzed for bacterial content, presence of *Mycobacterium Avium paratuberculosis* (MAP), and physical properties. Individual cow records were retrieved on mastitis incidence, somatic cell count (SCC) and linear score (LS) for cows in the pens from which samples were taken. Teat swabs and lameness were analyzed at the farm using sand and DMS, and teat end scoring was performed at all farms. Statistical analysis of all data was done with the JMP operating system. Mass nutrient balance data and economic data were collected. In addition, research at the SUNY Cobleskill dairy facility investigated the effect of composting on bacterial pathogens in bedding. In one barn, four types of bedding (air-dried DMS, partially composted DMS, mature compost from DMS and sawdust) were analyzed for bacterial content and physical properties over a 3 week period to assess differences between them.

### BACTERIAL CONCENTRATIONS IN BEDDING

One of the most important things learned from this study was that different bacteria respond differently. That is, just because the level of one type of bacteria is high in one type of bedding, does not mean that the levels of the other bacteria measured will be high, nor does it mean that levels of that same bacteria will consistently be high in additional samples of that same type of bedding. In addition, statistical analysis of SCC and mastitis returned only one bacterium (*Klebsiella*), as having a significant effect on the number of animals with elevated SCC, but it was in the opposite direction expected. Therefore, bedding sample analysis for bacterial levels will not necessarily return useful information for enhancing herd health.

### BACTERIAL CONCENTRATIONS IN UNUSED BEDDING

There were no differences in bacterial populations of *Staphylococcus* species, *Enterobacter* and *Proteus* in any unused bedding. For the rest of the bacteria analyzed, sand unused bedding had the lowest bacterial populations. Average levels of *E. coli* and *Klebsiella* were very low in all of the unused bedding, with significant differences between populations of these two pathogens occurring only between sand (significantly less) and two or three of the “green” DMS strategies. There was no *E. coli* found in the

unused bedding of the drum and windrow composted and sand strategies, and no *Klebsiella* in one of the drum composted and the sand strategies.

**BACTERIAL CONCENTRATIONS IN USED BEDDING**

In the used bedding, there were no significant differences in the levels of *E. coli*, *Enterobacter* or *Proteus* between any FBS. *Streptococcus* levels were significantly higher in the sand strategy used bedding than all other FBS except one. *Klebsiella* (which was absent from the unused bedding in one of the drum composted strategies) was found in significantly higher levels in the used bedding from that strategy than several other FBS. Although sand started out "cleaner", used bedding in the sand FBS had significantly higher levels of the bacteria analyzed (except *Klebsiella*) than at least one, and in many cases, more than one DMS FBS. In all cases (except *Streptococcus*), the three strategies at the side-by-side farm did not differ in bacterial levels, indicating that it is more likely that bacterial levels in used bedding are a result of bacteria in the manure of the cow and how well stalls are cleaned, rather than how "clean" the bedding is when it is put in the stall. In addition, those strategies that started out with "clean" bedding tended to have significantly higher levels of bacteria in used bedding, indicating the bedding may have started out too clean (i.e. no competition from other bacteria).

**COMPOSTING DMS**

Composting reduced bacterial numbers in unused bedding for 4 of the 7 bacteria found in the DMS products investigated. Of the 4 bacteria that had significantly higher counts in the unused air-dried DMS, only one (*Corynebacterium*) remained significantly higher in the used air-dried DMS. *Streptococcus* counts in the used DMS were significantly higher in both the mature and partially composted DMS than in the air-dried DMS, while *Klebsiella* counts were not different in any of the used DMS bedding. *E. coli*, which was not found in the mature compost prior to being used as bedding was found in significantly higher levels in the used mature compost bedding than the partially composted used bedding. This adds weight to the theory that bacterial levels in the used bedding are more likely a result of bacteria in the fresh manure of the animal, how well the stall is cleaned, and how much competition there is in the bedding.

**COMPARISON OF DMS AND SAWDUST**

In general, air-dried DMS had the highest levels of most bacteria in the unused bedding, while sawdust had the lowest. Molds appeared only in sawdust, while yeast was present in both sawdust and air-dried DMS. There was fungus in all but the air-dried DMS. Although present in unused bedding, there were no yeasts, molds or fungi in any of the used bedding materials. As with unused, sawdust had significantly lower levels of most bacteria in used bedding than the other materials.

**SEASONAL DIFFERENCES IN BEDDING BACTERIA**

Seasonal differences in bacterial counts of bedding have been noted in the literature. In this study, there were very few seasonal differences in bacterial levels of unused bedding, however, where there were, spring had the highest bacterial load. *Streptococcus* levels in unused bedding were significantly higher in the spring for most FBS, but were higher in the winter than the spring for sand bedding. Although spring levels of bacteria in unused bedding were highest, summer had higher levels in the used bedding. *Staphylococcus*, *E. coli*, *Klebsiella*, *Enterobacter* and *Corynebacterium* were all highest in used bedding in the summer, while *Streptococcus* levels were highest in the spring. *Klebsiella* levels in used bedding were the lowest in the spring.

**CORRELATION OF BACTERIAL COUNTS IN USED BEDDING TO BACTERIA COUNTS IN UNUSED BEDDING**

It is often assumed that the cleanliness of the unused bedding has an effect on the bacterial population of the used bedding. One would expect that if the bacterial content of the unused bedding determined the levels in the used, it would be the same bacteria (i.e. more *E. coli* in the unused would produce more *E. coli* in the used). However, multiple linear regression showed that increasing levels of bacteria in the unused bedding sometimes increased levels of bacteria and sometimes decreased levels of bacteria in the unused bedding. In addition, it wasn't always the same bacteria, and the r-square values indicate that levels of bacteria in the used bedding are due only 6 to 51% to the levels of the bacteria in the used. These data suggest that other factors besides the bacterial level of the unused bedding have an impact on bacterial levels in used bedding.

**PHYSICAL PROPERTIES OF UNUSED BEDDING**

Percent moisture, organic matter (OM) and particle size of the unused and used bedding were analyzed. As expected, moisture and OM in the unused bedding were significantly lower in the sand bedding strategy than any other bedding strategy. Fine particles in the unused bedding were expected to be higher in the sand, however, both drum composting and one separated farm/bedding strategy produced the same amount of particles less then 2mm as in sand bedding. There were significant differences in all of the physical properties between the DMS farm/bedding strategies. Moisture ranged from 64 to 73%, OM from 86 to 93% and the % of particles less than 2 mm and 0.84 mm ranged from 31 to 74% and 6 to 37%, respectively. These differences may indicate that it is the type and efficiency of the separator being used on the farm that determines the properties of the unused bedding.

**PHYSICAL PROPERTIES OF USED BEDDING**

As with the unused bedding, moisture and OM in the used bedding were significantly lower in the sand bedding strategy than any other system. The addition of feces increased the amount of OM in the sand bedding. There was no increase in OM between unused and used bedding in the DMS bedding strategies. Moisture ranged from 29 to 60% in used bedding with moisture being higher in the bedding strategies that used deep beds than those that used mattresses. This makes sense since those using mattresses spread the DMS in a 2" layer on top of the mattresses and thus it dries out. Fine particles were significantly higher in the sand bedding strategy than any other strategy, and tended to be lower in those bedding strategies that used deep beds versus those that used mattresses. DMS in deep beds tends to mat together from the weight of the cow, while the DMS on the mattresses tends to either fall off, or spread out.

**CORRELATION OF BACTERIAL COUNTS IN AND PHYSICAL PROPERTIES OF BEDDING WITH BACTERIAL COUNTS ON TEAT ENDS**

Some of the literature indicates that the greater the bacterial population in the bedding, the greater the bacterial population on the teat ends. High populations are proposed to cause an increase in somatic cell count (SCC) and cause greater incidence of mastitis. Comparison of the bacterial population on the teat ends of cows bedded on DMS from the separator and cows bedded on sand showed significant differences only for *Klebsiella*, gram negative and gram positive bacteria (significantly higher counts on cows in the DMS pen versus cows in the sand pen). Analysis of the bedding properties that caused differences in bacteria on the teat ends yielded variable responses. The percent of fine particles in the used bedding had a significant effect (either by itself, or in conjunction with other bedding properties and/or bacteria) on the level of bacteria found on the teat ends for 4 of the 8 bacteria analyzed. However, it did not behave as expected. *Streptococcus*, *Staphylococcus* and *Enterobacter* levels all decreased when the percent of fine particles increased in the used bedding. Bacterial levels in the used bedding had an affect on several bacterial levels on teat ends, but only in the case of *Klebsiella* were they the same bacteria (increased *Klebsiella* levels in the bedding caused increased *Klebsiella* levels on teat ends).

**CORRELATION OF BACTERIAL COUNTS ON TEAT ENDS WITH SCC**

It has been generally accepted that the cell count for "normal" milk is nearly always less than 200,000 cells/ml for cows ($2^{nd}$ lactation or greater). Higher counts are considered abnormal and indicate probable infection. Therefore individual cow SCC was divided into two categories; those cows with less than or equal to 200,000 cells/ml (normal) and those cows with > 200,000 cells/ml (abnormal). There were 18 out 57 cows in the DMS pen with an abnormal SCC, and 22 out of 60 in the sand pen. There was no difference in the number of animals between the two pens. Logistic regression for the log odds of having an abnormal cell count based on the bacterial population on the teat ends showed that the level of *Streptococcus* on the

teat ends was positively correlated and the level of gram negative bacteria was negatively correlated. That is, the odds of having an abnormal cell count increase 1.6 times for each 1 log cfu of *Streptococcus* on the teat ends, and decrease 1.2 times for each log cfu increase in gram negative bacteria.

**CORRELATION OF BACTERIAL COUNTS IN AND PHYSICAL PROPERTIES OF BEDDING WITH MASTITIS**

The odds of getting mastitis for heifers was significantly affected by only abnormal cell count (those heifers with >100,000 cells/ml were more likely to get mastitis), while the odds of getting mastitis for cows was significantly affected by farm/bedding system, season and abnormal cell count. Since farm/bedding system includes other farm variables besides bedding, Poisson regression was run to see which variables within farm/bedding system had an effect on mastitis incidence. Bacterial levels and properties of the bedding had no effect on the incidence of mastitis. SCC was a significant variable for all systems. Stage of lactation, milk production and season also had an effect, but not for all farm/bedding systems. When the three side-by-side systems were analyzed together, type of bedding did not have an effect, but the amount of moisture and particles < 2mm in the used bedding, as well as milk production were all positively correlated with mastitis incidence.

**CORRELATION OF BACTERIAL COUNTS IN AND PHYSICAL PROPERTIES OF BEDDING WITH SCC**

The odds of having an abnormal cell count for cows were affected by farm/bedding system, season (less likely in the winter), lactation number (greater for those in 3$^{rd}$ or greater lactation than 2$^{nd}$), and stage of lactation (as the number of days in milk increased, the odds of having an abnormal SCC also increased). The odds of having an abnormal cell count for heifers were affected by farm/bedding system and season. As with cows, the number of heifers with abnormal cell count was least in the winter and most in the spring and summer. Since farm/bedding system includes other farm variables besides bedding, Poisson regression was run to see which variables within each system had an effect on abnormal cell count. The only time bacterial levels had an effect on SCC was for the drum composted system at the side-by-side farm, where *Klebsiella* levels in the used bedding had a negative correlation with number of cows with abnormal cell count (i.e. less *Klebsiella* in the used bedding, more cows with abnormal SCC). Bedding properties had an effect only for CDigested where the amount of moisture and the amount of particles < 0.84 mm also had a negative correlation with abnormal SCC. Both of these responses for bedding bacteria and properties are not what would be expected. Otherwise, it was season, lactation number and milk production that had an effect.

**IMPACT OF CONTINUED USE OF DMS ON SCC AND LS**

Many producers and veterinarians believe that continued use of DMS as bedding is contributing to increasing somatic cell count on farms. Herds that participate in the Dairy Herd Improvement Program (DHIP) have many years worth of herd average milk production and SCC/LS data available. This information was available for our use from approximately January 1997 through January 2008 for all of the farms on the study except one for which data was available through August 2006. Linear regression of average monthly milk production and LS for all farms together and each farm individually was run on all of the data, as well as on the data generated prior to and after using DMS as bedding. This data was run for farm only, not farm/bedding strategy, as the 3 strategies at the farm using sand could not be separated out in this data set. Two additional farms, not in the study, that are using DMS as bedding also gave permission to access their data. Data was also available from 1997-2008 for 65 NYS dairy farms with comparable herd size, and linear regression over time was run for these 65 farms over the same time period. Data were not available about which of these farms might have been using DMS bedding, but knowledge about NYS practices indicates that this would be a very tiny percentage.

Looking at the study farms together from 1997 to 2008, average monthly milk production did not change significantly either prior to, or while using DMS as bedding  Linear regression of the data for linear score shows a positive correlation (+ 0.0002/cow/day or 0.07/cow/year) for LS over time for cows bedded on DMS and no significant correlation for those on some other bedding (i.e. LS did not change significantly over time). ANOVA analysis showed the change in LS over while using DMS was significantly different from the “no change” prior to using DMS on the 6 study farms.

Comparing the 65 NYS farms to the 6 study farms, ANOVA analysis showed no difference in the change in milk production over time between the two sets of farms. For the 65 farms there was an increase in milk production over that time period of 0.0007 lbs/cow/day (0.3 lbs/year), while the 6 study farms showed no change in milk production over the same time period.

Both the 65 farms and the 6 study farms showed an increase in LS between 2000 and 2007 (comparison was made only for the periods in which the study farms were using DMS). The 65 NYS farms showed an increase of 0.00002/cow/day (0.007/cow/year), while the 6 study farms showed an increase of 0.0002/cow/day (0.07/cow/year). ANOVA on these results showed a significant difference in the change in LS over time between the two sets of farms. Therefore, it is possible that continued use of DMS could be increasing LS more than other bedding, but since the dataset for those using DMS is much smaller than those using other bedding, and there is no way to be sure of what type of bedding the other farms are using, no conclusion should be made.

In addition, comparison of each individual farm while using DMS, as well as comparison of the additional 2 farms using DMS to the 65 NYS farms, showed only 3 of 8 farms incurring an increase in LS while using DMS, and only 2 of those were significantly different than the increase in LS that was occurring on the 65 NYS farms. These two farms have been using DMS for approximately 10 years. However, one of the additional farms (not a study farm) has been using DMS for over 15 years with no change in LS over that time period, so changes in SCC/LS may not have anything to do with DMS use.

**IMPACT OF BEDDING ON LAMENESS**

Some of the literature has indicated that sand is the best bedding for the health of feet and legs. There is concern that using DMS as bedding can have an adverse effect on feet and legs, causing increased lameness and thus culling of animals. A comparison of lameness at the farm using both sand and DMS as bedding showed that the cows on sand (particularly those in lactation 4 or greater) were significantly lamer than those bedded on DMS.

**JOHNES DISEASE**

There is some concern that since the bacteria responsible for Johnes disease (*Mycobacterium Avium paratuberculosis* –MAP) is shed in the manure, using manure solids as bedding may spread the disease throughout the herd if the bacteria remains viable in the DMS. MAP was found in small numbers in several of the unused bedding sources, including sand. The fact that MAP is not necessarily destroyed by separation, digestion or drum composting means that there could be some potential for the spread of Johnes through the use of DMS if bedding calves with DMS because they might be more inclined to eat it than adult animals.

**IMPACT OF DMS ON FARM NUTRIENT BALANCE**

Bedding management does not greatly impact overall farm nutrient balances on New York dairy farms.

**ECONOMIC IMPLICATIONS OF DMS**

Economic analysis showed that the cost of using manure solids as bedding ranged from a savings of 1 and 26 cents per hundredweight of milk produced. All five farms saved money using DMS through reduced costs of manure hauling and purchased bedding. Total savings, of course, depends on the amount of milk produced. For example, at the farm that showed a savings of 20 cents/cwt, total milk sales for the year were 38,325,000 lbs, saving the farm 383,250 * 0.20 = $76,650 on the cost of producing milk that year.

## SECTION 1

## INTRODUCTION

Dairy farms in NYS are under increasing pressure to improve manure management. Bedding for dairy cows is a costly and time consuming component of dairy farming that may have implications for herd health as well as the environment and economics. The cost and availability of bedding fluctuates and good consistent bedding can be hard to find and expensive.

In the northeast, there is increasing interest in and some limited experience with the use of dried manure solids (DMS). The semi-solid (25% solids) material derived from a manure stream runs through a separator to reduce moisture content for use as bedding. While interest is high, there are concerns, from veterinarians, farm advisors, and farmers, that using DMS as bedding will cause elevated levels of environmental pathogens that may negatively affect udder health (increased environmental mastitis) and milk quality.

The potential financial savings of using DMS are substantial and the potential to avoid bringing additional nutrients in bedding materials onto the farm is another benefit. Farmers using DMS report greater cow comfort than with other bedding materials they have used.

Mastitis is a costly disease for the dairy farmer. It is broken down into contagious mastitis (caused by bacteria that are found in the mammary gland and spread from cow to cow largely through the milking process), and environmental mastitis (caused by bacteria that live in the environment and spread through exposure to them in the environment). Control of contagious mastitis is sought through milking hygiene, the use of teat dips, treatment of infected animals in lactation, culling of animals with chronic infections, and dry cow antibiotic therapy. Control of environmental mastitis is sought through stall and animal hygiene, milking procedures and improvement of host resistance.

Because mastitis is frequently sub-clinical, a number of tests have been developed for detecting mastitis. Most tests estimate the somatic cell count (SCC) of a milk sample. All milk contains white blood cells known as leucocytes which constitute the majority of somatic (derived from the body) cells. It has been generally accepted that the cell count for “normal” milk is nearly always less than 200,000 cells/ml. Higher counts are considered abnormal or excessive and indicate probable infection. SCC can be done on individual cows or on bulk tank milk samples. Elevated SCC due to environmental mastitis is often short-lived, so SCC counts are not very useful in evaluating environmental mastitis infections. High SCC has been associated with milk yield loss.

Very low (< 20,000) levels of leucocytes in the mammary gland may increase the incidence of infection by environmental pathogens such as coliforms. Herds that have effectively controlled contagious mastitis pathogens (*Streptococcus agalactiae*, *Streptococcus dysgalactiae*, and *Staphylococcus aureus*) through programs of post-milking teat disinfection and dry-cow therapy, tend to have more problems with environmental mastitis pathogens.

The following bacteria are those commonly considered mastitis pathogens:

- Contagious pathogens:
    - *Staphylococcus aureus*
    - *Streptococcus agalactiae* and *Streptococcus dysgalactiae*, to a lesser extent also *Streptococcus uberis*.
    - Mycoplasmas
- Environmental pathogens:
    - *Streptococcus* species (other than the above)
    - *Staphylococcus* species (other than above)
    - *Enterococcus* species
    - Coliform bacteria (including: *Escherichia coli*, *Klebsiella* species, and *Enterobacter* species)
    - *Pseudomonas* species
    - *Proteus*
    - *Serratia* species
    - *Prototheca*
    - *Corynebacterium* species
    - Other gram negative and gram positive bacteria

Other organisms such as yeasts, mold and fungi may play a part.

The following report contains a summary of research literature on the contribution of bedding to cow health and milk quality as well as issues pertaining to bedding material, and the design and results of a six farm study that looked at the issues surrounding the use of DMS on udder health and milk quality.

## SECTION 2

## LITERATURE REVIEW

### OVERVIEW

A literature review was conducted in 2006 prior to initiating the research to address the use of dried manure solids (DMS) as bedding for dairy cows, specifically the relationship of DMS bedding to herd health. The concentration of pathogens in bedding, on teat ends and their relationship to mastitis is discussed in this review of literature (Appendix A). It is summarized below.

### TYPES OF BEDDING

There are two types of bedding, organic and inorganic. Organic bedding materials contain nutrients needed for bacterial growth, while inorganic bedding materials do not. However, once any type of bedding becomes soiled (with fecal matter and urine), pathogen growth can be supported. Inorganic bedding, such as sand, may start out with low pathogen concentrations. Some organic bedding materials start out with lower concentrations than others. However, research shows that within 24-48 hours of being in the stall, pathogen levels in all organic bedding materials rise to similar concentrations. The addition of lime to the stalls to reduce pathogens is not supported by the literature.

### AGE AND FREQUENCY OF BEDDING

The desirable frequency with which fresh organic bedding is added to the stalls is unclear. While "common wisdom" suggests frequent re-bedding, the research literature indicates that pathogen levels peak after a couple of days and may decline thereafter. This may be a result of bacteria having consumed the available nutrients and that frequent re-bedding provides a new source of food resulting in higher bacterial counts. More work is needed on this subject; an NYFVI grant is funding further research on this.

### BEDDING BACTERIA AND TEAT ENDS

The literature shows inconsistency regarding the relationship of bacterial concentrations in bedding to the bacterial concentration on teat ends. Factors such as particle size may be more important than simple bacterial counts in the used bedding. Further, the relationship of teat end counts to mastitis is unclear.

### BEDDING BACTERIA AND MASTITIS

Researchers have generally stated the rule of thumb that bedding materials should be kept below a maximum bacterial count of $10^6$ colony forming units (cfu) per gram of bedding wet weight. This number appears to be based on one study where there were no new cases of coliform mastitis when bedding counts were at $10^4$ and $10^5$ one summer, but there were several new cases the following summer when bedding counts were at $10^7$ cfu/g wet weight (Bramley and Neave, 1975). This paper does not claim that $10^6$ colony forming units (cfu) per gram of bedding wet weight is a critical level and it represents data from only two

summers on one farm. A few studies show a correlation between the number of bacteria in the bedding and/or the number on the teat ends and mastitis while a number of studies show no correlation. Few studies examined the relationship between bedding pathogens and milk quality.

**BEDDING BACTERIA AND SOMATIC CELL COUNT**

Several studies have been conducted on the differences between herds that have low average somatic cell counts (SCC) and herds that have high average SCC. Other studies look at the value of SCC in determining intra-mammary infection (IMI) status in herds. High SCC is correlated with decreased milk production. SCC is measured both with a bulk tank sample (BTSCC) and with individual milk samples from each cow. BTSCC can be a good indicator of a herd's general udder health status, with high BTSCC generally indicating a problem with contagious mastitis. Herds with lower BTSCC have lower subclinical mastitis and better general udder health. However, the presence of leucocytes in the udder helps protect it from getting other mastitis, therefore very low SCC (less than 20,000) appears to predispose cows to getting environmental mastitis. By looking at individual cow SCC over a period of several months, patterns can be established for each cow. Spikes in individual cow SCC usually indicate environmental mastitis and are often short in duration. When SCC is done on a monthly or other low frequency basis, these spikes may be missed. Thus typical BTSCC cannot generally be used to diagnose environmental mastitis at the herd level unless it is pervasive and persistent.

**OTHER ISSUES**

The impact of bedding, cleanliness of the udder and/or legs on the mastitis rate of a herd is unclear. Bedding may play a role in the cleanliness of the udder, and pre-milking udder hygiene may play a role in the amount of mastitis seen.

Other issues that may affect intramammary infection in dairy herds include stage of lactation and the dry period, parity (number of lactations), milking and milking machine factors including the use of post milking dips, teat end roughness and callosity, seasons of the year, nutrition, and housing conditions other than bedding.

## SECTION 3

## DESCRIPTION OF STUDY

### FARMS

Six farms participated in this study based on the fact that they had either been using DMS, or were beginning to use DMS for all or part of their herd. On one farm, a side-by-side trial of sand, drum composted DMS and DMS from a separator were compared using 3 pens in one barn. A description of the farm bedding strategy (FBS) used for analysis at each farm can be found in Table 3-1 and more detailed descriptions of each farm can be found in Appendix B.

**Table 3-1: Description of Bedding Practices at the Six Study Farms**

| Farm | Bedding Strategy Employed | Farm/Bedding Strategy |
|---|---|---|
| A | Manure from the stalls is separated, then drum composted for 24 hours. It sits in a pile for one day and is then spread in the stalls over the concrete 3 times per week. | ADrum |
| B | Manure from the stalls is separated and then put in windrows in a building to compost for about 10 days prior to spreading on mattresses in stalls. Started the study bedding 3 times per week, but after the first sampling, went to 6 days per week | BWindrow |
| C | Manure from the stalls is run through a digester, then separated and piled. It is used on mattresses in the stalls right out of the separator in the fresh cow pens. It is re-bedded 3 times per week. As the study progressed, all cows were bedded on DMS. | CDigested |
| D | Manure from the stalls is separated (in the first month of the study only, it was digested first), piled for approximately 7 days then spread in deep beds 2 times per week. There were some months when stalls were bedded with material directly from the separator. | DSeparated |
| E | There were 3 bedding treatments at this farm from May 06 through September 06, then only 2 from October 06 through April 07. Manure from the stalls is separated, then either piled or run through a drum composter with a 3 day retention time and bedded in deep beds 2 times per week. The drum composted bedding was dropped in September. The third bedding is sand in deep beds and bedded once a week. | EDrum, ESand, ESeparated |
| F | Manure from the stalls is separated and piled for about 7 days then spread in deep beds 2 times per week. | FSeparated |

Research was also conducted at the SUNY Cobleskill dairy barn to investigate the effect of composting on bacterial concentrations as well as to compare DMS to sawdust. During the research trial, four treatments (air-dried DMS, partially composted DMS, mature DMS compost and sawdust) were each replicated in four stalls. Student labor bedded these stalls by hand on Monday, Wednesday and Friday for three weeks. The compost was produced using a forced air system operating for 1-2 months.

## RESEARCH DESIGN

### Research Questions

The goal of the research was to evaluate the impact of bedding with DMS on herd health and farm economics. Data were collected and analyzed to answer the following questions:

1. Are bacterial concentrations in unused bedding in the various systems different?
2. Are bacterial concentrations in the used bedding different?
3. Are there seasonal differences in bacterial counts in bedding?
4. Are bacterial concentrations in the used bedding correlated with concentrations in the unused bedding?
5. Are there physical factors in the unused and used bedding that are different among the systems and are these correlated with bacterial concentrations?
6. Do the bacterial counts on teat ends differ between cows bedded on sand and those bedded on DMS?
7. Do the bacterial counts in and/or the properties of the used and unused bedding have an effect on the bacterial counts on teat ends?
8. Are bacterial levels on teats correlated with physical properties of the bedding?
9. Do the bacterial levels on teats have an effect on somatic cell count (SCC)?
10. Do the bacterial counts in and/or the properties of the used and unused bedding have an effect on mastitis or SCC?
11. How has milk production and linear score (LS) changed over time at these farms, taking into consideration when DMS was first used?
12. Is lameness greater on sand or DMS?
13. Will the bacterium that is responsible for Johne's disease be more prevalent in raw unused DMS versus composted DMS or sand?
14. Does using DMS have an impact on the overall farm nutrient balance?
15. What are the economic implications of the different bedding systems?

### Bedding Samples

The 6 research farms were visited over a period of one year from March 2006 through April 2007. Sampling at Farm E occurred monthly from May 2006 through April 2007; sampling occurred 8 times (March, May, July, August, September, October, December and February) at the other 5 farms. At each

visit, the owner or herdsperson was interviewed to assess changes in bedding, milking or other procedures since the last visit. Also at each visit, quadruplicate samples of used bedding and triplicate samples of unused bedding were taken according to the protocol in Appendix C.

The samples were sent to three different laboratories for analysis. Quality Milk Promotion Services (QMPS), Cornell University Animal Health Diagnostic Center, Ithaca, NY analyzed both the used and unused bedding for the following pathogens on a wet weight basis:

- Environmental *Streptococcus* species
- Environmental *Staphylococcus* species
- *Enterococcus* species
- Coliform bacteria (including: *Escherichia coli*, *Klebsiella* species, and *Enterobacter* species)
- *Pseudomonas* species
- *Proteus*
- *Serratia* species
- *Prototheca*
- *Corynebacterium* species
- Other gram negative and gram positive bacteria
- Yeast, mold and fungus

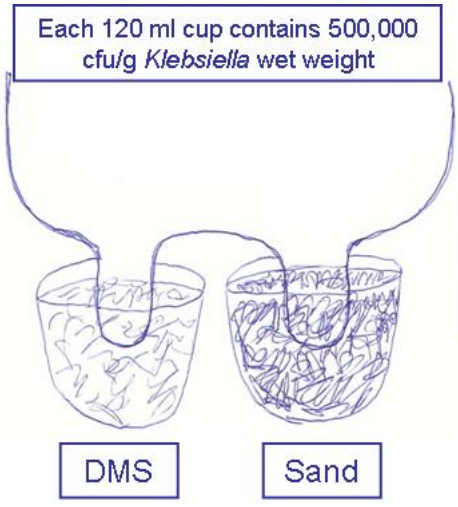
The Johnes Laboratory, Cornell University Animal Health Diagnostic Center, Ithaca, NY analyzed only the unused bedding (on a wet weight basis) for the presence of *Mycobacterium Avium paratuberculosis* (MAP) to see if the Johnes disease bacterium was present and thus could potentially be spread through the use of DMS.

Brookside Laboratories, New Knoxville, OH, analyzed both the used and the unused bedding for the following properties:

- % Moisture
- % Organic Matter
- Volume/Density
- % Total, Ammonia and Nitrate Nitrogen
- % Phosphorus
- % Potassium
- ppm Copper
- ppm Water Extractable Phosphorus
- pH

- Particle Size

The numbers of bacteria found in bedding materials can be reported on a wet weight ("as is"), dry weight or volume basis. Reporting on a wet weight basis has little significance since it will be highly dependent on how moist (heavy) the material is. When comparing bacterial counts within the same type of bedding material, it makes sense to do it on a dry weight basis. For example, dry weights might be used when examining the change in concentrations over time in the same barn using the same bedding. Comparing different materials with very different densities, such as sand and DMS, is challenging since the bedding in a stall of sand will weigh more than a stall with DMS. For the same volume of material, the higher density of sand would result in lower reported dry weight concentrations than a lighter material so the sand would "look cleaner" while the same samples compared using volume based concentrations might show higher concentrations in the sand. Figure 3-1 shows an illustration of this concept. The teat ends of a cow are immersed in two 120 ml cups of bedding material. The cup on the left contains DMS and the cup on the right contains sand. Because of the density of sand, much more of the bedding material is touching the teat end in the cup on the right than is touching the teat end in the cup on the left. Both cups contain 500,000 cfu/g wet weight of *Klebsiella*, The weight of the DMS in the cup on the left is 40.6 grams, while the weight of the sand is 142.3 grams. Because of the difference in weight in the same volume, the amount of *Klebsiella* to which each teat end is exposed differs between the two bedding types. The cup holding the DMS is exposing the teat end to 169,250 cfu/ml, while the one holding the sand is exposing it to 592,708 cfu/ml (see the literature review in Appendix A for a fuller discussion). Therefore, in this report all bacterial concentrations are reported on a volume basis. The information obtained on volume/density was used to convert the bacterial counts from the wet weight QMPS data to a volume basis.




| | DMS | Sand |
|---|---|---|
| Volume: | 120 ml | 120 ml |
| Weight | 40.6 g | 142.3 g |
| cfu/ml = (cfu/g)*(weight of material/volume of material) | 169,250 cfu/ml | 592,708 cfu/ml |

**Figure 3-1: Concentration of Bacteria in Bedding Materials**

At SUNY Cobleskill, individual samples of unused material from each stall were obtained just prior to spreading in the stalls on Monday and Wednesday following the general procedure reported in Appendix C. Individual samples of used bedding from each of the 4 stalls of each treatment were obtained on Wednesday and Friday just prior to the spreading of new bedding.

The samples for each stall of used and unused bedding were delivered to the QMPS laboratory at Cobleskill for analysis of bacteria and other organisms (i.e. molds, yeast and fungi). Composite samples of unused bedding material (one sample for each treatment) were shipped to Brookside Laboratory for analysis of moisture, organic matter, nitrogen, carbon, C:N ratio, pH and maturity.

No other data (i.e. farm records, SCC, teat swabs, etc) were collected.

**Teat Swabs**

Teat swab sampling was performed by CWMI at Farm E 3 times to assess the bacterial population on the teat ends of cows in the different bedding regimes. Samples were taken on the first 20 cows coming into the milking parlor in each of the three study pens (composted DMS, DMS from the separator, and sand) on September 27, 2006, then in the sand and DMS from the separator pens 2 more times (January 16, 2007 and May 1, 2007). The swabs were taken to QMPS for bacterial analysis.

**Teat End Scoring**

Teat end scoring (1 to 4) was performed by QMPS trained technicians one time at each of the six farms. This was done to determine the health of teat ends at each farm. The health of teat ends is an important determinant of the impact of bacteria on milk quality and cow health. While bedding is not expected to impact teat end health, teat end health may result in differences in the way bedding materials affect SCC and mastitis. Teat end scoring was done to ensure that differences in teat end health between the farms does not account for any differences in clinical mastitis.

**Farm Records**

The six dairy farms in this study use a computer-based record keeping system called Dairy Comp 305 (Valley Agricultural Software, Tulare, CA). This system includes a series of pages for each cow in the herd. The events page stores data concerning the current lactation, such as age, lactation number, days in milk, pen number, fresh date, mastitis incidences and other health related events (Figure 3-2). The Dairy Comp 305 files were obtained each time bedding samples were collected to keep track of the cows in each pen that was sampled on each farm. Through this, it was possible to get a count of mastitis incidence, as well as lactation number, days in milk and milk production for the cows in the sampled pens over the study period.

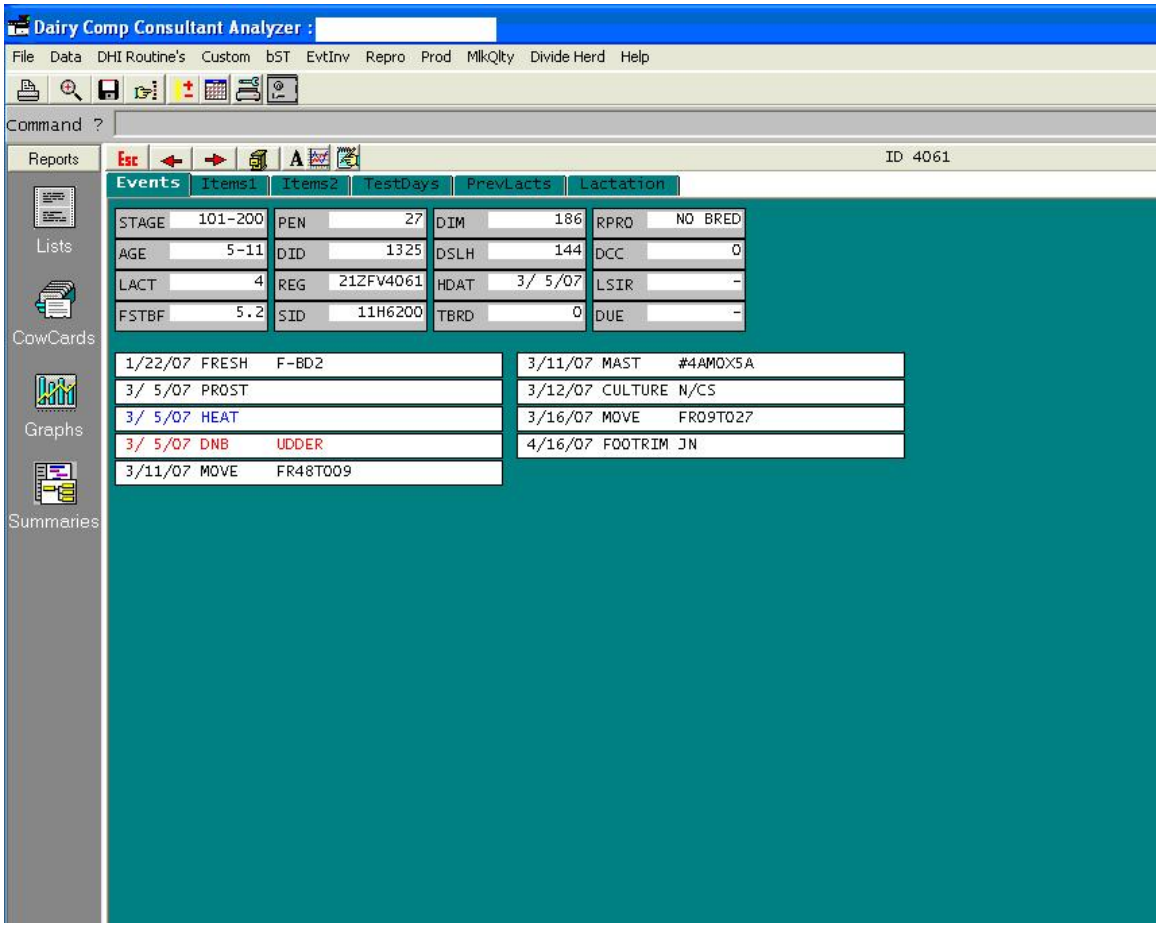



**Figure 3-2: Sample Events Page for Dairy Comp 305.**

Each of the six farms also participated in the NYS Dairy Herd Improvement Program (DHIP), in which trained technicians come to the farm once a month and take milk samples on the whole herd. Milk production is recorded and the samples are analyzed for fat, protein and somatic cell count (SCC) and linear score (LS). This information can also be found in Dairy Comp 305 (Figure 3-3). This was used to calculate average somatic cell count in the sampled pens over the study period. Farm A discontinued enrollment in DHIP in August 2006, so SCC records from Farm A were no longer available.

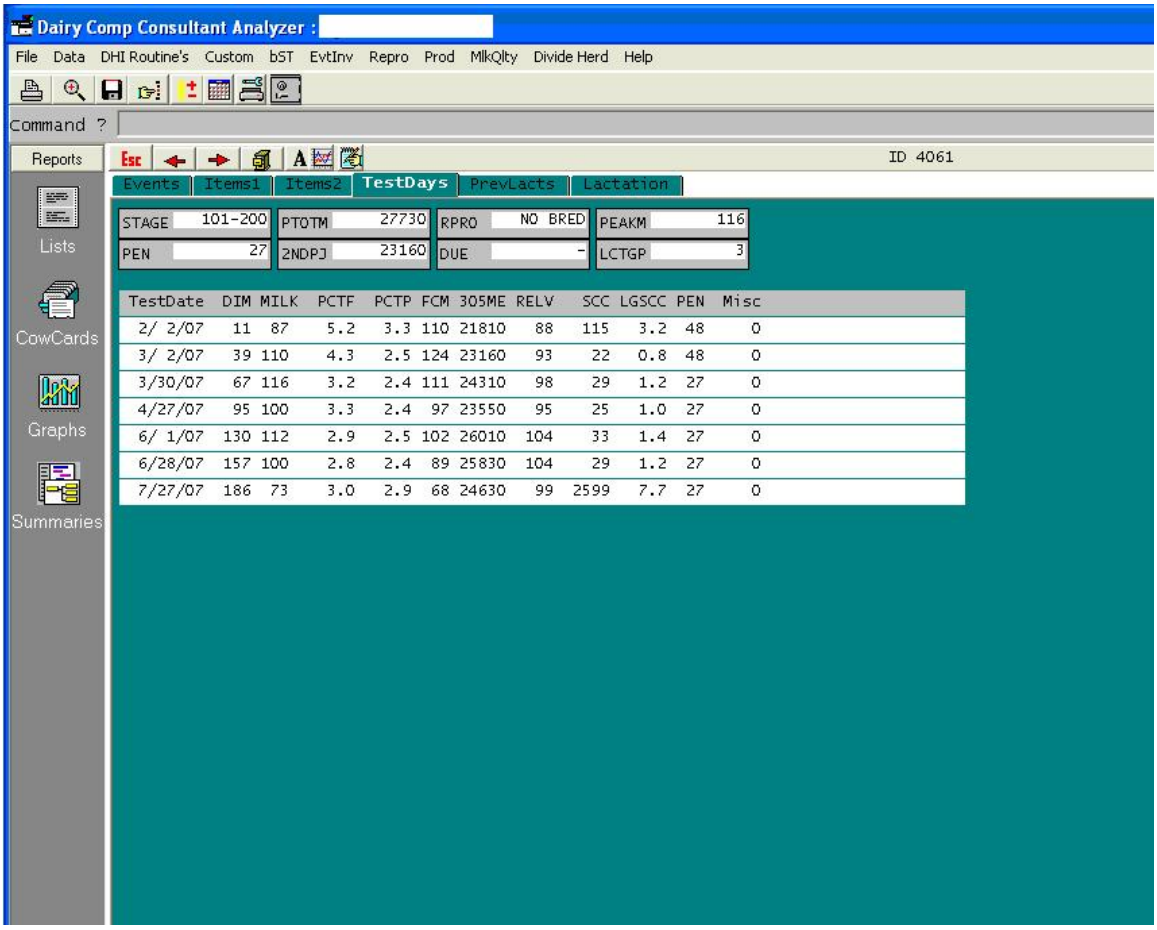



**Figure 3-3: Sample Test Days Page for Dairy Comp 305.**

Linear score is another measurement of SCC that is less variable than raw SCC. It is calculated based on the raw values, and each doubling of raw values increases the linear score by 1. Table 3-2 shows the relationship between SCC and LS. A linear score greater than 4 (200,000 SCC) indicates a possible intramammary infection.

**Table 3-2: Relationship Between Somatic Cell Count and Linear Score**

| Linear Score | Somatic Cell Count |
|---|---|
| 1 | 25,000 |
| 2 | 50,000 |
| 3 | 100,000 |
| 4 | 200,000 |
| 5 | 400,000 |
| 6 | 800,000 |

**Historical Farm Records**

Dr. Robert Everett, Animal Science professor at Cornell University, has access to DHIP records going back to the year 2000. He was able to pull out all of the DHIP records since that time for each of the farms on the study and put them into an excel file. These records include average milk production and linear score (LS) for the whole milking herd at each farm. In addition, he extracted a file with average milk production and linear score for the milking herd at 65 New York State Dairy farms that have a current herd size of between 750 and 2000 cows for the same time period.

**Lameness Scoring**

Lameness scoring was done twice at Farm E (4/25/07 and 5/22/07) on cows in the pen bedded with DMS from the separator and cows in the pen bedded with sand. Lameness scores are reported on a 1-4 scale. A score of 1 is normal: the cow stands and walks with a flat back, 2 is mildly lame: the cow stands with a flat back and arches when she walks, 3 is moderately lame: the cow stands and walks with an arched back and takes short strides on one or more leg, and 4 is lame: the cow stands and walks with an arched back, and one or more limbs are physically lame or non-weight bearing.

**Mass Nutrient Balance Data**

Caroline Rasmussen, Research Support Specialist with the Cornell Nutrient Management Spear Program, collected mass nutrient balance data on the six farms participating in the study. The Mass Nutrient Balance assessment is designed to measure the effectiveness of the farm's current nutrient management program and highlights areas of concern or improvement. It tracks the percent of nitrogen, phosphorus, and potassium that comes on to and off of the farm and in what manner.

Typically, more nutrients come onto farms as purchased feedstuffs and fertilizer than leave the farm as animal products and crops. An assessment of the nutrients entering and leaving the farm can be used to target farm practices that could be more efficient, thereby, potentially increasing farm profitability and decreasing nutrient losses. Each farm received a nutrient analysis of their farm.

**Economic Analysis**

An economic analysis assessing variables affecting the use of using DMS as bedding was performed by A. Edward Staehr, Extension Associate in the Department of Applied Economics and Management at Cornell University. He collected the information related to using DMS as bedding at five of the six farms that participated in the study: The annual cost per hundred weight of milk of using DMS was then calculated based on the information collected.

**STATISTICAL ANALYSIS**

Statistical analysis was performed using analysis of variance (ANOVA) for multiple comparisons with Tukey corrections, multiple linear regression, logistic regression and/or Poisson regression using the JMP statistical package. The analysis was run on a natural log transformation of the bacterial counts, and actual values of all other variables to help normalize the data. All of the analyses were performed with bacterial counts calculated on volume basis (log cfu/ml). To convert bacterial counts to cfu/ml, the anti-log of the value must be taken. Therefore, if there are 7.9 log cfu/ml *Streptococcus*, that is equivalent to $e^{13.8}$ = 1,000,000 cfu/ml.

ANOVA analysis measures the mean value of a response variable (i.e. bacterial concentration) for each predictor variable (i.e. farm/bedding strategy) and compares it to the variation of the mean response within each predictor. If the between-variable variation is large and the within-variable variation is small, a significant difference is concluded. ANOVA analysis, in this case, would tell whether or not farm/bedding strategy (predictor) has a significant effect on bacterial concentrations in bedding (response). Multiple comparisons with Tukey corrections compares the response for each possible combination of predictors to indicate which ones are significantly different from each other. For example, ADrum could have significantly higher levels of *Klebsiella* in the used bedding than FSeparated, but significantly lower levels than ESand.

Linear regression differs from the ANOVA analysis as it examines the relationship between the predictor (i.e. cfu/ml of *Streptococcus* in unused bedding) and response variable (i.e. cfu/ml of *Streptococcus* in the used bedding). It does not treat each predictor variable as a distinct point (as in the ANOVA), but considers the trend and measures whether the change in the response variable as the predictor variable changes is different from zero (i.e. as the number of cfu/ml of *Streptococcus* increases in the unused bedding, the amount of *Streptococcus* in the used bedding increases, decreases or remains the same).

Linear regression produces an equation in the form of:

$y = mx + b$, where

- y = the response variable
- m = the slope of the line (i.e. the amount by which the y-level changes)
- x = the predictor variable, and
- b = the y-intercept (i.e. the level of y at time 0).

An $r^2$ value is also generated, which indicates how well correlated the x variable (predictor) is with the y-value (response). In the example above, it would tell how much of the variation in *Streptococcus* in the used bedding is due to the cfu/ml of *Streptococcus* in the unused bedding. R-square values closer to 1 are a better fit.

Multiple linear regression is the same as linear regression, only it uses multiple predictor (x) variables. The equation would include additional values of $mx_1$, $mx_2$, etc for each predictor that has an effect on the response. The r-square value relates to how well all of the predictor variables together explain the change in the response variable.

Logistic regression measures the log odds of some response occurring based on a set of predictor variables. For example, what are the log odds of having an abnormal cell count (> 200,000 cells/ml) based on the FBS. The results are given as a number that represents the log odds of the event. The anti-log of that number represents the actual odds of the event occurring. In the example above, if the log odds of having an abnormal cell count for BWindrow versus DSeparated were -0.82, then the odds of having an abnormal cell count would be $e^{-0.82} = 0.44$. This means that it is estimated that the odds of having an abnormal cell count for BWindrow are 44% less than for DSeparated.

Poisson regression is used when the outcome is a count, with large-count outcomes being rare events. For example, the number of mastitis events occurring based on the stage of lactation of the cows. Since the number of animals in the pens being studied at each farm and at each sampling differed, number of animals was used as an offset variable for these regressions. The offset variable transforms the model into a model of rates (i.e. number of mastitis events per number of cows) and helps to equalize the data between FBS. The results are given as the difference in response between a specified level and the average of all other levels. In the example above, if the result for cows in early lactation versus mid lactation is -1.2, that means that the difference in log mean mastitis events between early and mid lactation is -1.2.This difference can then be converted to an estimate of the ratio of incidence by taking the anti-log. In this case, cows in early lactation are estimated to have $e^{-1.2} = 0.3$ or 30% of the number of mastitis events as those in mid lactation.

## SECTION 4

## RESULTS

### BACTERIAL COUNTS IN BEDDING

**By Farm/Bedding Strategy**

**Unused bedding.** There were no significant differences between the farm/bedding strategies (FBS) in the levels of *Staphylococcus* species, *Enterobacter*, and *Proteus* in the unused bedding (Table 4-1). FSeparated was the only FBS that had any molds in their unused bedding, so they had significantly more molds than any other FBS. ESand bedding started out "cleaner" than the three separated FBS, but the same as the other DMS bedding systems in respect to the rest of the bacteria analyzed. *Streptococcus* and gram negative bacteria were significantly lower in ESand FBS than all other FBS except EDrum and ESand had significantly lower levels of gram positive bacteria than all other FBS. *Escherichia coli* and *Klebsiella* levels were the same in ADrum, BWindrow, CDigested, EDrum and ESand FBS. All FBS had the same amount of *Corynebacterium* in the unused bedding, except DSeparated, which had significantly higher levels than ADrum, BWindrow, EDrum and ESand.

**Table 4-1: Average Bacterial Levels in Unused Bedding in each Farm/Bedding Strategy Over the Study Period on a Volume Basis (log cfu/ml).**

| | ADrum | BWindrow | CDigested | DSeparated | EDrum | ESand | ESeparated | FSeparated |
|---|---|---|---|---|---|---|---|---|
| *Streptococcus* | $7.0^{bc}$ | $7.2^{bc}$ | $12.0^{a}$ | $11.1^{ab}$ | $5.9^{cd}$ | $2.0^{d}$ | $9.9^{abc}$ | $12.5^{a}$ |
| *Staphylococcus* | $0.0^{a}$ | $0.0^{a}$ | $0.4^{a}$ | $0.5^{a}$ | $0.0^{a}$ | $0.8^{a}$ | $0.8^{a}$ | $0.0^{a}$ |
| *E. coli* | $0.0^{c}$ | $0.0^{c}$ | $0.5^{bc}$ | $2.7^{ab}$ | $0.0^{bc}$ | $0.0^{c}$ | $0.7^{bc}$ | $3.8^{a}$ |
| *Klebsiella* | $0.0^{c}$ | $1.0^{bc}$ | $1.1^{bc}$ | $4.7^{a}$ | $0.6^{bc}$ | $0.0^{c}$ | $3.8^{ab}$ | $3.9^{ab}$ |
| *Enterobacter* | $0.0^{a}$ | $0.0^{a}$ | $0.0^{a}$ | $0.6^{a}$ | $0.0^{a}$ | $0.0^{a}$ | $0.2^{a}$ | $0.4^{a}$ |
| *Proteus* | $0.0^{a}$ | $0.5^{a}$ | $1.4^{a}$ | $1.7^{a}$ | $0.0^{a}$ | $0.0^{a}$ | $0.9^{a}$ | $0.4^{a}$ |
| Gram negative | $12.0^{a}$ | $8.6^{ab}$ | $10.7^{ab}$ | $10.8^{a}$ | $6.6^{bc}$ | $3.2^{c}$ | $10.0^{ab}$ | $10.5^{ab}$ |
| Gram positive | $13.7^{a}$ | $12.2^{ab}$ | $12.0^{ab}$ | $12.1^{ab}$ | $10.4^{b}$ | $6.9^{c}$ | $12.6^{ab}$ | $12.9^{ab}$ |
| *Corynebacterium* | $0.9^{b}$ | $1.1^{b}$ | $3.9^{ab}$ | $5.5^{a}$ | $0.6^{b}$ | $0.5^{b}$ | $3.7^{ab}$ | $4.3^{ab}$ |
| Molds | $0.0^{b}$ | $0.0^{b}$ | $0.0^{b}$ | $0.0^{b}$ | $0.0^{b}$ | $0.0^{b}$ | $0.0^{b}$ | $1.6^{a}$ |

Values in each row with different letters are significantly different.

**Used bedding.** In the used bedding, there were no significant differences in the levels of *E. coli*, *Enterobacter*, *Proteus* and molds between any FBS (Table 4-2). *Streptococcus* levels were significantly higher in ESand used bedding than in all other FBS except BWindrow and DSeparated. ESand and EDrum FBS had significantly higher levels of *Staphylococcus* and gram negative bacteria than FSeparated. *Klebsiella* (which was not found in unused ADrum) was found in significantly higher levels in that system

than in BWindrow, CDigested, ESand and FSeparated. Although ESand started out "cleaner", used bedding in the ESand FBS had significantly higher levels of other bacteria studied (except *Klebsiella*) than at least one, and in many cases, more than one FBS. In all cases (except *Streptococcus*), the three farm E systems did not differ in bacterial levels, indicating that it is more likely that bacterial levels in used bedding are a result of bacteria in the manure of the cow and how well stalls are cleaned, rather than how "clean" the bedding is when it is put in the stall. In addition, those systems that started out with "clean" bedding tended to have significantly higher levels of bacteria in used bedding indicating the bedding may have started out too clean (i.e. no competition from other bacteria).

**Table 4-2: Average Bacterial Levels in Used Bedding in each Farm/Bedding Strategy Over the Study Period on a Volume Basis (log cfu/ml).**

| Bacteria | ADrum | BWindrow | CDigested | DSeparated | EDrum | ESand | ESeparated | FSeparated |
|---|---|---|---|---|---|---|---|---|
| *Streptococcus* | $16.7^{b}$ | $16.8^{ab}$ | $16.5^{b}$ | $17.0^{ab}$ | $16.4^{b}$ | $17.4^{a}$ | $16.7^{b}$ | $16.7^{b}$ |
| *Staphylococcus* | $4.7^{a}$ | $0.8^{ab}$ | $3.4^{ab}$ | $3.3^{ab}$ | $5.4^{a}$ | $3.8^{a}$ | $2.5^{ab}$ | $0.3^{b}$ |
| *E. coli* | $3.8^{a}$ | $3.2^{a}$ | $6.7^{a}$ | $2.3^{a}$ | $5.8^{a}$ | $5.6^{a}$ | $2.9^{a}$ | $4.3^{a}$ |
| *Klebsiella* | $13.7^{a}$ | $9.8^{bcd}$ | $7.4^{d}$ | $12.8^{ab}$ | $12.3^{ab}$ | $10.4^{bcd}$ | $12.8^{ab}$ | $8.7^{cd}$ |
| *Enterobacter* | $5.4^{a}$ | $2.2^{a}$ | $3.9^{a}$ | $3.1^{a}$ | $0.6^{a}$ | $3.5^{a}$ | $3.3^{a}$ | $2.4^{a}$ |
| *Proteus* | $0.3^{a}$ | $0.0^{a}$ | $0.3^{a}$ | $1.9^{a}$ | $2.0^{a}$ | $0.4^{a}$ | $2.0^{a}$ | $0.6^{a}$ |
| Gram negative | $12.0^{ab}$ | $13.6^{a}$ | $9.9^{b}$ | $13.6^{a}$ | $12.5^{ab}$ | $13.2^{a}$ | $13.9^{a}$ | $12.7^{ab}$ |
| Gram positive | $16.1^{abc}$ | $15.8^{abc}$ | $14.8^{c}$ | $15.6^{bc}$ | $17.1^{ab}$ | $17.0^{a}$ | $16.1^{abc}$ | $15.1^{c}$ |
| *Corynebacterium* | $14.1^{ab}$ | $11.1^{b}$ | $13.2^{ab}$ | $13.1^{ab}$ | $13.4^{ab}$ | $15.2^{a}$ | $15.3^{a}$ | $12.9^{ab}$ |
| Molds | $0.8^{a}$ | $0.0^{a}$ | $0.8^{a}$ | $0.7^{a}$ | $0.0^{a}$ | $0.0^{a}$ | $0.0^{a}$ | $1.2^{a}$ |

Values in each row with different letters are significantly different.

**Seasonality**

Analysis of the seasonality of bacterial counts in unused and used bedding was performed on each of the farm/bedding systems as well as for all FBS together. The following months were used in determining the seasons:

- Spring: March, April and May
- Summer: June, July and August
- Fall: September, October and November
- Winter: December, January and February

**Unused bedding.** There were no significant seasonal differences in the levels of *Staphylococcus* species, *E. coli*, *Enterobacter*, gram negative bacteria, or molds in the unused bedding for any of the farm/bedding systems. Table 4-3 shows the seasonality of the levels of other bacteria in the unused bedding that showed some significant difference between seasons. Spring appears to be the season in which bacterial levels are

higher in unused bedding in the few instances when there is a significant difference. *Streptococcus* levels in unused bedding were significantly higher in the spring for most farm/bedding systems, but were higher in the winter than the spring for ESand. *Klebsiella, Proteus* and gram positive bacteria were higher in the spring for all farm/bedding systems that showed seasonality. *Corynebacterium* did not show a clear pattern.

**Table 4-3: Seasonality of Bacterial Levels in Unused Bedding for each FBS and All Farms Together on a volume basis.**

| Code | *Streptococcus* | *Klebsiella* | *Proteus* | Gram Positive Bacteria | *Corynebacterium* |
|---|---|---|---|---|---|
| ADrum | SP=W>SU | NA | NA | NS | NS |
| BWindrow | SP=W>SU | NS | NS | NS | NS |
| CDigested | NS | NS | NS | NS | NS |
| DSeparated | SP>SU | NS | SP>SU=F=W | NS | SP>SU=W |
| EDrum | NS | NS | NA | SP>F | NS |
| ESand | W>SP=SU | NA | NA | NS | NS |
| ESeparated | SP>W>SU | SP>SU=W | SP>SU=F=W | SP>W | F>=SU=W |
| FSeparated | NS | NS | NS | SP>F | SU>F=W |
| All Farms | SP=F=W>SU | SP>SU | SP>F | SP>SU=F | NS |

SP = Spring, SU = Summer, F = Fall, W = Winter, NS = not significant, NA = not applicable

**Used bedding.** Although spring levels of bacteria in unused bedding were highest, summer had higher levels in the used bedding (Table 4-4). *Staphylococcus, E. coli, Klebsiella, Enterobacter* and *Corynebacterium* were all highest in used bedding in the summer, while *Streptococcus* levels were highest in the spring. Gram negative and gram positive bacterial showed no clear pattern.

**Table 4-4: Seasonality of Bacterial Levels in Used Bedding for each FBS and All Farms Together on a volume basis.**

| Code | *Streptococcus* | *Staphylococcus* | *E. coli* | *Klebsiella* | *Enterobacter* | Gram Negative | Gram Positive | *Corynebacterium* |
|---|---|---|---|---|---|---|---|---|
| ADrum | NS | NS | SP>F=W | SU>F=W>SP | SU>F>W | NS | NS | SU=F>SP |
| BWindrow | NS | NS | SU>=F=W | SU=F=W>SP | NS | F=W>SP=SU | SP>SU=W | SU=F>W |
| CDigested | F>SP=SU | NS | NS | SU=F>SP | NS | NS | NS | F=SU>SP |
| DSeparated | SP>SU | NS | SU>SP=F=W | SU=F=W>SP | NS | SU=F=W>SP | NS | W>SP=SU=F |
| EDrum | SP>SU | SU>SP=F | NS | NS | NS | NS | SP>SU | SU=F>SP |
| ESand | SP=F=W>SU | NS | NS | F>SP | F>SP | NS | NS | SU=F>SP |
| ESeparated | NS | F>W | NS | SU=F>W | W>SP=SU | NS | SU=W>F | SU>SP=F=W |
| FSeparated | NS | NS | NS | SU=F=W>SP | SU>F | NS | NS | NS |
| All Farms | SP=F>SU | SU>SP=F=W | SU>SP=F=W | SU=F=W>SP | SU>SP | NS | NS | SU=F>SP=W |

SP = Spring, SU = Summer, F = Fall, W = Winter, NS = not significant

**EFFECT OF BACTERIAL COUNTS OF UNUSED BEDDING ON COUNTS IN USED BEDDING**

Data were analyzed to address the question on whether the cleanliness of the unused bedding has an effect on the bacterial population of the used bedding. That is, will lower bacterial counts in the unused bedding necessarily lead to lower bacterial counts in the used bedding? Multiple linear regression was performed on the effect of bacterial counts in unused bedding on the counts in used bedding. Table 4-5 shows the results. One would expect that if the bacterial content of the unused bedding determined the levels in the used, it would be the same bacteria (i.e. more *E. coli* in the unused would produce more *E. coli* in the used). However, Table 4-5 shows that this is only the case for *Staphylococcus, Klebsiella* and *Proteus*. *Staphylococcus* levels in used bedding are positively correlated with *Staphylococcus* and *Corynebacterium*, and negatively correlated with *Streptococcus* levels in the unused bedding. That is, one could lower the levels of *Staphylococcus* in used bedding by lowering levels of *Staph* and *Corynebacterium* and increasing levels of *Strep* in the unused bedding. Similarly, decreasing levels of *Klebsiella* and increasing levels of molds in unused bedding would allow for lower levels of *Klebsiella* in used bedding. However, r-square

values for both of these indicate that the levels of these bacteria in the used bedding are due only 18 and 29% to the levels of the bacteria in the unused bedding. The best fit (r-square = 0.51) is for levels of gram negative bacteria in the used bedding. In this case, if *Enterobacter* and *Proteus* levels in the unused bedding were increased, then gram negative bacteria in the used bedding would decrease. These data suggest that other factors besides the bacterial level of the unused bedding have an impact on bacterial levels in used bedding.

**Table 4-5: Effect of Bacterial Counts of Unused Bedding on Counts in Used Bedding**

| Bacteria in Used Bedding (Y) | Multiple Linear Regression Equation (all x variables are in unused bedding) | p-value | r-square |
|---|---|---|---|
| *Streptococcus* (vol) | Y= 16.9 – 0.1* gram negative bacteria + 0.1* gram positive bacteria | 0.0011 | 0.1943 |
| *Staphylococcus* (vol) | Y = 8.6 – 0.5* *Streptococcus* + 0.6* *Staphylococcus* + 0.3* *Corynebacterium* | 0.0049 | 0.1860 |
| *E. coli* (vol) | Y = 7.5 – 0.9* molds | 0.0372 | 0.0661 |
| *Klebsiella* (vol) | Y = 11.7 + 0.2* *Klebsiella* – 1.0* molds | <.0001 | 0.2928 |
| *Enterobacter* (vol) | Y = 5.4 + 0.5* *E. coli* – 0.9* molds | 0.0080 | 0.1420 |
| *Proteus* (vol) | Y = 2.2 + 0.7* *Enterobacter* + 0.4* *Proteus* – 0.2* *Corynebacterium* | 0.0010 | 0.2286 |
| Gram Negative (vol) | Y= 14.1 – 0.5* *Enterobacter* – 0.3* *Proteus* | <.0001 | 0.5138 |
| Gram Positive (vol) | Y = 17.6 – 0.1* gram negative bacteria – 0.1* *Corynebacterium* | <.0001 | 0.2632 |
| *Corynebacterium* (vol) | Y = 14.5 – 0.5* *Proteus* | 0.0392 | 0.0647 |
| Molds (vol) | Y = 0.9 + 0.5* *E coli* – 0.6* *Enterobacter* | 0.0035 | 0.1645 |

**BEDDING PROPERTIES**

Bedding (both unused and used) was analyzed for % moisture, % organic matter (OM) and particle size. It has been suggested in the literature that with more moisture and more organic matter, bacterial populations thrive. It has also been suggested that the amount of fine particles in the bedding has an effect on bacterial populations on the teat ends (the finer the material, the more likely it will stick to the teat ends, and therefore there will be a higher population of bacteria on the teat ends). This is hypothesized to, in turn, cause more mastitis. Therefore, particle size was analyzed as % of particles < 2 mm and % of particles < 0.84 mm. ANOVA with multiple comparisons were run on the properties of bedding between each FBS and are presented below.

**Unused Bedding**

There were significant differences between farm/bedding systems for all of the bedding properties analyzed (Table 4-6). As expected, moisture and OM in the unused bedding were significantly lower in ESand than any other FBS. Fine particles in the unused bedding were expected to be higher in ESand, however, ADrum, EDrum, DSeparated and ESeparated consisted of the same amount of particles less then 2mm as ESand, and ADrum, EDrum and ESeparated had the same amount of particles less than 0.84 mm as did ESand.

Moisture among the unused DMS bedding ranged between 64 and 73% with ADrum producing the driest bedding among DMS and BWindrow and FSeparated producing the wettest. Organic matter ranged from 86 to 93% with CDigested and FSeparated having the lowest and ADrum, BWindrow, DSeparated and ESeparated producing the highest. Particles less than 2mm were significantly lower in the FSeparated bedding than in any other FBS. These differences may indicate that it is the type and efficiency of the separator being used on the farm that determines the properties of the unused bedding.

**Table 4-6: Properties of Unused Bedding for each Farm/Bedding System**

| FBS | % Moisture | % OM | % Particles < 2 mm | % Particles < 0.84 mm |
|---|---|---|---|---|
| ADrum | 63.7$^{c}$ | 92.7$^{a}$ | 74.3$^{a}$ | 36.8$^{a}$ |
| BWindrow | 72.7$^{a}$ | 92.5$^{a}$ | 37.9$^{b}$ | 6.7$^{c}$ |
| CDigested | 69.9$^{ab}$ | 85.7$^{b}$ | 36.2$^{b}$ | 8.3$^{bc}$ |
| DSeparated | 68.6$^{abc}$ | 91.3$^{a}$ | 46.2$^{ab}$ | 13.2$^{bc}$ |
| EDrum | 65.9$^{bc}$ | 90.3$^{ab}$ | 59.0$^{ab}$ | 20.9$^{abc}$ |
| ESand | 11.3$^{d}$ | 0.8$^{c}$ | 70.3$^{a}$ | 24.2$^{ab}$ |
| ESeparated | 67.5$^{abc}$ | 90.7$^{a}$ | 70.5$^{a}$ | 20.7$^{abc}$ |
| FSeparated | 72.7$^{a}$ | 86.7$^{b}$ | 31.2$^{b}$ | 5.9$^{d}$ |

Values in each column with different letters are significantly different

**Used Bedding**

Table 4-7 shows the properties of the used bedding for each of the farm/bedding systems. As with the unused bedding, moisture and OM in the used bedding were significantly lower in ESand bedding than any other FBS. The addition of feces increased the amount of OM in the sand bedding. One would have expected the OM to increase in the DMS systems with the addition of fecal matter, but it did not. All of the FBS except ESand showed about 3% less OM in the used bedding versus the unused, except in EDrum and ESeparated that showed 10% less OM in the used. Moisture ranged from 29 to 60% in used DMS bedding with moisture being higher in those systems that used deep beds (DSeparated and FSeparated) than those that used mattresses (ADrum and CDigested). This is likely due to those using mattresses spreading the DMS in a 2” layer on top of the mattresses thus allowing it to dry out. BWindrow, which used mattresses,

did not have lower moisture in the used bedding than those using deep beds, but bedding there was changed daily and may not have had a chance to dry out. Fine particles were significantly higher in ESand bedding than any FBS, and tended to be lower in farm/bedding systems that used deep beds versus those that used mattresses. This may be because DMS in deep beds tends to mat together from the weight of the cow, while the DMS on the mattresses tends to either fall off, or spread out.

**Table 4-7: Properties of Used Bedding for each Farm/Bedding System**

| FBS | % Moisture | % OM | % Particles < 2 mm | % Particles < 0.84 mm |
|---|---|---|---|---|
| ADrum | 43.7$^{cd}$ | 87.2$^{ab}$ | 66.6$^{b}$ | 41.0$^{b}$ |
| BWindrow | 50.0$^{bc}$ | 91.7$^{a}$ | 66.8$^{b}$ | 31.4$^{bc}$ |
| CDigested | 28.5$^{e}$ | 83.3$^{bc}$ | 52.4$^{d}$ | 30.1$^{c}$ |
| DSeparated | 55.1$^{ab}$ | 86.6$^{ab}$ | 62.2$^{bc}$ | 31.6$^{bc}$ |
| EDrum | 42.5$^{d}$ | 79.6$^{c}$ | 54.0$^{cd}$ | 32.3$^{bc}$ |
| ESand | 6.4$^{f}$ | 3.2$^{e}$ | 82.1$^{a}$ | 73.5$^{a}$ |
| ESeparated | 49.2$^{bcd}$ | 71.2$^{d}$ | 60.1$^{bcd}$ | 31.6$^{bc}$ |
| FSeparated | 60.0$^{a}$ | 83.5$^{bc}$ | 42.4$^{e}$ | 19.6$^{d}$ |

Values in each column with different letters are significantly different

**COUNTS ON TEAT ENDS**

Teat swabs were taken at Farm E on three separate occasions on the cows in the pen bedded with DMS from the separator and the pen bedded with sand. These data were analyzed to determine if cows bedded on DMS have more bacteria on their teat ends than those bedded with sand, and whether the bacterial levels in the bedding had an effect on the bacterial levels on the teat ends. Ultimately, the important question is whether there was an effect on SCC and mastitis.

**Comparison of DMS versus Sand**

Analysis of the difference between bacterial counts on the teat ends of cows bedded on DMS versus cows bedded on sand was done using ANOVA and student's t-test in the JMP statistical system (Table 4-8). There were no significant differences between levels of *Staphylococcus, E. coli, Enterobacter, Corynebacterium* or molds on the teat ends of cows bedded on DMS or sand. Cows in the sand pen had significantly lower levels of *Streptococcus, Klebsiella,* gram negative and gram positive bacteria on their teat ends than did cows bedded on DMS from the separator.

Teat swabs were taken once in the fall, once in the winter, and once in the spring. Analysis of seasonality of bacterial levels on teat ends that differed between DMS and sand bedded cows showed that *Streptococcus* levels were significantly higher in the DMS pen in all three seasons; and in the sand pen in the fall, than in the sand pen in the winter. *Klebsiella* levels were higher in the fall in the DMS pen than in the winter in the

DMS pen and all seasons in the sand pen. Gram positive levels were significantly higher in the spring (for both DMS and sand pens) and the winter in the DMS pen, than in the fall for both DMS and sand bedded cows. There were no seasonal differences in gram negative bacteria levels.

**Table 4-8: Average Levels of Bacteria on the Teat Ends of Cows Bedded on DMS and Sand (log cfu)**

| Bacteria | DMS | Sand |
|---|---|---|
| *Streptococcus* | 8.0[a] | 7.1[a] |
| *Staphylococcus* | 4.2[a] | 4.0[a] |
| *E. coli* | 0.5[a] | 0.8[a] |
| *Klebsiella* | 2.1[a] | 0.7[b] |
| *Enterobacter* | 0.4[a] | 0.2[a] |
| Gram Negative | 5.9[a] | 3.1[b] |
| Gram Positive | 7.1[a] | 6.5[b] |
| *Corynebacterium* | 6.0[a] | 5.3[a] |
| Molds | 0.2[a] | 0.1[a] |

Values in each row with different letters are significantly different

**Table 4-9: Average Levels of Bacteria on the Teat Ends of Cows Bedded on DMS and Sand by Season (log cfu)**

| | DMS | | | Sand | | |
|---|---|---|---|---|---|---|
| Bacteria | Spring | Fall | Winter | Spring | Fall | Winter |
| *Streptococcus* | 8.2[a] | 7.6[a] | 8.2[a] | 7.8[a] | 7.4[ab] | 6.1[b] |
| *Klebsiella* | 1.6[ab] | 3.6[a] | 1.1[b] | 0.9[b] | 1.1[b] | 0.0[b] |
| Gram negative | 5.4[ab] | 6.6[a] | 5.4[ab] | 3.3[bc] | 3.8[bc] | 2.2[c] |

**Effect of Properties and Bacterial Counts of Bedding on Teat End Bacterial Counts**

Multiple linear regression was performed on the effect that the properties and bacterial counts of used bedding had on the bacterial counts on the teat ends of cows. The predictor variables used were the physical properties of used bedding (i.e. moisture, OM, percent of fine particles), and bacterial levels in used bedding (i.e. cfu/ml *Streptococcus*, *E. coli*, *Klebsiella*, gram negative bacteria and *Corynebacterium*). A natural log transformation of the bacterial counts was performed to help normalize the data. Table 4-10 shows the results. In all cases, the r-square value is below 0.43 indicating that the level of bacteria on the teat ends is due 43% or less to the characteristics of the used bedding. The percent of fine particles in the used bedding had a significant effect (either by itself, or in conjunction with other bedding properties and/or bacteria) on the level of bacteria found on the teat ends for 4 of the 8 bacteria analyzed. However, it did not behave as expected (more fine particles, less bacteria on the teat ends). *Streptococcus*,

*Staphylococcus* and *Enterobacter* levels all decreased when the percent of fine particles increased in the used bedding. Bacterial levels in the used bedding had an affect on several bacterial levels on teat ends, but only in the case of *Klebsiella* were they the same bacteria (increasing *Klebsiella* levels in the bedding caused increased *Klebsiella* levels on teat ends).

**Table 4-10: Effect of Bacterial Counts (cfu/ml) and Properties of Bedding on Bacteria Counts on the Teat Ends of Cows**

| Bacteria on Teat Ends (Y) | Multiple Linear Regression Equation | p-value | r-square |
|---|---|---|---|
| *Streptococcus* | Y = 11 – 0.04* fine particles < 0.84 mm | 0.0001 | 0.1184 |
| *Staphylococcus* | Y = 27 – 0.1*moisture – 0.1*fine particles < 0.84 mm – 1.0**Streptococcus* | 0.0049 | 0.1047 |
| *E. coli* | Nothing significant | | |
| *Klebsiella* | Y = -9 + 0.8**Klebsiella* | <.0001 | 0.1624 |
| *Enterobacter* | Y = 11 + 0.1*moisture – 0.1*OM – 0.03*fine particles < 0.84 mm – 0.6*gram negative | 0.0070 | 0.0601 |
| Gram Negative | Y = 6 – 1.5*gram negative + 1.6**Klebsiella* | <.0001 | 0.2511 |
| Gram Positive | Y = 7 + 0.8**Streptococcus* – 0.8**Corynebacterium* | <.0001 | 0.3121 |
| *Corynebacterium* | Y = 86 – 2.7**Streptococcus* – 0.8*fine particles < 2 mm + 0.4*fine particles < 0.84 mm | <.0001 | 0.4303 |

**Effect of Teat End Bacterial Counts on SCC and Mastitis**

SCC and mastitis incidence on animals for which teat swabs were taken were analyzed using logistic and Poisson regression with the JMP statistical analysis package. Logistic regression measures the log odds of some response occurring based on a set of predictor variables. For example what are the log odds of having abnormal SCC based on the pen in which the cow was housed. Poisson regression is used when the outcome is a count, with large-count outcomes being rare events. For example, the number of times the cows in each pen get mastitis.

It has been generally accepted that the cell count for "normal" milk is nearly always less than 200,000 cells/ml for multiparous (2$^{nd}$ or greater lactation) cows. Higher counts are considered abnormal and indicate probable infection. Therefore individual cow SCC was divided into two categories; those cows with less than or equal to 200,000 cells/ml (normal) and those cows with > 200,000 cells/ml (abnormal).

There were 18 of 57 cows in the DMS pen with an abnormal SCC, and 22 of 60 in the sand pen. Logistic regression was run to see if the odds of getting an abnormal cell count was different than getting a normal cell count based on pen (sand or DMS bedding), season (fall, winter or summer), lactation (a=2$^{nd}$, b=3$^{rd}$ or

greater) and stage of lactation (early=0 to 60, mid=61 to 200, late=greater than 200 days in milk), as well as the amount of *Streptococcus*, *E. coli*, *Klebsiella*, gram negative bacteria and *Corynebacterium* on the teat ends. The results are shown in Table 4-11. All of the indicator variables fall out of the model except the levels of *Streptococcus* and gram negative bacteria on the teat ends. The estimate for *Streptococcus* and gram negative bacteria on the teat ends is interpreted as the log odds of having an abnormal cell count when the level of bacteria increases by 1 log cfu/ml (i.e. 2.7 cfu/ml). In the case of *Streptococcus*, this means that for each log cfu increase, the odds of having an abnormal SCC increase by $e^{0.48} = 1.6$ times. For gram negative bacteria, since the estimate is negative, for each log cfu increase, the odds of having an abnormal SCC decrease by $e^{0.18} = 1.2$ times. However, Poisson regression yielded no variables as having a significant effect on the number of animals with abnormal SCC.

**Table 4-11: Logistic Regression Results for the Log Odds of Having an Abnormal Cell Count**

| Term | Log odds | Odds ratio | p-value |
|---|---|---|---|
| log *Streptococcus* | 0.48 | 1.6 | 0.0037 |
| log gram negative bacteria | -0.18 | 1.2 | 0.0285 |

There were 7 cows that got mastitis within one month of when the teat swabs were taken. Two of the seven were in the sand pen and both of them occurred in the winter. The other 5 were in the DMS pen with 1 occurring in the fall, 2 in the winter, and 2 in the spring. Both logistic and Poisson regression failed to show any of the variables as significantly affecting the number of mastitis incidences for these cows.

**TEAT END SCORES**

Mastitis pathogens enter the teat canal through the opening in the teat end. Part of the teat end barrier to the entrance of mastitis pathogens are the keratin cells that line the teat canal. These keratin cells have a sticky, or adhesive property that enable them to stop pathogens from completely penetrating the teat canal. If too much keratin is produced, it can form projections, or fronds and/or a ring around the teat opening. If this hyperkeratosis becomes severe, it may be associated with an increase in both non-clinical and clinical mastitis. Trained QMPS technicians scored the teat ends of the cows in the study pens for two characteristics. The first characteristic was the amount of keratinization, and the second was whether the teat end was cracked or not. The scoring system for keratinization ranged from 0 to 4, with 4 having the most callous tissue and 0 having none. A half point (0.5) was added to each whole number score if cracks were present. For example, a teat with moderate callosity and cracks would have been given a score of 2.5, where a teat with high callosity and no crack would have been given a score of 4.0. Scores of > 2 would be considered to be at greater risk for entrance of mastitis pathogens. Having greater than 20% of the animals in the herd with teat end scores > 2 can indicate a problem.

Table 4-12 shows the scores for each FBS. Scores greater than 2.0 ranged between 20.4 and 38.8% of animals within each FBS. The only significant difference between the number of animals at each farm with a score greater than 2 was between CDigested and DSeparated. Therefore, differences in SCC and/or mastitis between the two could be attributed to the roughness and callosity of teat ends at DSeparated. All FBS had greater than 20% of animals with elevated teat end scores. Other variables that were looked at in regard to teat end scores were lactation number and stage of lactation. Heifers were less likely to have scores of > 2, and cows in early lactation were less likely than those in mid, late or extended lactation.

**Table 4-12: Percent of Animals at each FBS with a Teat End Score Greater than 2.0**

| FBS | % of animals |
|---|---|
| BWindrow | 28.8[ab] |
| CDigested | 20.4[b] |
| DSeparated | 38.8[a] |
| ESand | 35.9[ab] |
| ESeparated | 30.5[ab] |
| FSeparated | 29.5[ab] |

Values with different letters are significantly different

**UDDER HEALTH**

Udder health is measured by incidence of mastitis and SCC. One of the farms (ADrum) stopped using the Dairy Herd Improvement Program (DHIP) halfway through the study. DHIP was used to get records concerning SCC. Since SCC information was not available after August 2006 for ADrum, this farm/bedding system was not used in the analysis of udder health.

**Mastitis**

**All farms together.** Table 4-13 shows the number and percent of mastitis events over the course of the study for the cows in the pens from which the bedding samples were taken. Since EDrum was discontinued after September 2006, there is no data for winter. The animals were split into multiparous cows and heifers. There were no heifers in the study pens on Farms E and F. Logistic regression was run to see if the odds of getting mastitis was different based on FBS, season, lactation (only for multiparous animals), stage of lactation (early=0 to 60, mid=61 to 200, late=greater than 200 days in milk) and SCC (normal or abnormal) in that month. This analysis was run separately for cows and heifers. In addition, the split for normal/abnormal SCC for heifers is considered to be at 100,000 cell/ml rather than 200,000 cells/ml as in cows. The odds of getting mastitis for heifers was significantly affected by abnormal cell count only (Table 4-14), while the odds of getting mastitis for cows was significantly affected by FBS, season and abnormal cell count. The odds ratio of 2.3 for heifers means that the odds of getting mastitis when SCC is abnormal are 230% or 1.3 times greater than if SCC is normal.

**Table 4-13: Number of Mastitis Events and % of Animals in Study Pens over the Course of the Study**

| | Cows | | | | | | | | Heifers | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring | | Summer | | Fall | | Winter | | Spring | | Summer | | Fall | | Winter | |
| FBS | # | % | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| BWindrow | 10 | 14.7 | 13 | 18.8 | 17 | 19.3 | 20 | 20.0 | 1 | 1.4 | 5 | 5.4 | 9 | 5.7 | 6 | 4.5 |
| CDigested | 17 | 13.7 | 19 | 10.1 | 18 | 8.7 | 11 | 8.3 | 0 | 0.0 | 3 | 5.9 | 1 | 0.9 | 2 | 4.1 |
| DSeparated | 3 | 4.7 | 5 | 3.3 | 17 | 11.5 | 14 | 12.6 | 3 | 4.9 | 0 | 0.0 | 2 | 5.6 | 1 | 4.0 |
| EDrum | 6 | 5.9 | 7 | 3.5 | 2 | 2.0 | NA | NA | | | | | | | | |
| ESand | 11 | 3.7 | 8 | 4.0 | 7 | 2.5 | 6 | 2.4 | | | | | | | | |
| ESeparated | 18 | 9.8 | 7 | 3.6 | 23 | 7.5 | 13 | 5.0 | | | | | | | | |
| FSeparated | 30 | 12.7 | 10 | 4.4 | 9 | 4.0 | 7 | 3.5 | | | | | | | | |

**Table 4-14: Logistic Regression Results for the Log Odds of Getting Mastitis for Heifers**

| Term | Level 1 | Level 2 | Odds Ratio | p-value |
|---|---|---|---|---|
| SCC | Abnormal | Normal | 2.3 | 0.0235 |

**Farm E (side-by-side comparison).** Since FBS significantly affected number of mastitis events, and FBS includes other farm variables besides bedding, logistic regression was run on the number of mastitis events at Farm E to determine if cows bedded on composted DMS versus sand versus DMS directly from the separator on the same farm differed. The indicator variables that had a significant effect on mastitis events at Farm E were FBS and SCC (Table 4-15). The odds of getting mastitis were highest in the pens with cows bedded with DMS directly from the separator (0.7 and 1.1 times greater) than for cows bedded with composted DMS and sand, respectively. In addition the odds of cows bedded on sand getting mastitis were 0.8 times that of cows bedded on composted DMS. At Farm E, sand bedding allowed for lower mastitis events during the study period. In addition, cows at Farm E with abnormal SCC were 1.4 times more likely to get mastitis than those with normal SCC.

**Table 4-15: Logistic Regression Results for the Log Odds of Getting Mastitis for Farm E**

| Term | Level 1 | Level 2 | Odds Ratio | p-value |
|---|---|---|---|---|
| FBS | ESand | EDrum | 0.80 | 0.0018 |
| | ESeparated | EDrum | 1.7 | |
| | ESeparated | ESand | 2.1 | |
| SCC | Abnormal | Normal | 2.4 | <.0001 |

**Individual FBS.** Poisson regression was run on the number of mastitis events to determine which variables within each FBS had a significant effect on the number of animals with mastitis over the study period. The response variable was total number of mastitis events over the study period and the indicator variables were season, lactation number, stage of lactation, abnormal or normal cell count (SCC), unused and used bedding properties and bacteria (*Streptococcus*, *E. coli*, *Klebsiella*, gram negative bacteria and *Corynebacterium*), and average milk production per cow. Cows and heifers were run separately. Table 4-16 shows the results for cows. SCC was a significant variable for all FBS.

**Table 4-16: Poisson Regression Results for the Number of Mastitis Events for Cows within each FBS**

| Farm | Predictor Variables | Contrast | Diff in log mean | p-value |
|---|---|---|---|---|
| BWindrow | Stage of lactation | Early to mid | -1.2 | 0.0006 |
| | | Early to extended | NS | 0.3758 |
| | | Mid to extended | NS | 0.1140 |
| | Cell count | Abnormal to normal | 1.0 | 0.0002 |
| CDigested | Cell count | Abnormal to normal | 0.8 | 0.0035 |
| DSeparated | Cell count | Abnormal to normal | 1.8 | <.0001 |
| | Milk production | | 0.05 | <.0001 |
| Farm E | Cell count | Abnormal to normal | 1.0 | <.0001 |
| | Used moisture | | 0.08 | 0.0054 |
| | Used Fines2 | | 0.06 | 0.0215 |
| | Milk production | | 0.04 | 0.0043 |
| EDrum | Stage of lactation | Mid to late | NS | 0.2353 |
| | | Mid to extended | -1.7 | 0.0334 |
| | | Late to extended | -2.5 | 0.0078 |
| | Cell count | Abnormal to normal | 1.3 | 0.0153 |
| ESand | Nothing significant | | | |
| ESeparated | Cell count | Abnormal to normal | 0.6 | 0.0126 |
| FSeparated | Season | Spring to summer | 1.0 | 0.0010 |
| | | Spring to fall | 1.2 | 0.0003 |
| | | Spring to winter | 1.1 | 0.0035 |
| | | Summer to fall | NS | 0.7065 |
| | | Summer to winter | 0.02 | 0.0021 |
| | | Fall to winter | NS | 0.0841 |
| | Cell Count | Abnormal to normal | 0.9 | 0.0005 |

To estimate the ratio of incidence of mastitis for the categories within each variable, the antilog of the difference in log mean is calculated. For CDigested and ESeparated, cell count was the only significant variable. Cows at CDigested with an abnormal cell count were $e^{0.8} = 2.2$, 220% or 1.2 times more likely to have mastitis than those with a normal cell count, and for ESeparated they were 0.8 times more likely. For BWindrow, in addition to cell count (1.7 times more likely for cows with abnormal SCC), stage of lactation had a significant effect on the number of mastitis events over the course of the study. Cows in early lactation (0 to 60 DIM) with mastitis were 30% of the number of cows in mid lactation (61 to 200 DIM). There were no significant differences in the number of cows with mastitis between early and extended or mid and extended lactation. Cows with abnormal cell count at DSeparated were 1.7 times more likely to get mastitis than those with a normal cell count. Milk production also had an effect on the number of cows with mastitis at DSeparated. The average amount of milk produced was positively correlated with the number of cows with mastitis (i.e. higher milk production, more mastitis). Cows with abnormal cell counts at FSeparated were 1.5 times more likely to have mastitis than those with normal cell count. In addition, season was a significant variable. In the spring, cows were 1.7, 2.3 and 2 times more likely to have mastitis than in the summer, fall or winter, respectively, and in the summer, cows were just slightly more likely (0.02 times) to get mastitis than in the winter.

Since logistic regression showed that the odds of getting mastitis were significantly different between the three Farm E FBS, Poisson regression was run on all three systems together (Farm E results in Table 4-16). Poisson regression does not show FBS as a significant variable. Instead, the significant variables were cell count (1.7 times more likely for abnormal cell count than normal cell count), the amount of moisture and particles < 0.84 mm in the used bedding, and milk production (all positively correlated, meaning greater moisture and fine particles in used bedding, and greater milk production yielded more animals with mastitis). When each system within Farm E was run separately, cell count was the predominant significant variable.

Table 4-17 shows Poisson regression results for number of mastitis events in heifers for the three FBS that had heifers in the study. Only CDigested had any significant variables. Heifers in early lactation were 7% less likely to get mastitis than those in mid- lactation, and heifers with abnormal cell count were 12 times more likely to get mastitis than those with normal cell count.

**Table 4-17: Poisson Regression Results for the Number of Mastitis Events for Heifers within each FBS**

| Farm | Predictor Variables | Contrast | Diff in log mean | p-value |
|---|---|---|---|---|
| BWindrow | Nothing significant | | | |
| CDigested | Stage of lactation | Early to mid | -2.7 | 0.0117 |
| | Cell count | Abnormal to normal | 2.6 | 0.0031 |
| DSeparated | Nothing significant | | | |

**Somatic Cell Count**

**All farms together.** As stated previously, 200,000 cells/ml is considered "normal" for cows. That number is 100,000 for heifers. Therefore, individual SCC was divided into two categories for cows and heifers based on the number of cells/ml (i.e. 200,000 or less for cows, and 100,000 or less for heifers was considered normal, and greater than that was considered abnormal). Table 4-18 shows the number and percent of animals over the course of the study in the pens from which the bedding samples were taken that had an abnormal cell count. Since EDrum was discontinued after September 2006, there is no data for winter. The animals were split into multiparous cows and heifers. There were no heifers in the study pens on Farms E and F. Logistic regression was run to see if the odds of having an abnormal cell count was different based on FBS, season, lactation (only for multiparous animals) and stage of lactation (early=0 to 60, mid=61 to 200, late=greater than 200 days in milk). This analysis was run separately for cows and heifers. The odds of getting an abnormal cell count for heifers was significantly affected by FBS and season, while the odds of getting an abnormal cell count for cows was significantly affected by FBS, season, lactation and stage of lactation. The odds ratios of having an abnormal cell count for season, lactation and stage of lactation for cows is given in Table 4-19. Cows were least likely to have an abnormal cell count in winter, and more likely in spring and summer. The same was true for heifers. Cows in 2$^{nd}$ lactation were less likely to have an abnormal cell count than those in 3$^{rd}$ or greater lactation (i.e. the number of cows in 2$^{nd}$ lactation was 0.49 times that of 3$^{rd}$ or greater). As the number of days in milk increased, the odds of having abnormal SCC also increased. The number of cows with abnormal SCC in early lactation was 0.39, 0.26 and 0.12 times the number of cows in mid, late and extended lactation, respectively. Mid lactation cows were 0.66 and 0.31 times that of extended lactation cows, and late lactation cows were 0.48 times that of extended.

**Table 4-18: Number and of % of Animals in Study Pens with Abnormal Cell Count over the Course of the Study**

| | Cows | | | | | | | | Heifers | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring | | Summer | | Fall | | Winter | | Spring | | Summer | | Fall | | Winter | |
| FBS | # | % | # | % | # | % | # | % | # | % | # | % | # | % | # | % |
| BWindrow | 7 | 10.2 | 17 | 24.6 | 21 | 23.9 | 10 | 10.1 | 17 | 23.6 | 42 | 45.2 | 48 | 30.1 | 25 | 18.9 |
| CDigested | 17 | 12.7 | 31 | 16.4 | 31 | 15.0 | 7 | 5.3 | 19 | 51.4 | 19 | 37.2 | 21 | 18.4 | 8 | 16.3 |
| DSeparated | 19 | 29.7 | 82 | 53.9 | 96 | 64.8 | 65 | 58.6 | 29 | 47.5 | 1 | 33.3 | 12 | 33.3 | 9 | 36.0 |
| EDrum | 34 | 33.7 | 64 | 32.0 | 22 | 21.8 | NA | NA | | | | | | | | |
| ESand | 95 | 31.7 | 61 | 30.2 | 104 | 33.9 | 76 | 51.0 | | | | | | | | |
| ESeparated | 69 | 37.7 | 59 | 30.6 | 90 | 39.6 | 96 | 36.9 | | | | | | | | |
| FSeparated | 81 | 34.1 | 96 | 42.5 | 90 | 39.6 | 33 | 16.4 | | | | | | | | |

**Table 4-19: Logistic Regression Results for the Log Odds of Having an Abnormal Cell Count for Cows**

| Term | Level 1 | Level 2 | Odds Ratio | p-value |
|---|---|---|---|---|
| Season | Spring | Summer | 0.90 | 0.0009 |
| | Spring | Fall | 0.81 | |
| | Spring | Winter | 1.2 | |
| | Summer | Fall | 0.90 | |
| | Summer | Winter | 1.3 | |
| | Fall | Winter | 1.4 | |
| Lactation | 2nd | 3rd and greater | 0.49 | <.0001 |
| Stage of Lactation | Early | Mid | 0.39 | <.0001 |
| | Early | Late | 0.26 | |
| | Early | Extended | 0.12 | |
| | Mid | Late | 0.66 | |
| | Mid | Extended | 0.31 | |
| | Late | Extended | 0.48 | |

**Farm E (side-by-side comparison).** Since FBS significantly affected SCC, and FBS includes other farm variables besides bedding, logistic regression was run on the number of animals with abnormal cell count at Farm E to determine if cows bedded on composted DMS versus sand versus DMS directly from the separator on the same farm differed. All of the indicator variables, including FBS, fall out of the model except lactation (Table 4-20). The odds of having an abnormal cell count for 2nd lactation cows at Farm E were 0.44 times that of cows in 3rd or greater lactation.

**Table 4-20: Logistic Regression Results for the Log Odds of Having an Abnormal Cell Count for Farm E**

| Term | Level 1 | Level 2 | Odds Ratio | p-value |
|---|---|---|---|---|
| Lactation | 2nd | 3rd and greater | 0.44 | <.0001 |

Poisson regression was run on the number of animals with abnormal cell count to determine which variables within Farm E had a significant effect on the number of animals with abnormal cell count over the study. The response variable was total number of cows with abnormal SCC over the study period and the indicator variables were season, lactation number, stage of lactation, unused and used bedding properties and bacteria (*Streptococcus*, *E. coli*, *Klebsiella*, gram negative bacteria and *Corynebacterium*), and average milk production per cow. Table 4-21 shows the results. For all FBS within Farm E together, the variables which had an effect on the number of cows with abnormal milk production were lactation number and milk production. The number of cows in 2nd lactation that would be expected to have an abnormal cell count was 0.55 times that of cows in 3rd or greater lactation, and milk production was negatively correlated with SCC (i.e. greater milk production, lower number of cows expected to have abnormal SCC). For ESand and ESeparated by themselves, the only significant variable was lactation. The number of cows in 2nd lactation with abnormal cell count was 0.6 times that of 3rd and greater for both FBS. For the EDrum FBS, in addition to lactation number, milk production and the amount of *Klebsiella* in the used bedding were both negatively correlated with the number of cows expected to have abnormal SCC (i.e. greater milk production and more *Klebsiella* in the used bedding, fewer animals with abnormal SCC).

**Table 4-21: Poisson Regression Results for the Number of Cows with Abnormal Cell Count at Farm E**

| Farm | Predictor Variable | Contrast | Diff in log mean | p-value |
|---|---|---|---|---|
| Farm E | Lactation | 2nd to 3rd and greater | -0.59 | <.0001 |
| | Milk production | | -0.01 | 0.0310 |
| EDrum | Lactation | 2nd to 3rd and greater | -0.93 | <.0001 |
| | Milk production | | -0.07 | 0.0005 |
| | Used *Klebsiella* | | -0.42 | 0.0148 |
| ESand | Lactation | 2nd to 3rd and greater | -0.51 | <.0001 |
| ESeparated | Lactation | 2nd to 3rd and greater | -0.51 | <.0001 |

**Remaining Farms.** Poisson regression was run on the number of animals with abnormal cell count to determine which variables within each FBS had a significant effect on the number of animals with abnormal SCC over the study period. Cows and heifers were run separately. Table 4-22 shows the results for cows. SCC was a significant variable for all FBS. Season, lactation and milk production were the most common variables that had a significant effect on the number of animals with abnormal SCC within each

FBS. The number of cows expected to have abnormal SCC was lower in the spring than the summer or fall for BWindrow, and lower in the winter than the summer. For DSeparated, spring was expected to have fewer animals with abnormal SCC than all other seasons. Cows in 2nd lactation were expected to have fewer incidences of abnormal SCC at BWindrow and CDigested than those in 3rd and greater, and milk production was negatively correlated with number of cows with abnormal SCC for DSeparated and FSeparated. The only FBS where the properties of the bedding had an effect on the number of cows with abnormal SCC was at CDigested. The amount of moisture and particles < 2 mm in the used bedding were negatively correlated with the number of cows with abnormal SCC (i.e. higher moisture and more fine particles, fewer animals with abnormal cell count).

**Table 4-22: Poisson Regression Results for the Number of Cows with Abnormal SCC within each FBS**

| Farm | Predictor Variables | Contrast | Diff in log mean | p-value |
|---|---|---|---|---|
| BWindrow | Season | Spring to summer | -0.94 | 0.0272 |
| | | Spring to fall | -0.89 | 0.0309 |
| | | Spring to winter | NS | 0.8413 |
| | | Summer to fall | NS | 0.8569 |
| | | Summer to winter | 0.84 | 0.0301 |
| | | Fall to winter | 0.79 | 0.0342 |
| | Lactation | 2nd to 3rd and greater | -0.84 | 0.0036 |
| CDigested | Lactation | 2nd to 3rd and greater | -0.71 | 0.0034 |
| | Used Moisture | | -0.08 | 0.0016 |
| | Used Fines1 | | -0.01 | 0.0292 |
| DSeparated | Season | Spring to summer | -0.51 | 0.0374 |
| | | Spring to fall | -0.81 | 0.0005 |
| | | Spring to winter | -0.75 | 0.0043 |
| | | Summer to fall | NS | 0.0599 |
| | | Summer to winter | NS | 0.1875 |
| | | Fall to winter | NS | 0.7161 |
| | Milk production | | -0.01 | 0.0292 |
| FSeparated | Milk production | | -0.03 | <.0001 |

Table 4-23 shows Poisson regression results for number of heifers with abnormal cell count for the three FBS that had heifers in the study. When all three FBS were analyzed together, the significant variables were FBS, season and the amount of moisture in the unused bedding. The number of heifers estimated to have an abnormal cell count at BWindrow and CDigested were 0.59 and 0.67 times that at DSeparated. Summer was likely to have more animals with abnormal SCC than spring, fall or winter, and spring was

less likely than fall or winter. The amount of moisture in the unused bedding was positively correlated with the number of heifers expected to have abnormal SCC. Separately, season was the only significant variable for BWindrow and CDigested. Winter and spring were expected to have less heifers with abnormal SCC than summer for BWindrow, while winter and fall were expected to have more heifers with abnormal SCC than summer for CDigested. Stage of lactation was the only significant variable for DSeparated heifers. The number of heifers in early lactation with abnormal SCC were expected to be 1.6 and 1.5 times greater than those in mid or late lactation.

**Table 4-23: Poisson Regression Results for the Number of Heifers with Abnormal SCC within each FBS**

| Farm | Predictor Variables | Contrast | Diff in log mean | p-value |
|---|---|---|---|---|
| All 3 | FBS | BWindrow to CDigested | NS | 0.4914 |
| | | BWindrow to DSeparated | -0.53 | 0.0107 |
| | | CDigested to DSeparated | -0.40 | 0.0440 |
| | Season | Spring to summer | -0.46 | 0.0456 |
| | | Spring to fall | NS | 0.7447 |
| | | Spring to winter | 0.64 | 0.0025 |
| | | Summer to fall | 0.50 | 0.0004 |
| | | Summer to winter | 1.1 | 0.0000 |
| | | Fall to winter | 0.60 | 0.0156 |
| | Unused moisture | | 0.07 | 0.0330 |
| BWindrow | Season | Spring to summer | -0.65 | 0.0190 |
| | | Spring to fall | NS | 0.3750 |
| | | Spring to winter | NS | 0.4866 |
| | | Summer to fall | NS | 0.0586 |
| | | Summer to winter | 0.87 | 0.0004 |
| | | Fall to winter | NS | 0.0537 |
| CDigested | Season | Spring to summer | NS | 0.3236 |
| | | Spring to fall | 1.0 | 0.0017 |
| | | Spring to winter | 1.1 | 0.0041 |
| | | Summer to fall | 0.70 | 0.0286 |
| | | Summer to winter | 0.82 | 0.0408 |
| | | Fall to winter | NS | 0.7695 |
| DSeparated | Stage of Lactation | Early to mid | 0.97 | 0.0220 |
| | | Early to late | 0.90 | 0.0196 |
| | | Early to extended | NS | 0.1159 |
| | | Mid to late | NS | 0.9047 |
| | | Mid to extended | NS | 0.3526 |
| | | Late to extended | NS | 0.3878 |

**IMPACT ON MILK PRODUCTION AND LINEAR SCORE OVER TIME**

There is a perception that continued use of DMS as bedding is contributing to increasing somatic cell count on farms. Herds that participate in DHIP have many years of herd average milk production and average linear score (LS) data available. This information was available for our use from January 1997 through July

2008 for all of the farms on the study except Farm A for which data was available through August 2006. Linear regression of average monthly milk production and LS for all farms together and each farm individually was run on all of the data, as well as on the data generated prior to and after using DMS as bedding. Since the data is based on all milking cows in the herds, this analysis is on the results for farms, not farm/bedding strategies (i.e. Farm E is not divided into three separate bedding strategies). Two other farms (G and H) that used DMS as bedding during that time period also gave permission to access their data, and are included here.

In addition, average milk production and LS data for 65 New York State dairy farms with current herd size of between 750 to 2000 cows was available to compare with our 6 study farms to see if the same trends in milk production and LS were happening within the state. The data analyzed for the 65 farms was from the same time period as that of the study farms. Linear regression was run on each set of data to determine if there were any differences.

**Milk Production**

**All Farms Together.** Farm A started using DMS in Nov 2005, Farm B in Apr 2004; Farm C started May 2005; Farm D in Jan 2000, Farm E in March 2006, and Farm F started in Oct 2000. Linear regression of the data for milk production for cows bedded on DMS (blue "z" and blue line) shows no significant change in milk production over time, and those on some other bedding (pink square and pink line) shows a decrease of 0.0009/day (Figure 4-1). The two are not significantly different from each other.

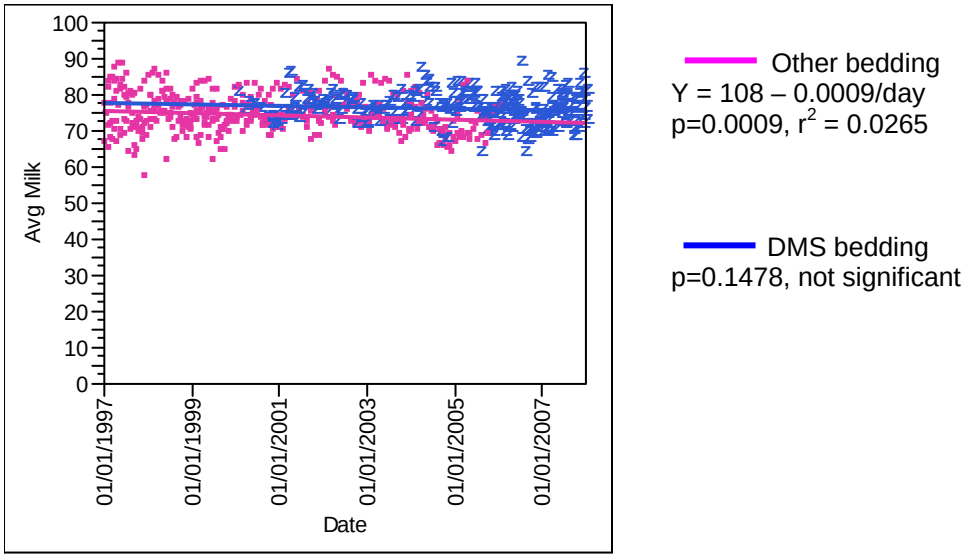



**Figure 4-1: Linear Regression for Average Monthly Milk Production per Cow for All Farms in the Study Bedded on DMS or Some Other Bedding**

**New York State Farms.** Linear regression of average monthly milk production per cow on 65 NYS dairy farms (green square and pink line) and on the 6 study farms while using DMS (blue "z" and blue line) is

shown in Figure 4-2. The 65 farms showed an increase in milk production over that time period of 0.0007 lbs/cow/day, while milk production at the 6 study farms did not significantly change over the same time period. ANOVA on these results showed there was a significant difference in the change in milk production over time between the two sets of farms.

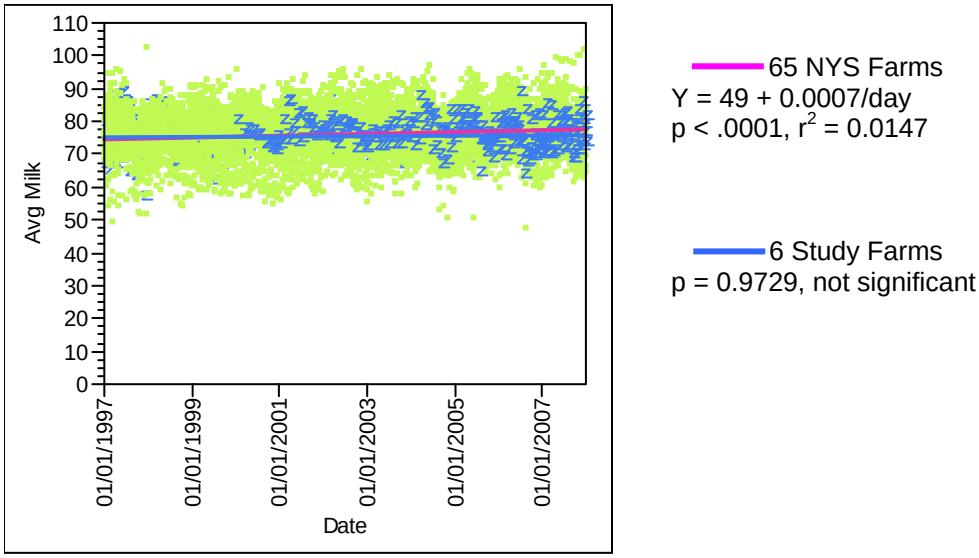



**Figure 4-2: Linear Regression for Average Monthly Milk Production per Cow for 65 NYS Dairy Farms and 6 Study Farms**

**Individual Farms.** Figures 4-3 through 4-8 show the linear regression for average monthly milk production per cow for each individual farm in the study prior to and while using DMS. Farms B through F show no significant change in milk production over time prior to or while using DMS as bedding. Linear regression of the data for milk production prior to using DMS on Farm A shows a negative correlation for milk production, and while using DMS shows a positive correlation over time (Figure 4-3). Prior to using DMS, average monthly milk production decreased by 0.002 lbs/cow/day with an r-square of 0.28. While using DMS, average monthly milk production increased by 0.015 lbs/cow/day with an r-square of 0.43. The increase in milk production over time while using DMS was not significantly different from the decrease in milk production prior to using DMS. In fact only one farm showed a correlation for milk production over time indicating that milk production on these farms has not changed dramatically since 1997 regardless of whether or not DMS was used as bedding.

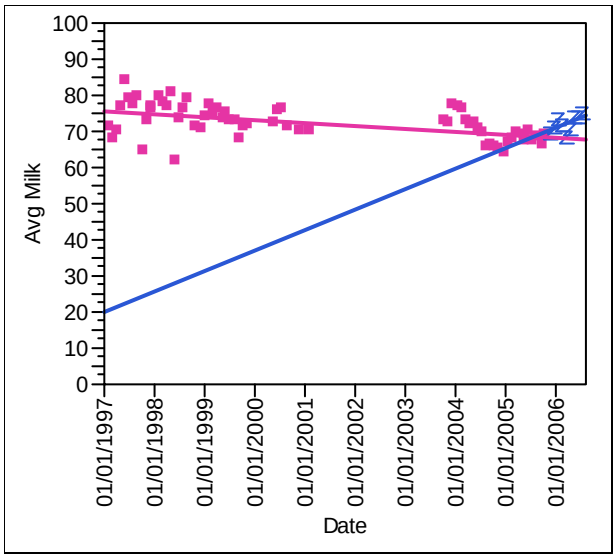



**Figure 4-3: Linear Regression for Average Monthly Milk Production for Farm A Prior to and While Using DMS as Bedding**

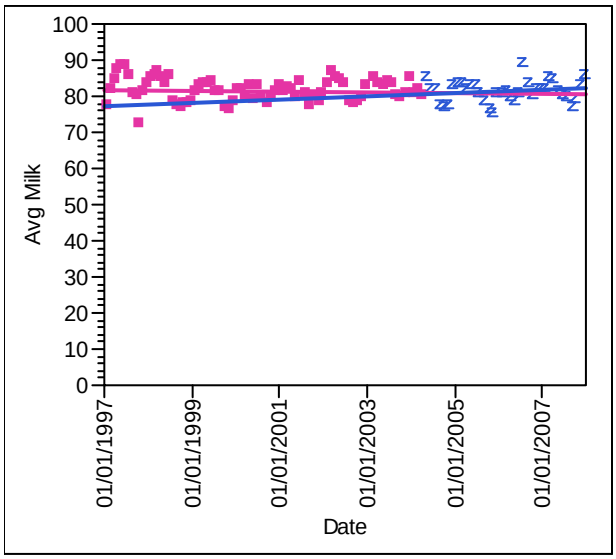



**Figure 4-4: Linear Regression for Average Monthly Milk Production for Farm B Prior to and While Using DMS as Bedding.**

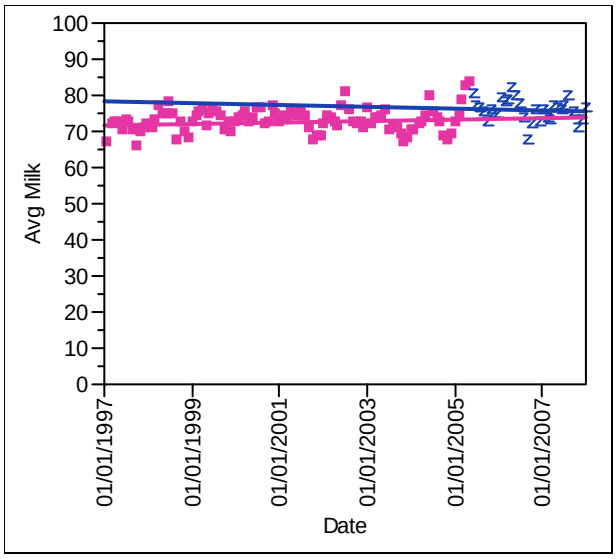



**Figure 4-5: Linear Regression for Average Monthly Milk Production for Farm C Prior to and While Using DMS as Bedding.**

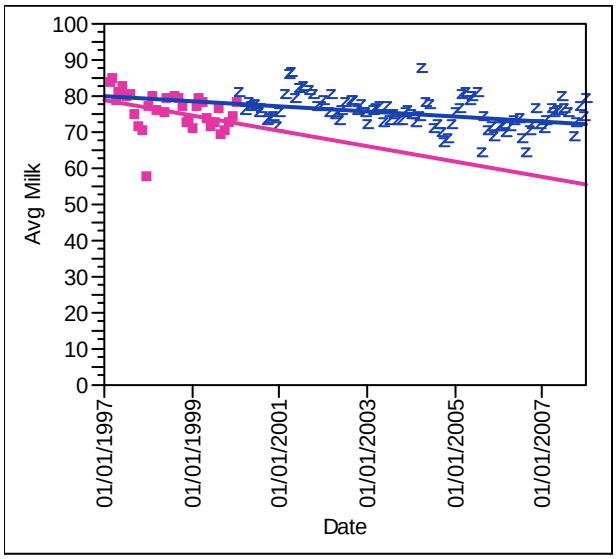



**Figure 4-6: Linear Regression for Average Monthly Milk Production for Farm D While Using DMS as Bedding.**

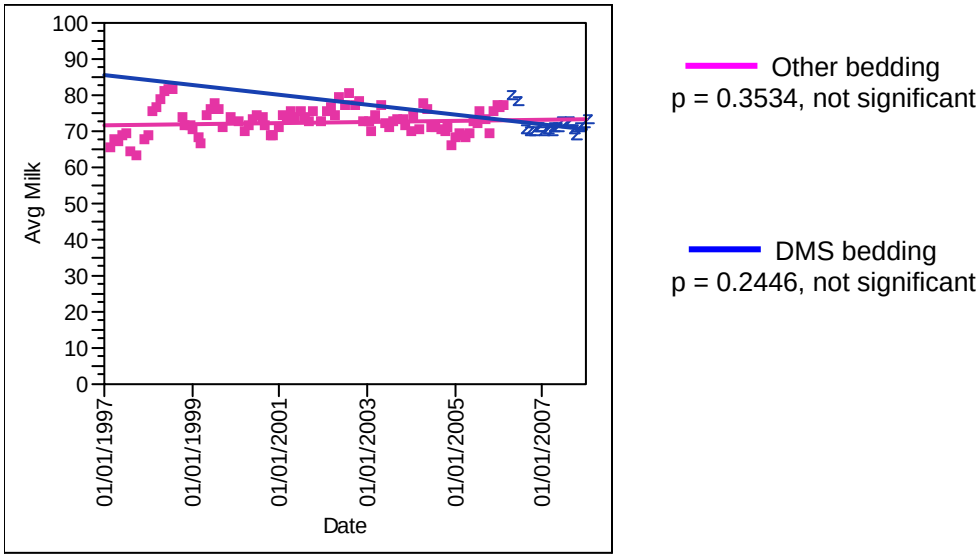



**Figure 4-7: Linear Regression for Average Monthly Milk Production for Farm E Prior to and While Using DMS as Bedding.**

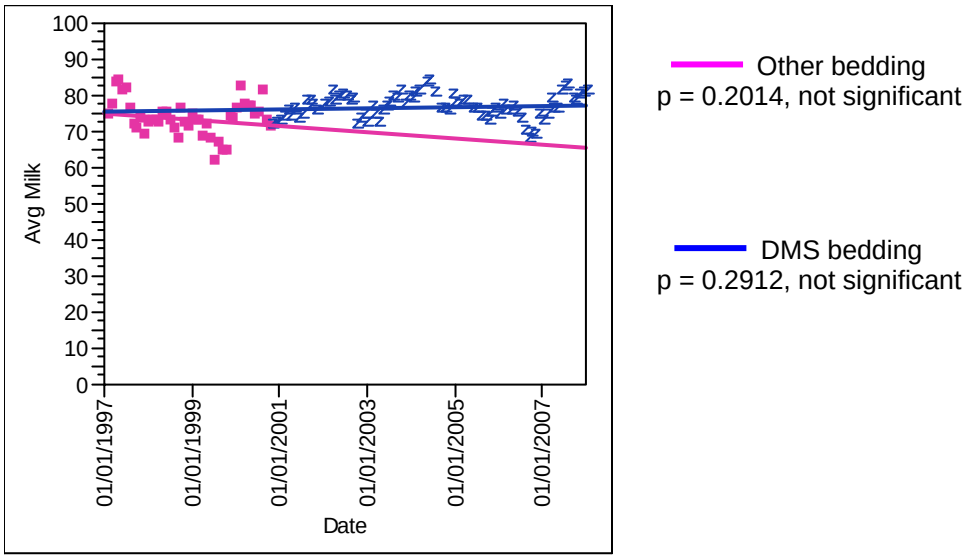



**Figure 4-8: Linear Regression for Average Monthly Milk Production for Farm F While Using DMS as Bedding.**

**Additional DMS Farms.** Figures 4-9 and 4-10 show the linear regression for average monthly milk production per cow for Farms G and H prior to and while using DMS. Farm G started using DMS in Nov 2006, while Farm H has been on solids for over 15 years. Farm G showed a significant increase in milk production over time of 0.002 lbs/cow/day prior to using DMS, but the increase was not significantly different from "no change" in milk production while using DMS. Farm H showed a significant increase in milk production from January 1997 through January 2008 (while using DMS) of 0.001 lbs/cow/day.

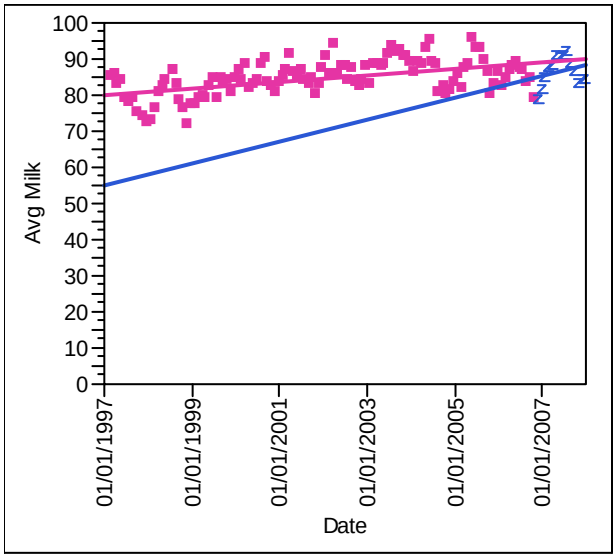



**Figure 4-9: Linear Regression for Average Monthly Milk Production for Farm G Prior to and While Using DMS as Bedding.**

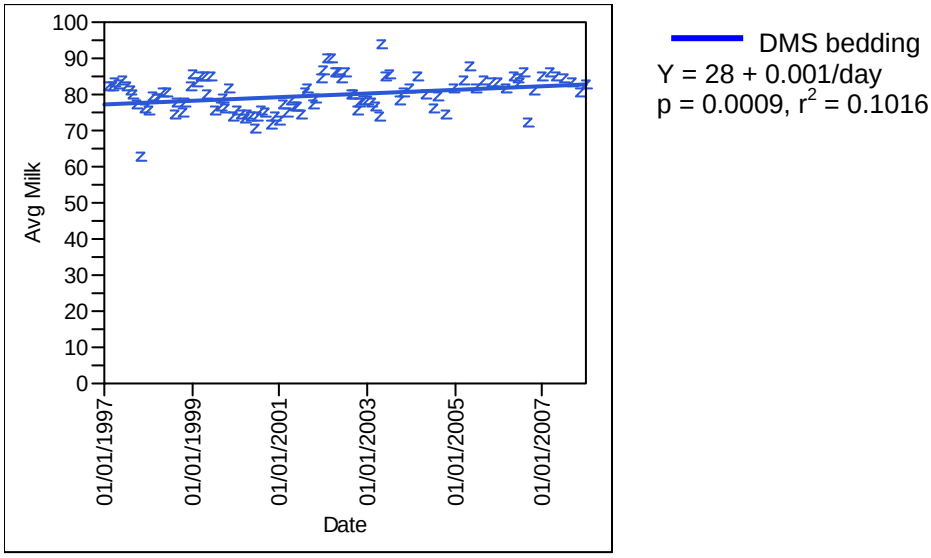



**Figure 4-10: Linear Regression for Average Monthly Milk Production for Farm H While Using DMS as Bedding.**

**Linear Score**

**All Farms Together.** When the 6 research farms are analyzed together, linear regression of the data for LS for cows bedded on DMS (blue "z" and blue line) and those on some other bedding (pink square and pink line ) shows a positive correlation for LS over time for cows bedded on DMS and no significant correlation for those on some other bedding (Figure 4-11). For cows bedded on DMS, average monthly LS increased by 0.0002/cow/day (0.07/year) with an r-square of 0.15. The increase in LS over time while using DMS is significantly different from the "no change" in LS while using some other bedding.

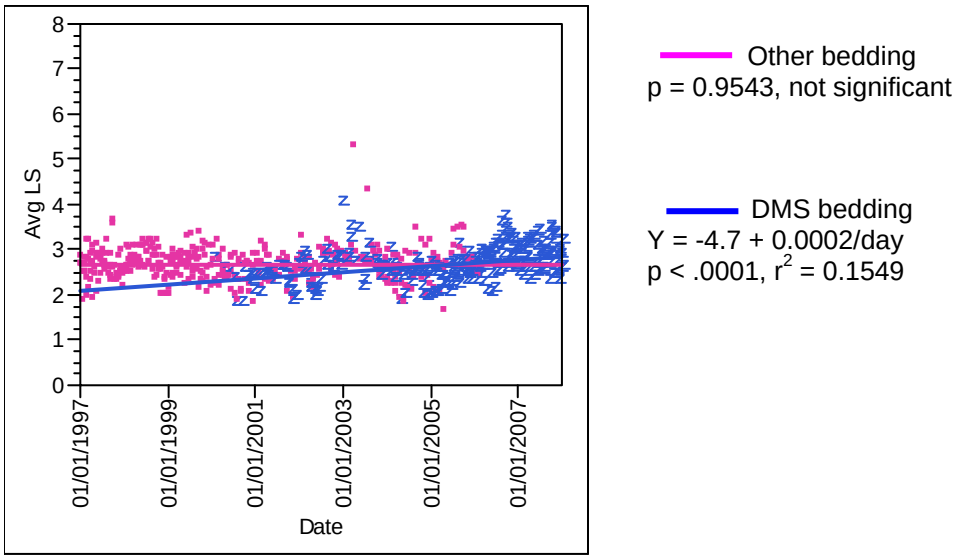



**Figure 4-11: Linear Regression for Average Linear Score per Cow for All Farms in the Study Bedded on DMS or Some Other Bedding**

**New York State Farms.** Linear regression of LS per cow on 65 NYS dairy farms (green square and pink line) and on the 6 study farms (blue "z" and blue line) while using DMS (from January 2000 through January 2008) is shown in Figure 4-12. Both the 65 farms and the 6 study farms showed an increase in LS between 2000 and 2007. The 65 NYS farms showed an increase of 0.00002/cow/day, while the 6 study farms showed an increase of 0.0002/cow/day. ANOVA on these results showed a significant difference in the change in LS over time between the two sets of farms. Therefore, it is possible that continued use of DMS could be increasing LS more than other bedding, but since the dataset for those using DMS is much smaller than those using other bedding, and there is no way to be sure of what type of bedding the other farms are using, no conclusion should be made.

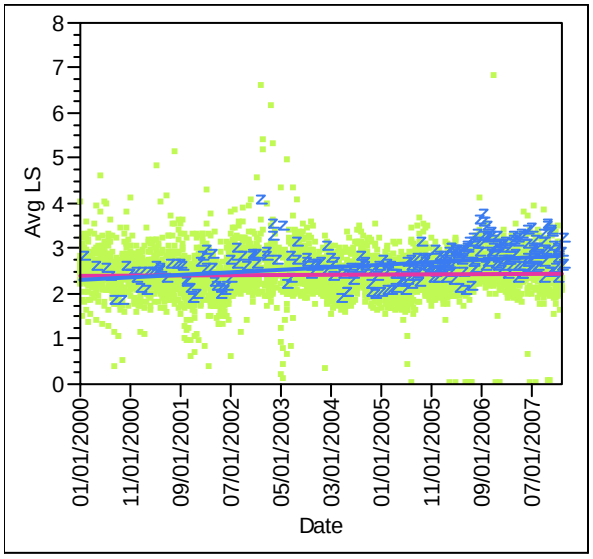



**Figure 4-12: Linear Regression for Average LS per Cow for 65 NYS Dairy Farms and 6 Study Farms**

**Individual Farms:** Figures 4-13 through 4-18 show average monthly LS for each of the 6 farms in the study individually. At Farm A, linear regression prior to using DMS shows no correlation over time, and while using DMS shows a negative correlation over time (Figure 4-13). While using DMS, average monthly LS decreased by 0.002/cow/day with an r-square of 0.86. The increase in average LS over time prior to using DMS is not significantly different from the "no change" over time while using DMS.

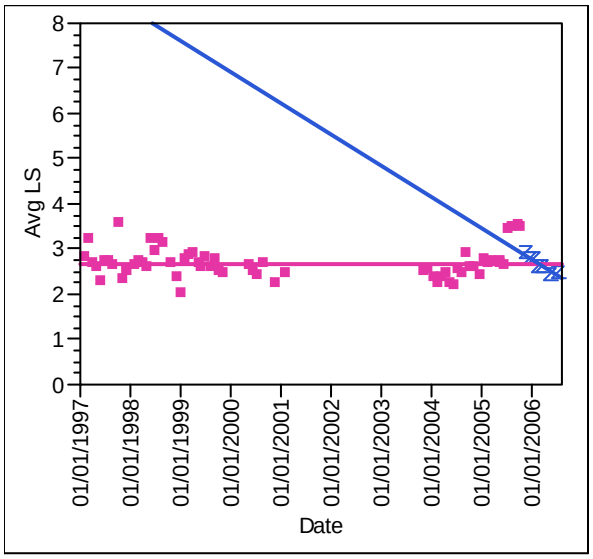



**Figure 4-13: Linear Regression for Average Monthly Linear Score for Farm A Prior to and While Using DMS as Bedding.**

At Farm B, there was no significant change over time in LS either prior to, or while using DMS as bedding (Figure 4-14).

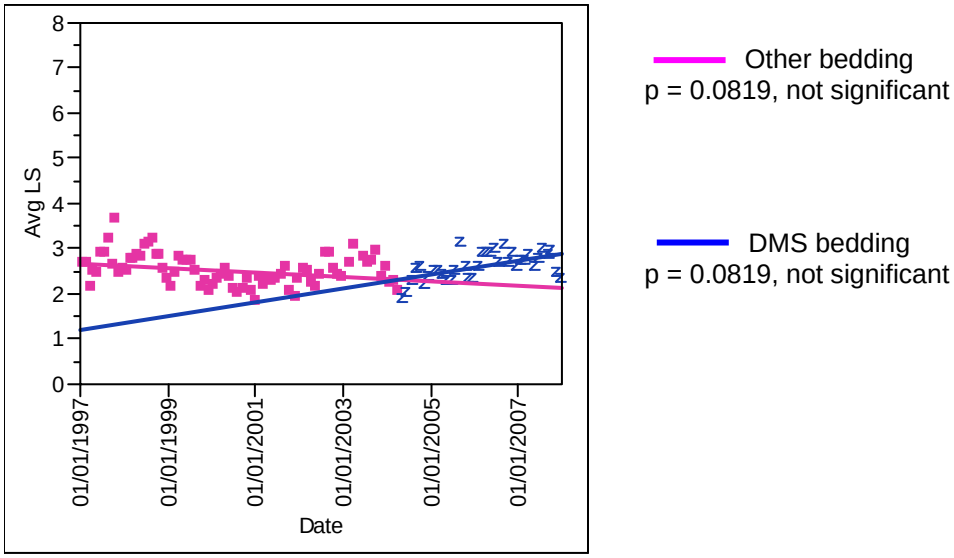



**Figure 4-14: Linear Regression for Average Monthly Linear Score for Farm B Prior to and While Using DMS as Bedding.**

Linear regression shows a negative correlation for LS prior to using DMS, and no significant correlation while using DMS at Farm C (Figure 4-15). Prior to using DMS, average LS decreased by 0.0002/cow/day with an r-square of 0.15. The change in linear score over time prior to and while using DMS is not significantly different from each other.

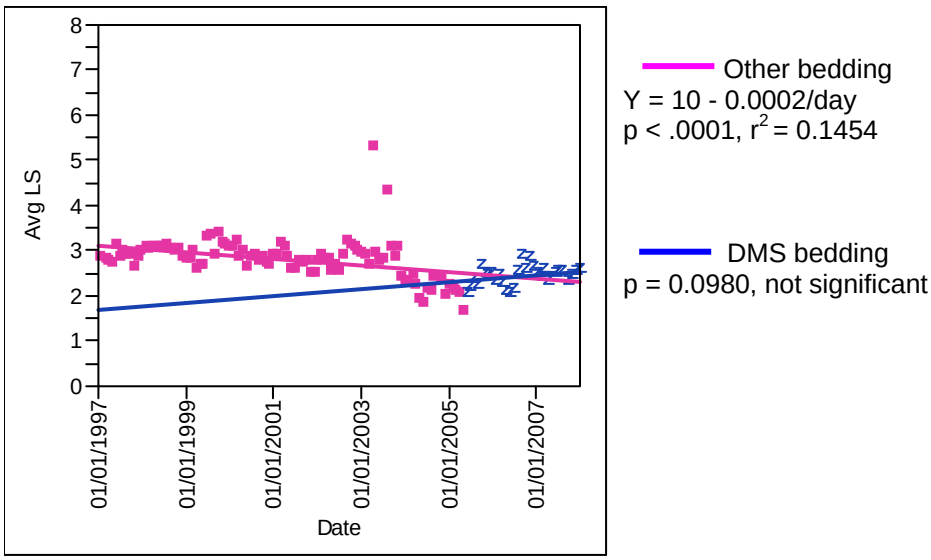



**Figure 4-15: Linear Regression for Average Monthly Linear Score for Farm C Prior to and While Using DMS as Bedding.**

At Farm D, prior to using DMS, there was no change in linear score over time. While using DMS, linear score increased by 0.0003/day, but this change over time is not significantly different than the "no change" prior to using DMS (Figure 4-16).

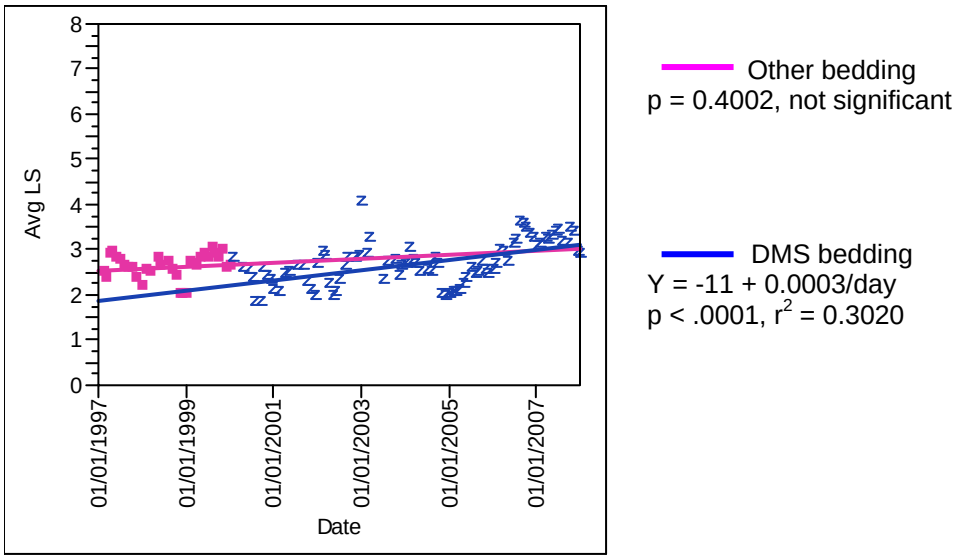



**Figure 4-16: Linear Regressions for Average Monthly Linear Score for Farm D Prior to and While Using DMS as Bedding.**

Linear regression of the data for LS at farm E prior to and while using DMS showed no significant correlation over time (Figure 4-17).

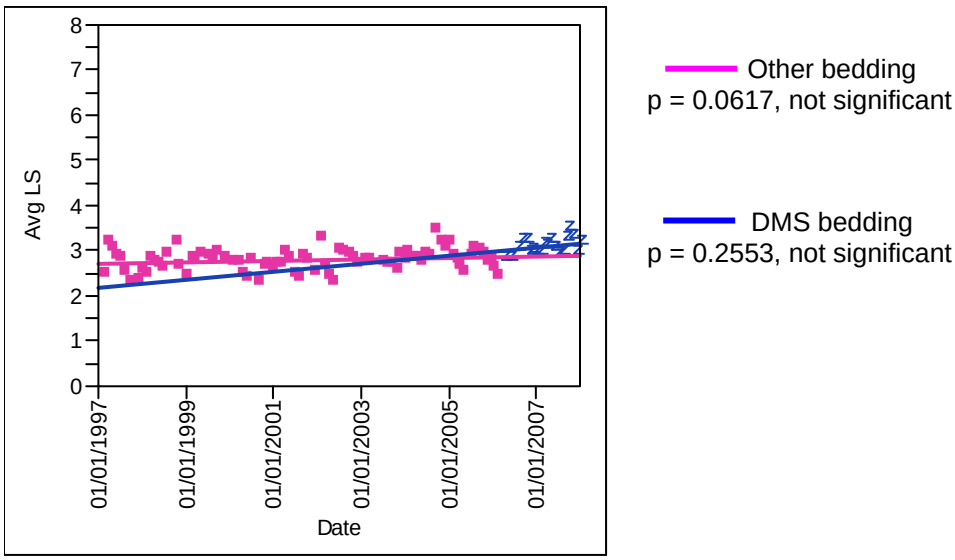



**Figure 4-17: Linear Regression for Average Monthly Linear Score for Farm E Prior to and While Using DMS as Bedding.**

Linear regression of LS at Farm F (Figure 4-18) was the same as at Farm D (no change prior to using DMS, and an increase of 0.0002/day while using DMS). The two are not significantly different from each other.

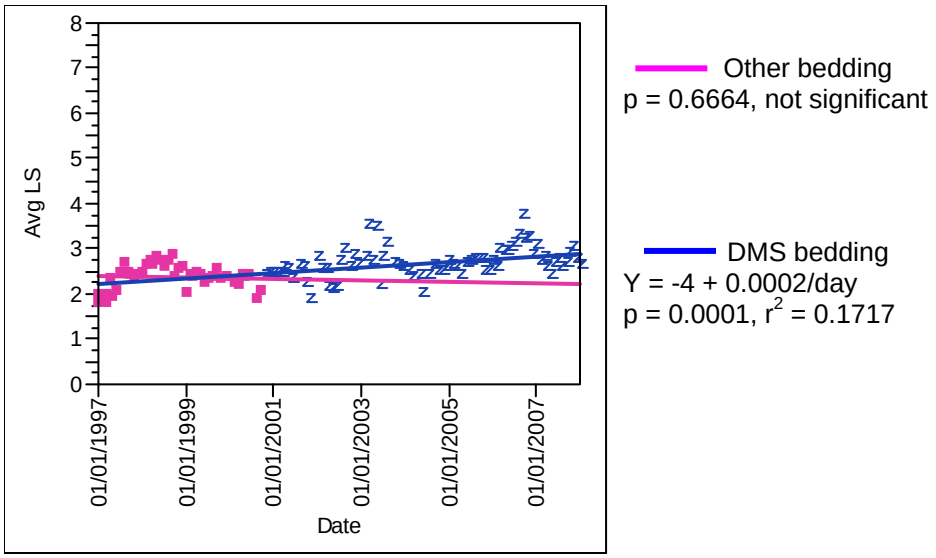



**Figure 4-18: Linear Regression for Average Monthly Linear Score for Farm F Prior to and While Using DMS as Bedding.**

Table 4-24 shows a summary of the change in LS over time prior to using and while using DMS for the 6 study farms. Although 2 of the 6 farms showed an increase in linear score over time, there was no significant difference between the change in LS prior to or while using DMS for these farms. This indicates that linear score has not changed dramatically for these farms since 2000 regardless of whether or not DMS was used as bedding.

**Table 4-24: Change in LS Over Time Prior to and While Using DMS**

| Farm | Prior to Using DMS | While Using DMS | Are they different? |
|---|---|---|---|
| A | No change | - 0.73/year | No |
| B | No change | No change | No |
| C | - 0.07/year | No change | No |
| D | No change | + 0.11/year | No |
| E | No change | No change | No |
| F | No change | + 0.07/year | No |

**Additional DMS Farms.** Figures 4-19 and 4-20 show the linear regression for average linear score for Farm G prior to and while using DMS, and Farm H while using DMS (Farm H has been using DMS as

bedding for over 15 years). Linear regression shows no change in linear score over time at Farm G prior to or while using DMS as bedding.

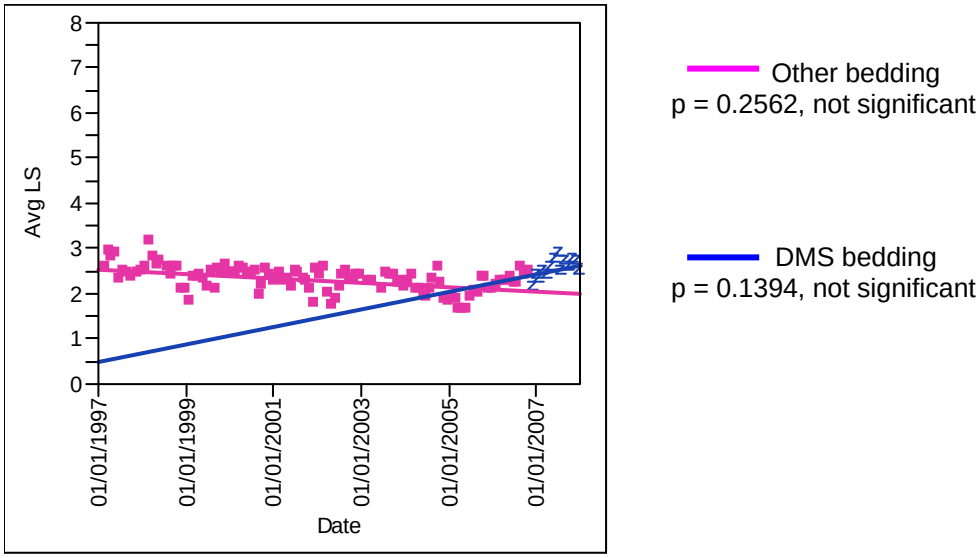



**Figure 4-19: Linear Regression for Average Monthly Linear Score for Farm G Prior to and While Using DMS as Bedding.**

At Farm H, where DMS has been used at bedding for over 15 years, there has been no significant change in linear score over time (Figure 4-20).

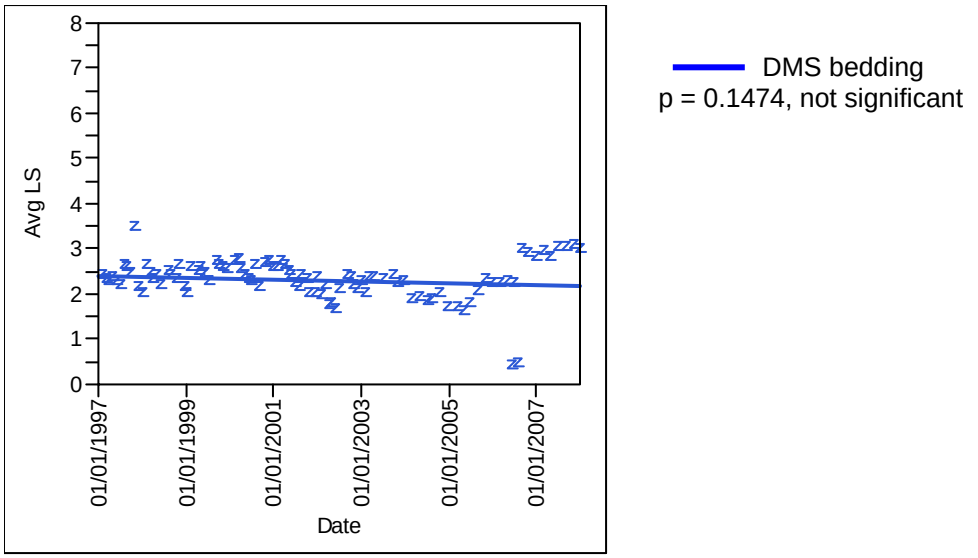



**Figure 4-20: Linear Regression for Average Monthly Linear Score for Farm G While Using DMS as Bedding.**

**Comparison of Individual Farms with 65 NYS Farms.** Table 4-25 shows a comparison of change in LS over the time each individual farm was using DMS to 65 NYS farms during the same time period. Change in linear score for the 65 NYS farms ranges from a decrease of 0.01/year to an increase of 0.11/year depending on the time period. Only 3 of 8 farms using DMS show a change in LS over the time in which it was being utilized. Farm B's change in linear score is no different than that of the other NYS farms. Farms D and F, however, show an increase that is significantly different from the other farms. Based on these two, it is possible that continued use of DMS (both have been using it since 2000) may have an impact on increasing SCC. However, comparison of Farm H (where DMS has been used as bedding for over 15 years) with the 65 NYS dairy farms shows no difference in the change in LS over time, which indicates that changes in SCC over time may not necessarily have anything to do with DMS use.

**Table 4-25: Change in LS Over Time for Farms Using DMS in Comparison to 65 NYS Farms in the Same Time Period**

| Farm | Time Period | Change in LS on Farm | Change in LS on 65 NYS Farms | Are they different? |
|---|---|---|---|---|
| A | Nov 05 – Aug 06 | -0.73/year | +0.29/year | No |
| B | Apr 04 – Jan 08 | +0.15/year | +0.07/year | No |
| C | May 05 – Jan 08 | No change | +0.11/year | No |
| D | Jan 00 – Jan 08 | +0.11/year | +0.01/year | Yes |
| E | Mar 06 – Jan 08 | No change | No change | No |
| F | Oct 00 – Jan 08 | + 0.04/year | +0.01/year | Yes |
| G | Nov 06 – Jan 08 | No change | No change | No |
| H | Jan 97 – Jan 08 | No change | -0.01/year | No |

**OTHER ISSUES WITH DMS**

**Johnes Disease**

There is some concern that since the bacteria responsible for Johnes disease is shed in the manure, using manure solids as bedding may spread the disease throughout the herd if the bacterium remains viable in the DMS. Each month, triplicate samples of the unused bedding were analyzed for this bacterium. All of the farms participating in the study indicated that they did have Johnes disease in the herd. Table 4-26 shows the average total colony forming units (tcfu) on a wet weight basis found in the unused bedding samples taken from each farm, as well as the number of samples in which *Mycobacterium Avium paratuberculosis* (MAP) was found and the total number of samples taken. FSeparated had the most MAP found in the unused bedding with an average of 174 total colony forming units (tcfu) per gram wet weight basis, as well as having found it most often, in 12 of the 24 samples taken at each farm. ADrum and DSeparated had the next highest amounts, but they were found in only 1 and 4 of the 24 samples taken, and they were not

significantly different in total cfu/g than the other farms. There was no MAP found in the DMS from the drum composter at Farm E. The fact that MAP is not necessarily destroyed by separation, digestion or drum composting means that there could be some potential for the spread of Johnes through the use of DMS, however, since the number of colony forming units was so small, that possibility is also small, and may be of concern only in the bedding of calves.

**Table 4-26: Average Total Colony Forming Units (tcfu) of MAP found in the Unused Samples Taken from Each Farm**

| Farm/Bedding Strategy | # of Times MAP Found | Total # of Samples Taken | tcfu/g MAP |
|---|---|---|---|
| ADrum | 1 | 24 | $69.7^{ab}$ |
| BWindrow | 2 | 24 | $1.2^{b}$ |
| CDigested | 2 | 21 | $1.0^{b}$ |
| DSeparated | 4 | 24 | $58.0^{ab}$ |
| EDrum | 0 | 15 | $0.0^{b}$ |
| ESand | 1 | 33 | $0.4^{b}$ |
| ESeparated | 11 | 36 | $8.9^{ab}$ |
| FSeparated | 12 | 24 | $174.0^{a}$ |

Values in each column with different letters are significantly different

**Lameness**

Some of the literature has indicated that sand is the best bedding for the health of feet and legs. One of the ways in which foot and leg health is evaluated is through lameness scoring. Twice over the study at Farm E, cows in the sand pen and cows in the pen bedded with DMS from the separator were scored. Lameness scores are reported on a 1-4 scale. A score of 1 is normal: the cow stands and walks with a flat back, 2 is mildly lame: the cow stands with a flat back and arches when she walks, 3 is moderately lame: the cow stands and walks with an arched back and takes short strides on one or more legs, and 4 is lame: the cow stands and walks with an arched back, and one or more limbs are physically lame or non-weight bearing. Since lameness can also be a function of lactation number (or age), that information was collected as well for the cows that were scored. Lactation number was divided into three categories for the statistical analysis: A = second lactation, B = third lactation and C = fourth and higher.

The analysis showed a significant difference in lameness score by pen (type of bedding) and lactation. The cows in the sand pen had a significantly higher mean lameness score (1.5) than those in the DMS pen (1.3). There was also a significant difference between lactations. Cows in $4^{th}$ or greater lactation were significantly more lame (1.9) than $3^{rd}$ lactation cows (1.3), which were significantly lamer than $2^{nd}$ lactation animals.

Figure 4-21 and Table 4-27 show the least squares means plot and values for lactation number crossed by pen. Fourth lactation and higher cows in the sand pen (2.1) had significantly higher lameness scores than all other lactation/pen combinations. Also, 4th lactation cows in the DMS pen (1.6) had significantly higher lameness scores than 3rd lactation cows in the DMS pen (1.3), 2nd lactation cows in the sand pen (1.2) and 2nd lactation cows in the DMS pen (1.1). Third lactation cows in the sand pen (1.5) had significantly higher lameness scores than 2nd lactation cows on sand (1.2) and 2nd lactation cows on DMS (1.1). There were no other significant differences.

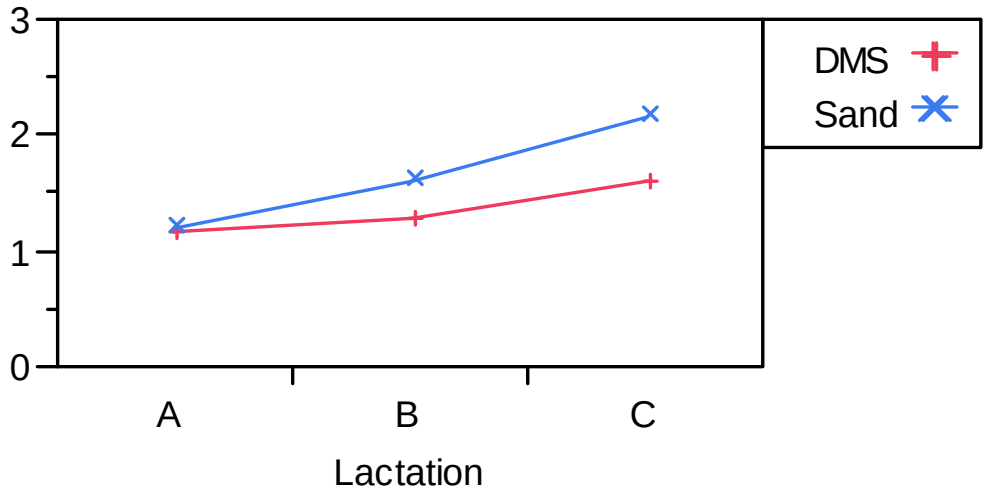



**Figure 4-21: Mean Lameness Score by Type of Bedding Crossed with Lactation Number for Cows on DMS and Sand**

**Table 4-27: Mean Lameness Score by Type of Bedding Crossed with Lactation Number for Cows on DMS and Sand**

| Pen | Lactation | Lameness Score |
|---|---|---|
| Sand | 2nd | 1.2d |
| DMS | 2nd | 1.1d |
| Sand | 3rd | 1.5bc |
| DMS | 3rd | 1.3cd |
| Sand | 4th and greater | 2.1a |
| DMS | 4th and greater | 1.6b |

Values in each column with different letters are significantly different

**Mass Nutrient Balance Data**

Appendix D shows the mass nutrient balance data collected by Caroline Rasmussen, Integrated Nutrient Management, Cornell University. The MNB of the 6 farms was conducted within a broader, multiple year study of nutrient management on NYS livestock farms. Of the 53 New York State dairy farms that

submitted 2006 mass balance data, imported bedding constituted only 1% of all N imports, 1% of all P imports, and 2% of all K imports. The percentage of N imported with bedding was less than 0.5% on 5 of the 6 farms in this study, lower than the average for the other 47 dairy farms (1%). The percentage of P imported as a component of bedding was slightly lower than the average for all 6 of the study farms. Work is ongoing to determine inefficiency indicators and management options for improvement of whole farm nutrient imbalances but it is obvious from this dataset that bedding management does not greatly impact overall farm nutrient balances on New York dairy farms.

**Economic Analysis**

Appendix E shows the economic analysis data collected by A. Edward Staehr, Extension Associate, Department of Applied Economics and Management. The following information was used to calculate the annual cost per hundred weight of milk for farms using DMS.

- Total cost of production of DMS
    - Machinery and services operating costs per hour for construction, including site preparation, grading, rolling and design
    - Machinery operating costs per hour for operations and annual equipment operating hours
    - Personnel costs per hour
    - Start up costs in hours
    - Total facility and equipment capitalized costs
- Costs and returns from using DMS
    - Annual income received from DMS sales
    - Reduced expenses in the form of manure hauling and purchased bedding
    - Annual variable expenses including machinery, record keeping, electricity, repairs and labor
    - Annual fixed expenses including insurance, facility depreciation, DMS equipment depreciation and average annual interest on investment

Only information regarding costs and returns associated with the production of DMS were utilized. Costs incurred prior to DMS production were also included to provide an accurate reflection of expenses to evaluate technology that best fit each farm's specific needs. Some farms spent considerable time examining which system could be integrated most effectively into their manure handling operation. In addition, changes resulting from utilizing DMS for bedding were factored in. When producers felt that DMS bedding resulted in a higher somatic cell count, a value was placed on lost milk premiums to account for reduced receipts.

Machinery operating costs were determined by researching industry average costs on a per hour basis for equipment such as a skid steer, payloader or other equipment used to produce/spread DMS. The farms

provided the number of hours each equipment type was used. Depreciation on structures and non-machinery equipment was calculated on each class of assets using MACRS and taking straight line depreciation on an annual basis over the life of a specific asset. Additional insurance costs were also factored in when structures associated with DMS production were built.

To determine the annual cost of implementing a DMS bedding program, all costs and returns were divided into specific areas and calculated. Expenses were divided into fixed and variable categories. In addition, reduced expenses such as manure hauling and savings, when compared to conventional bedding were accounted for. Expenses were not the only area where information was quantified. One farm generated income from the sale of DMS to other farms. The total economic cost to the farm of using manure solids as bedding was calculated by adding the total fixed and variable expenses, and the annual cost to the farm was calculated by subtracting the annual income and reduced expenses generated using DMS from the total economic cost. Finally, the annual cost per hundred weight of milk of using DMS was calculated by dividing the annual cost by the pounds of milk sold per year (Table 4-28).

**Table 4-28: Total Costs and Returns from Using Manure Solids as Bedding on Five Study Farms**

| | Returns (d) = a + b + c | | | | | |
|---|---|---|---|---|---|---|
| Farm | DMS Sales (a) | Savings on Manure Hauling (b) | Savings on purchased bedding (c) | Total Fixed and Variable Expenses (e) | Annual Cost to Farm = (e – d) | Annual Cost per Hundred Weight of Milk |
| B | $0 | $5,490 | $57,200 | $51,750 | -$10,940 | -$0.05 |
| C | $0 | $8,450 | $44,800 | $22,236 | -$31,014 | -$0.08 |
| D | $0 | $8,325 | $53,082 | $59,856 | -$1,552 | -$0.01 |
| E | $0 | $8,425 | $156,115 | $87,161 | -$77,378 | -$0.20 |
| F | $15,000 | $50,000 | $81,600 | $79,257 | -$67,343 | -$0.26 |

All five farms for which the economic analysis was run showed a savings of between 1 and 26 cents per hundred weight of milk (cwt) sold per year. For example, at the farm that showed a savings of 20 cents/cwt, total milk sales for the year were 38,325,000 lbs, saving the farm 383,250 * 0.20 = $76,650 on the cost of producing milk that year (Table 4-29).

**Table 4-29: Total Annual Savings or Cost of Producing Milk by Using Manure Solids as Bedding on Four Study Farms**

| Farm | Annual Cost/cwt of milk (a) | Pounds of Milk Sold/Year (b) | Annual cwt of Milk (c) = b/100 | Cost or Savings to Produce Milk (d) = c * b |
|---|---|---|---|---|
| B | -$0.05 | 24,000,000 | 240,000 | -$12,000 |
| C | -$0.08 | 36,500,000 | 365,000 | -$29,200 |
| D | -$0.01 | 22,478,997 | 224,790 | -$2,248 |
| E | -$0.20 | 38,325,000 | 383,250 | -$76,650 |
| F | -$0.26 | 25,520,000 | 255,200 | -$66,352 |

## THE EFFECT OF COMPOSTING: COBLESKILL RESULTS

### Properties of Unused Bedding

Composite samples of unused bedding were analyzed for moisture, organic matter, total nitrogen, carbon, carbon to nitrogen ratio, pH, and maturity (measured by carbon dioxide and ammonia release). Table 4-30 shows the results.

**Table 4-30: Properties of Unused Bedding Materials at Cobleskill**

| | Air-Dried | Partially Composted | Mature Compost | Sawdust |
|---|---|---|---|---|
| Moisture (%) | 72.8[a] | 71.9[a] | 63.0[b] | 21.2[c] |
| Organic Matter (%) | 94.2[a] | 95.6[a] | 93.6[a] | 99.4[a] |
| Nitrogen (%) | 1.3[c] | 1.6[b] | 2.0[a] | 0.2[d] |
| Carbon (%) | 46.8[a] | 46.7[a] | 46.2[a] | 47.9[a] |
| C:N Ratio | 36.6[b] | 28.9[b] | 22.7[b] | 283.3[a] |
| pH | 8.2[a] | 8.0[ab] | 7.7[b] | 5.2[c] |
| Maturity | 3.3[c] | 4.5[bc] | 5.0[b] | 8.0[a] |

Values with differing superscripts in each row are significantly different ($p < 0.05$)

The results indicate that the partially composted DMS did not differ significantly from the mature compost and there were few differences between the two composted materials and air-dried DMS. The sawdust was significantly drier, had a lower pH and a higher C:N ratio than the DMS materials.

### Composting DMS

**Bacterial Levels in Unused DMS Bedding.** The air-dried unused DMS, had significantly higher levels of *Streptococcus*, *E. coli*, *Klebsiella*, and *Corynebacterium* than both partially composted and mature compost prior to being used as bedding (Figure 4-22 and Table 4-31). However, Figure 4-24 also shows that air-dried and partially composted DMS had significantly lower levels of *Staphylococcus* and gram-negative

bacteria than mature composted DMS. Gram-positive levels in air-dried DMS were also significantly lower than those in partially composted DMS. In this case, composting reduced bacterial numbers in unused bedding for 4 of the 7 bacteria.

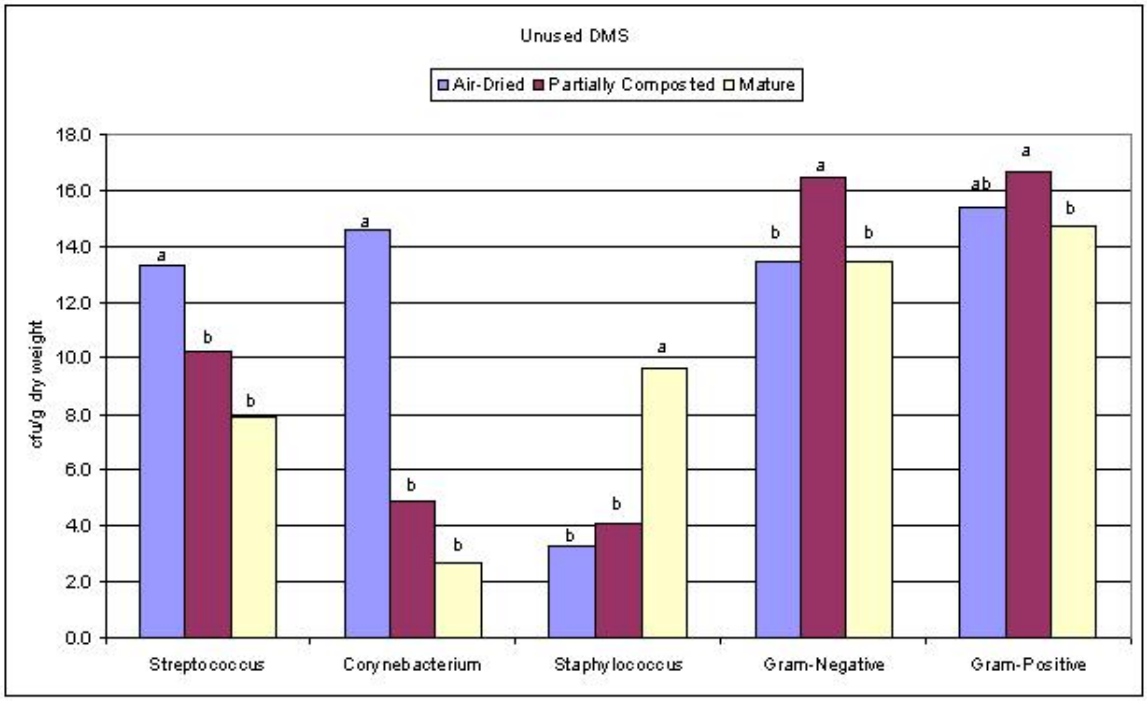



**Figure 4-22: Bacterial Levels (log cfu/ml) in Unused DMS at Cobleskill**
Values with differing superscripts within each bacteria are significantly different ($p < 0.05$)

**Table 4-31: *Escherichia coli* and *Klebsiella* Counts (log cfu/ml) in Unused and Used DMS at Cobleskill**

| Type of DMS | Unused *E coli* | Used *E. coli* | Unused *Klebsiella* | Used *Klebsiella* |
|---|---|---|---|---|
| Air-Dried DMS | $6.9^{a}$ | $12.2^{a}$ | $3.7^{a}$ | $9.3^{a}$ |
| Partially Composted | $1.0^{b}$ | $8.2^{b}$ | $0.0^{b}$ | $6.3^{a}$ |
| Mature Compost | $0.0^{b}$ | $12.3^{a}$ | $0.5^{b}$ | $6.1^{a}$ |

Values with differing superscripts in each column are significantly different ($p < 0.05$)

**Bacteria Levels in Used DMS Bedding.** Of the 4 bacteria that had significantly higher counts in the unused air-dried DMS, only one (*Corynebacterium*) remained significantly higher in the used air-dried DMS (Figure 4-25). *Streptococcus* counts in the used DMS were significantly higher in both the mature and partially composted DMS than in the air-dried DMS, while *Klebsiella* counts were not different in any of the used DMS bedding (Table 4-31). *E. coli*, which was not found in the mature compost prior to being used as bedding was found in significantly higher levels in the used mature compost bedding than the partially composted used bedding. This adds weight to the theory that bacterial levels in the used bedding are more likely a result of bacteria in the manure of the animal, how well the stall is cleaned, and how much

competition there is in the bedding. Relative levels of gram-negative and gram-positive bacteria remained the same as they were in unused DMS (i.e. partially composted DMS had significantly higher levels of both bacteria than air-dried or mature).

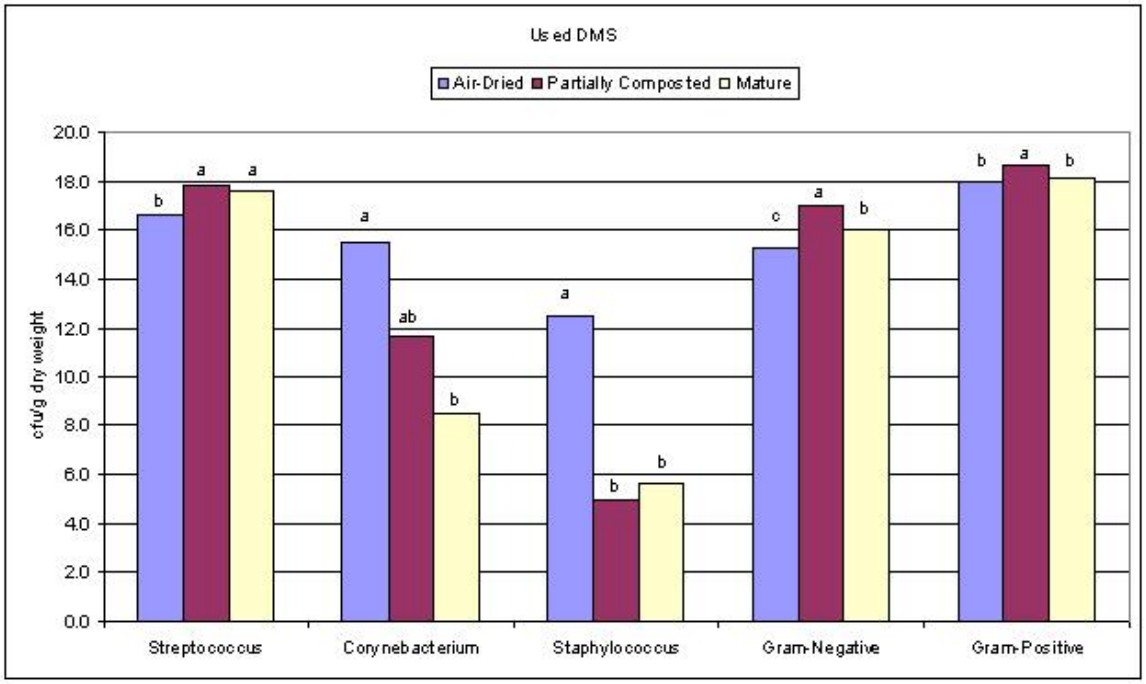



**Figure 4-23: Bacterial Levels (log cfu/ml) in Used DMS at Cobleskill**
Values with differing superscripts within each bacterium are significantly different ($p < 0.05$)

**Comparison of Organic Bedding Materials**

Comparison of organic bedding materials in the literature has generally been between sawdust, straw and shavings. Little research has been done in comparing DMS with other organic bedding sources. The following data shows a comparison of DMS to sawdust.

**Bacterial Levels in Unused DMS and Sawdust.** Table 4-32 shows the bacterial levels on a volume basis in the unused bedding material. In general, air-dried DMS had the highest counts, while sawdust had the lowest. As with the comparison of the three DMS treatments alone, air-dried DMS had significantly higher levels of *Streptococcus, E. coli, Klebsiella,* and *Corynebacterium* than all other bedding materials. Mature DMS had significantly higher levels of *Staphylococcus* than the two DMS, but the same amount as in sawdust. Molds appeared only in sawdust, while yeast was present in both sawdust and air-dried DMS. There was fungus in all but the air-dried DMS.

**Table 4-32: Bacterial Counts (log cfu/ml) in Unused Bedding Materials at Cobleskill**

| | Air-Dried | Partially Composted | Mature Compost | Sawdust |
|---|---|---|---|---|
| *Streptococcus* | 13.3[a] | 10.2[b] | 7.9[bc] | 5.4[c] |
| *Staphylococcus* | 3.3[b] | 4.1[b] | 9.6[a] | 5.7[ab] |
| *E. coli* | 6.9[a] | 1.0[b] | 0.0[b] | 0.9[b] |
| *Klebsiella* | 3.7[a] | 0.0[b] | 0.5[b] | 0.0[b] |
| Gram-Negative | 13.4[b] | 16.5[a] | 14.8[ab] | 4.3[c] |
| Gram-Positive | 15.4[ab] | 16.7[a] | 14.7[b] | 8.8[c] |
| *Corynebacterium* | 14.6[a] | 4.9[b] | 2.7[bc] | 0.2[c] |
| Yeast | 2.1[a] | 0.0[b] | 0.0[b] | 1.3[ab] |
| Mold | 0.0[b] | 0.0[b] | 0.0[b] | 6.9[a] |
| Fungus | 0.0[c] | 3.6[b] | 11.0[a] | 1.8[bc] |

Values with differing superscripts in each row are significantly different ($p < 0.05$)

**Bacterial Levels in Used DMS and Sawdust.** Although present in unused bedding, there were no yeasts, molds or fungi in any of the used bedding materials. Table 4-33 shows the bacterial counts in the used bedding materials at Cobleskill. In general, sawdust had significantly lower bacterial levels in used bedding than all other materials. Sawdust had significantly lower counts of *Klebsiella*, gram-negative and gram-positive bacteria than all others. Sawdust and mature compost had significantly less *Corynebacterium* than air-dried DMS. Sawdust and air-dried DMS had significantly lower counts of *Streptococcus* than partially composted and mature DMS and air-dried DMS had significantly higher counts of *Staphylococcus* than all but sawdust. *E. coli* levels were significantly higher in air-dried and mature than in partially composted DMS.

**Table 4-33: Bacterial Counts (log cfu/ml) in Used Bedding Materials at Cobleskill**

| | Air-Dried | Partially Composted | Mature Compost | Sawdust |
|---|---|---|---|---|
| *Streptococcus* | 16.6[b] | 17.8[a] | 17.6[a] | 16.8[b] |
| *Staphylococcus* | 12.5[a] | 4.9[b] | 5.6[b] | 7.0[ab] |
| *E. coli* | 12.2[a] | 8.2[b] | 12.3[a] | 11.4[ab] |
| *Klebsiella* | 9.3[a] | 6.3[a] | 6.1[a] | 0.4[b] |
| Gram-Negative | 15.3[s] | 17.0[a] | 16.0[a] | 11.1[b] |
| Gram-Positive | 18.0[s] | 18.6[a] | 18.1[a] | 16.3[b] |
| *Corynebacterium* | 15.5[a] | 11.6[ab] | 8.5[bc] | 3.9[c] |

Values with differing superscripts in each row are significantly different ($p < 0.05$)

**Effect of Bacterial Counts of Unused Bedding on Counts in Used Bedding**

Multiple linear regression was performed on the effect of the material, week of trial, moisture and the log transformation of bacterial counts of unused bedding on the log transformation of bacteria counts in used bedding on a volume basis. Table 4-34 shows the results.

Gram positive bacteria and *Corynebacterium* levels in the used bedding were affected by the amount of gram positive and *Corynebacterium*, respectively, in the unused bedding, but in both cases, there was a negative correlation, meaning that more of that bacterium in the unused bedding resulted in less of it in the used. Week of trial had a significant effect on the amount of bacteria in the used bedding for 4 of the 7 bacteria, which could mean that the animals were shedding more of that particular bacterium in certain weeks, since the levels of those bacteria in the unused bedding did not differ significantly by week of trial.

**Table 4-34: Effect of Bacterial Counts in Unused Bedding on Bacterial Counts in Used Bedding at Cobleskill**

| Bacteria in Used Bedding (Y) | Regression Equation (all bacteria listed are in unused bedding) | p-value | r-square |
|---|---|---|---|
| *Streptococcus* | Y = 17.2 + Bedding Material + Week of Trial + 0.2*gram negative bacteria – 0.2*gram positive bacteria | <.0001 | 0.4476 |
| *Staphylococcus* | Y = Bedding Material + Week of Trial | <.0001 | 0.4405 |
| *Escherichia coli* | Y = 3.6 + Bedding Material + Week of Trial + 0.6*gram negative bacteria | 0.0034 | 0.1930 |
| *Klebsiella* | Y = - 2.6 + 0.1*Moisture | <.0001 | 0.2352 |
| Gram-Negative | Y = 11.3 + Bedding Material + 0.2*gram negative bacteria + 0.5*mold | <.0001 | 0.5939 |
| Gram-Positive | Y = 17.8 + Bedding Material + Week of Trial + 0.1**Streptococcus* + 0.1**Klebsiella* + 0.1*gram negative bacteria – 0.2*gram positive bacteria – 0.1*Yeast | <.0001 | 0.7095 |
| *Corynebacterium* | Y = 16.4 + Bedding Material – 0.5**Streptococcus* – 0.4**Corynebacterium* | <.0001 | 0.3464 |

**APPENDIX A**

**USING MANURE SOLIDS AS BEDDING – LITERATURE REVIEW**

# Cornell Waste Management Institute

# Using Manure Solids as Bedding

## Literature Review

## December 2006

This work is part of a larger research and outreach project on the use of manure solids for bedding in dairy barns. That project is supported in part by the New York State Energy Research and Development Authority (Project # 8823), the New York Farm Viability Institute, Cornell Cooperative Extension and the NYS College of Agriculture and Life Sciences.

Information on the project can be accessed at: **http://cwmi.css.cornell.edu/bedding.htm**.

Department of Crop and Soil Sciences • 101b Rice Hall • Ithaca, NY 14853 • 607-255-1187
http://cwmi.css.cornell.edu

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# Summary

This work seeks to address questions regarding the use of dried manure solids (DMS) as bedding for dairy cows, specifically the relationship of DMS bedding to herd health. The concentration of pathogens in bedding, on teat ends and their relationship to mastitis is discussed in this review of the literature. Caution is needed in reviewing data since concentration based on wet weight vs. dry weight vs. volume will be different. There can also be a seasonal effect on bacterial numbers.

There are two types of bedding, organic and inorganic. Organic bedding materials contain nutrients needed for bacterial growth, while inorganic bedding materials do not. However, once any type of bedding becomes soiled (with fecal matter and urine), pathogen growth can be supported. Inorganic bedding, such as sand, may start out with low pathogen concentrations. Some organic bedding materials start out with lower concentrations than others. However, research shows that within 24-48 hours of being in the stall, pathogen levels in all organic bedding materials rise to similar concentrations. The addition of lime to the stalls is not supported by the literature.

The desirable frequency with which fresh organic bedding is added to the stalls is unclear. While "common wisdom" suggests frequent re-bedding, the research literature indicates that pathogen levels peak after a couple of days and may decline thereafter. This may be a result of bacteria having eaten up the available nutrients and that frequent re-bedding provides a new source of food resulting in higher bacterial counts. More work is needed on this subject.

The literature shows inconsistency regarding the relationship of bacterial concentrations in bedding to the bacterial concentration on teat ends. Factors such as particle size may be more important than simply bacterial counts in the used bedding. The relationship of teat end counts to mastitis is unclear and is reviewed below.

Researchers have generally stated the rule of thumb that bedding materials should be kept below a maximum bacterial count of $10^6$ colony forming units (cfu) per gram of bedding wet weight. This number appears to be based on one study where there were no new cases of coliform mastitis when bedding counts were at $10^4$ and $10^5$ one summer, but there were several new cases the following summer when bedding counts were at $10^7$ cfu/g wet weight (Bramley and Neave, 1975). This paper does not claim that $10^6$ colony forming units (cfu) per gram of bedding wet weight is a critical level and it represents data from only two summers on one farm. A few studies show a correlation between the number of bacteria in the bedding and/or the number on the teat ends and mastitis while a number of studies show no correlation. Few studies examined the relationship between bedding pathogens and milk quality.

Several studies have been conducted on the differences between herds that have low average SCC counts and herds that have high average SCC counts. Other studies look at the value of SCC count in determining intra-mammary infection (IMI) status in herds. High SCC is correlated with decreased milk production. SCC is measured both with a bulk tank sample (BTSCC) and with individual milk samples from each cow. BTSCC can be a good indicator of a herd's general udder health status, with high BTSCC generally indicating a problem with contagious mastitis. Herds with lower BTSCC have lower subclinical mastitis and better general udder health. However, the presence of leucocytes in the udder helps protect it from getting other mastitis, therefore low SCC (less than 20,000) appears to predispose cows to getting environmental mastitis. By looking at individual cow SCC over a period of several months, patterns can be established for each cow. Spikes in individual cow SCC usually indicate environmental mastitis and are often short in duration. When SCC is done on a monthly or other low frequency basis, these spikes may be missed. Thus typical BTSCC cannot generally be used to diagnose environmental mastitis at the herd level unless it is pervasive and persistent.

The impact of bedding, cleanliness of the udder and/or legs on the mastitis rate of a herd is unclear. Bedding may play a role in the cleanliness of the udder, and pre-milking udder hygiene may play a role in the amount of mastitis seen.

Other issues that may affect intramammary infection in dairy herds include stage of lactation and the dry period, parity (number of lactations), milking and milking machine factors including the use of post milking dips, teat end roughness and callosity, seasons of the year, nutrition, and housing conditions other than bedding.

# Introduction

Dairy farms in NYS are under increasing pressure to improve their management of manure. Increasing environmental regulation and neighbor odor concerns are factors encouraging the separation of manure solids rather than direct spreading of manure. Implementation of anaerobic digestion on farms for energy recovery and for odor management also generates manure solids. Thus, the need for a use for the separated solids becomes ever more apparent.

Bedding is a costly and time consuming component of dairy farming that has implications for herd health as well as the environment and economics. The cost and availability of bedding fluctuates and good consistent bedding can be hard to find and expensive. Some bedding materials (i.e. straw and sawdust) result in additional nutrients being brought onto the farm, adding to nutrient management concerns.

In the northeast, there is increasing interest in and some limited experience with the use of dried manure solids, the semi-solid (25% solids) material derived from a manure stream run through a separator (DMS) for bedding. While interest is high, there is resistance on the part of some veterinarians, farm advisors, and farmers to using DMS as bedding primarily due to concerns that use of DMS will cause elevated levels of environmental pathogens that may negatively affect udder health (increased environmental mastitis) and milk quality.

The potential financial savings of using dried manure solids (DMS) are substantial and the potential to avoid bringing additional nutrients in bedding materials onto the farm is another benefit. Farmers using dried manure solids (DMS) report greater cow comfort than with other bedding materials they have used.

Mastitis is a costly disease to the dairy farmer. It is broken down into contagious mastitis (caused by bacteria that are found in the mammary gland and spread from cow to cow largely through the milking process), and environmental mastitis (caused by bacteria that live in the environment and spread through exposure to them in the environment). Control of contagious mastitis is sought through milking hygiene, the use of teat dips, treatment of infected animals in lactation, culling of animals with chronic infections, and dry cow anti-biotic therapy. Control of environmental mastitis is sought through stall and animal hygiene and through improvement of host resistance.

Because mastitis is frequently sub-clinical, a number of tests have been developed for detecting mastitis. Most tests estimate the somatic cell count (SCC) of a milk sample. All milk contains white blood cells known as leucocytes which constitute the majority of somatic (derived from the body) cells. It has been generally accepted that the cell count for “normal” milk is nearly always less than 200,000 cells/ml. Higher counts are considered abnormal and indicate probable infection. SCC can be done on individual cows or on bulk tank milk samples. Elevated SCC for environmental mastitis are often short-lived, so periodic SCC counts are less useful in evaluating environmental mastitis infections. High SCC has been associated with milk yield loss.

Low levels of leucocytes in the mammary gland may increase the incidence of infection by environmental pathogens such as coliforms. Herds that have effectively controlled contagious mastitis pathogens (*Streptococcus agalactiae, Streptococcus dysgalactiae,* and *Staphylococcus aureus*) through programs of post milking teat disinfection and dry-cow therapy, tend to have more problems with environmental mastitis pathogens.

The following bacteria are those commonly considered mastitis pathogens:

Contagious pathogens:

- *Staphylococcus aureus*

- *Streptococcus agalactiae* and *Streptococcus dysgalactiae*, to a lesser extent also *S. uberis.*
- Mycoplasmas

Environmental pathogens:

- *Streptococcus* species (other than the above)
- *Enterococcus* species
- Coliform bacteria (including: *Escherichia coli*, *Klebsiella* species, and *Enterobacter* species)
- *Pseudomonas* species
- *Proteus*
- *Serratia* species
- *Prototheca*
- *Corynebacterium* species

The following is a summary of research literature on the contribution of bedding to cow health and milk quality and other issues pertaining to bedding material.

# Bacterial Counts in Bedding

There are two types of bedding, organic and inorganic. Organic bedding materials contain nutrients needed for bacterial growth, while inorganic bedding materials do not. However, once any type of bedding becomes soiled (with fecal matter and urine), pathogen growth can be supported. Inorganic bedding, such as sand, may start out with very low pathogen concentrations. Some organic bedding materials start out with lower concentrations than others. However, research shows that within 24-48 hours of being in the stall, pathogen levels in all organic bedding materials rise to similar concentrations. Thus the expense of composting DMS prior to bedding may not accomplish a reduction in pathogen exposure. Similarly, the addition of lime to the stalls is not supported by the literature. There can also be a seasonal effect on bacterial numbers.

The desirable frequency with which fresh organic bedding is added to the stalls is unclear. While "common wisdom" suggests frequent re-bedding, the research literature indicates that pathogen levels peak after a couple of days and may decline thereafter. This may be a result of bacteria having eaten up the available nutrients and that frequent re-bedding provides a new source of food resulting in higher bacterial counts.

### *Calculating Concentrations*

The numbers of bacteria found in bedding materials is reported on both a dry and wet weight ("as is") basis in the research literature which is confusing. One researcher has suggested reporting pathogen concentrations on a volume rather than a weight basis (Gabler, et al 2001). How the numbers are measured should be kept in mind when looking at data. When comparing bacterial counts within the same type of bedding material, it might make sense to do it on a dry weight basis. For example, dry weights might be used when examining the change in concentrations over time in the same barn using the same bedding. Comparing different materials with very different densities, such as sand and DMS, is challenging since the bedding in a stall of sand will weigh more than a stall with DMS. For the same volume of material, the higher density of sand would result in lower reported concentrations than a lighter material so the sand would "look cleaner." Knowing what is important in terms of what the cows are exposed to is unclear.

Wet vs. Dry Weight Calculations:

The number of bacteria can be reported as colonies per gram of material on an "as is" wet weight basis. In order to determine the concentration on a dry weight basis, the lab will dry the material after testing it for bacteria and convert the number of colonies to a dry weight basis.

Sample calculation to convert wet to dry weight bacterial concentrations

**1000 colonies/ 100 grams wet weight**
Sample is 20% solids, 80% moisture by weight
thus:
1000 colonies/20 grams solids
=50 colonies/gram solids
**= 5000 colonies/100 grams dry solids**

Weight vs. Volume Calculations:

The number of bacteria can be reported as colonies per gram of material on an “as is” wet weight basis. In order to determine the number of colonies per ml of material on an “as is” basis, the lab will need to weigh a known volume of the bedding. The number of colonies per ml can then be calculated on a volume basis as follows: (cfu/g wet weight) * (wet weight/volume).

Sample calculation to convert weight to volume bacterial concentrations

**1,000,000 colonies/gram wet weight**
100 milliliters of the bedding weighs 33 grams
thus:
(1,000,000 colonies/gram) * (33 grams/100 ml)
**= 330,333 colonies/ml**

## Comparison of Fecal Coliform Counts in Used and Unused DMS on One Farm Calculated on Wet (as is), Dry and Volume Basis

NOTE: These data are from one set of samples and are provided only as an example.

| | Dry Matter (%) | Volume (g/ml) |
|---|---|---|
| **Unused** | 37 | 0.41 |
| **Used** | 71 | 0.23 |

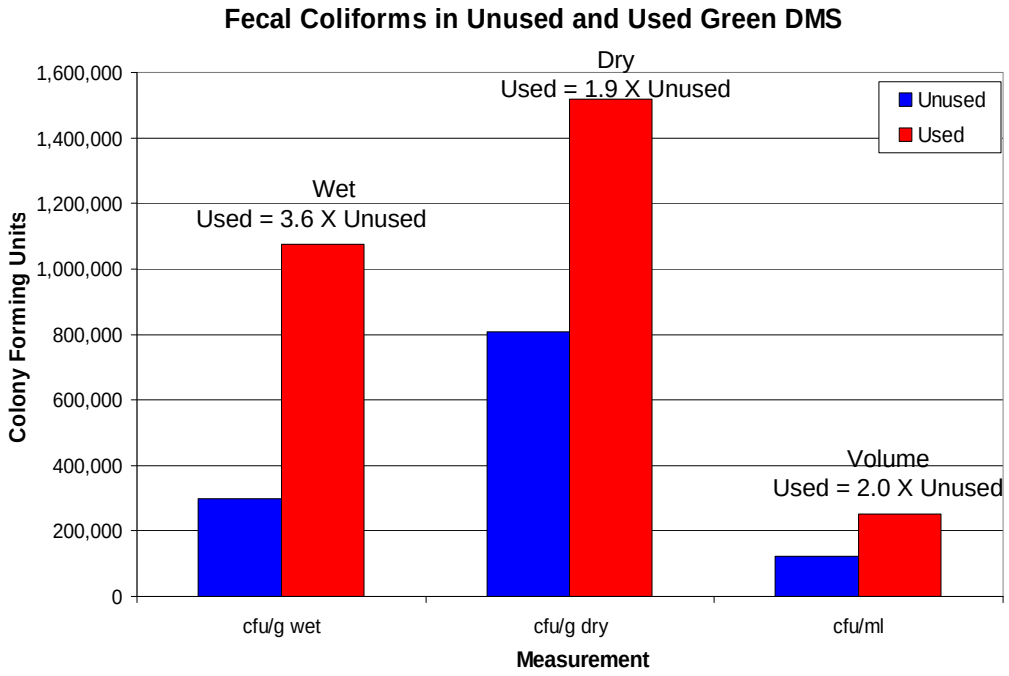



Figure 1.

**Comparison of Fecal Coliform Counts in Different Bedding Materials Calculated on Wet (as is), Dry and Volume Basis**

NOTE: These data are from one set of samples and are provided only as an example.

| | Dry Matter (%) | Volume (g/ml) |
|---|---|---|
| **Sand** | 96 | 1.16 |
| **CDMS** | 60 | 0.25 |
| **GDMS** | 66 | 0.32 |

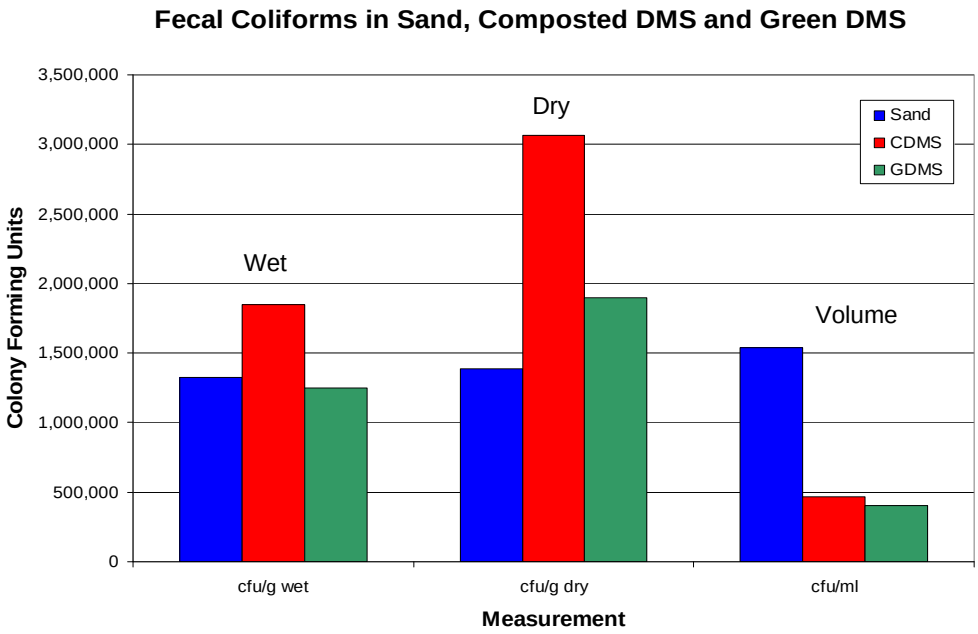



Figure 2.

Figures 1 and 2 show the difference between fecal coliform concentrations reported on a wet weight (as is), dry weight and volume basis. When comparing the same bedding source used vs. unused (Fig. 1), the fact that the material has dried in the barn so that the used is drier than the unused means that the difference between concentrations made on a wet weight basis is much greater than the difference on a dry weight basis or on a volume basis.

When comparing different materials, the impact of wet vs. dry vs. volume measures is more apparent. Fig. 2 shows that in one set of tests used, sand bedding was comparable to the green DMS and lower than composted DMS on a wet weight basis, but is much higher in fecal coliform when looked at on a volume basis. Note: These data are from one set of samples and are provided only as an example.

### *Organic vs. Inorganic Bedding Materials*

Brim and Timms (1989) – wet weight basis

- Trial to evaluate growth of environmental mastitis pathogens (*E. coli, K. pneumoniae* and *S. uberis*) in various bedding materials (all materials were clean – never used in a barn)
- Inorganic bedding sources (sand, limestone, and limestone treated with pine disinfectant) showed rapid bacterial growth by 6 hours and significantly higher growth of all organisms in 6-54 hours as compared to oat straw and cedar sawdust.
- Organic bedding sources (oat straw and cedar sawdust) showed a bimodal growth curve with increased bacterial growth at 6-24 hrs (slower rate than inorganic), followed by a decline from 36-54

hours. By 96-120 hours, coliform organisms in the oat straw and cedar sawdust were similar or higher than inorganic bedding sources.

- Coliform numbers remained elevated at 96 hours, while strep numbers declined for all bedding materials.

Hogan, et al (1989a) – dry weight basis

- Independent comparison of bedding materials showed mean seasonal bacterial counts measured over one year of used organic materials (sawdust and chopped straw) had significantly higher gram-negative, coliform, *Klebsiella* species and streptococcal bacteria than used inorganic materials (sand and crushed limestone)

Janzen, et al (1982) – wet weight basis

- *E. coli*, Enterobacter and *Streptococcus* counts in used and unused crushed limestone bedding < than DMS = 50:50 mixture of limestone and DMS. ($P < 0.05$)
- *Staphylococcus aureus* and *Staph. epidermis* counts in crushed limestone < DMS = 50:50 mixture. ($P < 0.05$)

Kristula, et al (2005)

- Comparison of bacterial counts in clean sand (CS) and recycled sand (RS)
- There was a significant increase in bacterial counts from day 0 to d 1 for gram-negative bacteria, coliforms, and *Streptococcus* spp. in both winter and summer for both CS and RS.
- In the winter, counts of the above bacteria did not differ from days 1 – 7.
- In the summer, gram-negative counts did not differ from d 1-7, but coliform counts were lower on d1 than days 5-7 and *Klebsiella* spp. counts were lower on d 1 than on d 3-7.
- The number of *Streptococcus* spp was high in both CS and RS during the sampling periods.

LeJeune and Kauffman (2005) – volume basis

- Took used bedding from the stalls and brought them into the lab and inoculated with *E. coli* O157:H7. Samples were taken over a period of 112 days.
- *E. coli* O157:H7 survived at higher concentrations in used sawdust bedding than in sand.

Newman and Kowalski (1973) – wet weight basis

- Large numbers of *Klebsiella* were isolated from unused sawdust bedding and storage bins in a 54-cow dairy herd having trouble with *Klebsiella* mastitis.
- At the second collection, *Klebsiella* numbers decreased which coincided with a change in bedding from sawdust to sand.
- According to the authors, the role of sawdust as a possible source of *Klebsiella* organisms is not unequivocal in this report and requires additional study. In this context it should be emphasized that changes in bedding from sawdust to sand preceded the decrease in the number of *Klebsiella* isolates in the milk and that a high percentage of sawdust samples from varied sources did contain *Klebsiella* organisms.

Zdanowicz (2002) dry weight basis – (fresh bedding added every 7 days)

- Sand Bedding:
  - Coliforms: d 0 < d 1 = d 2 = d 6
  - *Klebsiella* species: d 0 < d 1 < d 2<br>d 1 = d6; d2 = d 6
  - *Strep.* species: d 0 < d 2<br>d 1 < d 6<br>d 1 = d2; d6 = d 2
- Sawdust Bedding:
  - Coliforms: d 0 < d 1 < d 2 = d 6
  - *Klebsiella* species: d 0 < d 1 < d 2 = d 6
  - *Strep.* species: d 0 < d 1 = d 2 < d 6

Zdanowicz, et al (2004) dry weight basis - (fresh bedding added every 7 days)

- Sand Bedding:
  - Coliforms: d 0 < d 1 = d 2 = d 6
  - *Klebsiella* species: d 0 < d 1 < d 2 = d 6
  - *Strep.* species: d 0 < d 1 < d 2 < d 6

- Sawdust Bedding:
  - Coliforms: d 0 < d 1 < d 2 = d 6
  - *Klebsiella* species: d 0 = d 1 < d 2 = d 6
  - *Strep.* species: d 0 < d 1 < d 2 = d 6

Fairchild (1982) – dry weight basis

- Average total coliform counts over 9 weeks in used bedding were higher in sawdust ($4.1 \times 10^6$) and paper ($8.7 \times 10^4$) than in sand ($< 1.0 \times 10^3$) and lime ($< 1.0 \times 10^3$). The same was true for *Klebsiella.*

### *Comparison of Organic Bedding Materials*

Bramley and Neave (1975) – wet weight basis

- $10^4 – 10^5$ coliforms/g wet weight in all used bedding materials (sand cubicles, straw yards, wood shaving yards, sawdust yards) on one farm in 1971-72.
- $10^7$ coliforms/g wet weight in used sawdust yards on the same farm in 1972-73.

Hogan, et al (1989a) – dry weight basis

- *Klebsiella:* used sawdust > straw
- Streptococcal counts: straw > sawdust.

Hogan, et al (1990) – dry weight basis

- Gram-negative, coliform and streptococcal counts: used chopped newspaper = used corn cobs
- Staphylococcal counts: used chopped newspaper < used corn cobs
- Gram-negative and staphylococcal counts: used chopped newspaper > used wood shavings
- Streptococcal and coliform counts: used chopped newspaper = used wood shavings

Rendos, et al (1975) - wet weight basis

- Bedding only replaced where manure scraped – sampling at 7, 14 and 21 days old
- Unused bedding – pooled means from 9 samples/week
  - Total coliforms: straw > sawdust = shavings
  - *Klebsiella*: sawdust > shavings = straw
  - *Strep.*: straw > sawdust = shavings
  - *Staph.*: straw = sawdust > shavings
- Unused vs. used: all organisms significantly different
- Used bedding – pooled means from 9 samples/week
  - Total coliforms: no difference
  - *Klebsiella*: no difference
  - *Strep.*: straw > sawdust = shavings
  - *Staph.:* straw > sawdust > shavings
- Used bedding by week (bedding remained in the stalls over a 3 week period)
  - Total coliforms: no difference between weeks
  - *Klebsiella*: no difference between weeks
  - *Strep.*: wk 1 = wk 3 > wk 2
  - *Staph.*: wk 3 > wk 2, no difference between wk 1 and 2 or 1 and 3.

Zehner, et al (1986) dry weight basis - bacteria grown in bedding materials that were not exposed to urine or feces or in a barn environment at all – all samples were sterilized before inoculation.

- Growth of all bacteria: DMS > straw > hardwood chips > paper = sawdust
- In general, paper and softwood sawdust did not support growth of any of the bacteria (*E. coli, K. pneumoniae* and *S. uberis*.
- *Klebsiella* counts were significantly greater than *E. coli* counts in all bedding materials. Coliforms were significantly greater than *S. uberis* counts.
- The most rapid changes in growth of *Klebsiella* occurred in the first 24 h after inoculation with populations stabilizing after about 54 h.
- Coliforms grow more rapidly and decline less rapidly than environmental streptococci on all types of bedding studied.

- By comparing these results with data from studies under barn conditions, it appears that high bacterial counts under barn conditions are influenced by factors more complex than type of bedding used.

### *Composting and Addition of Lime and other Bactericides*

Carroll and Jasper (1978) – wet weight basis

- Total coliforms directly from the separator were about $10^7$/g wet weight at about 80% moisture.
- After composting for 9 months, they ranged from 0 to $10^4$.
- Once they were used as free stall bedding for several months, they ranged from $10^6$ to $10^8$.

Mote, et al (1988) – wet weight basis

- Composting manure solids in static piles decreased the number of coliforms and gram-negative bacteria to below detectable numbers, but as composting continued over the 10-wk period, both coliforms and gram-negative bacteria increased in numbers to that of fresh DMS (coincided with decline in internal temperature of piles).
- No justification for composting before use.

Fairchild, et al (1982) – dry weight basis

- *Klebsiella*: unused sawdust = unused sawdust plus lime.
- There was a significant difference between unused and used, but no significant increase after 1st week, with a reduction from wk 1 to wk 3. (the stalls were re-bedded after 1 week for 3 weeks)

Ward, et al (2002) – wet weight basis

- Studied 4 dairy farms that used straw yards for bedding
- The pH of the top layers of straw was usually between 8.5 and 9.5
- Adding lime daily to the top layer of the straw failed to raise the pH to levels at which *Escherichia coli* and *Streptococcus uberis* do not survive.
- Most of the counts of *E. coli* and fecal streptococci in the top layers of straw were above $10^6$ colony-forming units/g.

Hogan & Smith (1997) – looked at bacteria counts in sawdust only (control), sawdust plus lime (treatment 1) and sawdust re-bedded daily (treatment 2)– dry weight study

- Treatment effects on bacterial numbers and pH were limited after 1 day in the stall. The ability of lime to alter bacteria counts and pH apparently was diminished within 48 hours after application.
- Day 1: All bacteria: treatment 1 < treatment 2 = control
- Day 2: *Klebsiella* species: treatment 1 < treatment 2; treatment 1 = control
- Control: *Strep.* species, *Klebsiella* species, dry matter, pH: d 1 = d 2 = d 6
  Gram-negative, Coliforms: d 1 > d 6
- Treatment 1: All bacteria: d 1 > d 2 = d 6
- Treatment 2: All bacteria: d 1 = d 2 = d 6

Hogan, et al (1999) – additives to DMS and sawdust to reduce counts – dry weight basis

- Recycled manure – Gram negative counts
  - Unused: DMS > all treatments (DMS + lime = DMSL; DMS + acidic conditioner = DMSAcid; and DMS + alkaline conditioner = DMSAlk)
  - Day 1: DMS > DMSL; no other differences
  - Day 2 and 6: No difference in counts for any treatment.
- Recycled manure – Coliform counts
  - Unused: DMS > all treatments
  - Day 2: DMS = DMSAcid > DMSAlk
  - Day 1 and 6: No difference in counts for any treatment.
- Recycled manure – *Klebsiella* counts
  - Unused: DMS > all treatments
  - Day 1: DMS = DMSAcid > DMSL = DMSAlk
  - Day 2: DMS = DMSAcid > DMSL > DMSAlk
  - Day 6: No difference in counts for any treatment.

- Recycled manure – Streptococcal counts
  - Unused: DMS > all treatments
  - Day 1: DMS > all treatments
  - Day 2: DMS = DMSL = DMSAcid > DMSAlk
  - Day 6: No difference in counts for any treatment.
- Sawdust – Gram negative counts
  - Unused: SAW > all treatments (sawdust + lime = SAWL; sawdust + acidic conditioner = SAWAcid; sawdust + alkaline conditioner = SAWAlk)
  - Day 2: SAW > SAWAcid
  - Day 1 and 6: No difference in counts for any treatment.
- Sawdust – Coliform counts
  - No effect on counts with use of any of the additives at any time.
- Sawdust – *Klebsiella* counts
  - Unused: No difference in counts for any treatment.
  - Day 2: SAW > SAWAcid
  - Day 1 and 6: No difference in counts for any treatment.
- Sawdust – Streptococcal counts
  - Unused: SAW > SAWAcid
  - Day 2: SAW = SAWL = SAWAlk > SAWAcid
  - Day 1 and 6: No difference in counts for any treatment.

### *Seasons and Bacterial Counts in Bedding*

Hogan, et al (1989a) – dry weight basis
- Bacterial counts in long straw differed among seasons of the year:
  - Gram-negative: summer = fall > winter = spring
  - Coliforms: summer > winter
  - *Klebsiella* species: no seasonal differences
- *Klebsiella* counts in sawdust: summer = fall > winter = spring

Smith, et al, (1985a) – wet weight basis [Note: Since concentrations were based on wet weight measures, the drier DMS in summer would show higher counts than the same material when wetter.]
- Highly significant effect of season on colony forming units ($log_{10}$) of coliforms in recycled manure used in free stalls. Colony forming units in used DMS were higher in summer compared with other seasons. Summer > fall > spring = winter.
- The same was true for the pelleted corn cob bedding used in maternity units. Highest cfu coliforms in summer and lowest in winter.
- No data on streptococcal numbers.

Todhunter, et al (1995) – dry weight basis
- The number of streptococci in bedding materials exceeded $10^6$ cfu/g of dry weight for all bedding types during all seasons of the year.
- Streptococcal numbers in bedding of pelleted corn cobs were similar across seasons of the year.
- Season of the year had no effect on numbers of streptococci in bedding of wood shavings.
- The number of streptococci in recycled manure was lower ($P < .05$) during the summer than during the winter and spring.

## Bacteria in Bedding and on Teat Ends

The literature shows inconsistency regarding the relationship of bacterial concentrations in bedding to the bacterial concentration on teat ends. Factors such as particle size may be more important than simply bacterial counts in the used bedding. The relationship of teat end counts to mastitis is unclear and is reviewed below.

### *Studies Showing Counts in Bedding Correlated with Counts on Teat Ends*

Bishop, et al (1981)

- There was a significant difference in *E. coli* and *Enterobacter* counts between composted DMS (higher) and rubber mats and a significant difference on the teat ends (higher on cows bedded on DMS).

Fairchild (1982)

- *Klebsiella* teat end swabs and bedding samples were highly correlated (more on teat ends of cows bedded with sawdust than those bedded on lime).

Hogan and Smith (1997)

- Bacterial counts in bedding positively correlated with teat skin swabs.

Hogan, et al (1999)

- Recycled Manure: Coliforms
  - Day 2: Teat ends: DMS > DMSAlk
    Bedding: DMS > DMSAlk
  - Day 1 & 6: Teat ends: No difference
    Bedding: No difference
- Recycled Manure: *Klebsiella*
  - Day 2: Teat ends: DMS = DMSAcid > DMSL > DMSAlk
    Bedding: DMS = DMSAcid > DMSL > DMSAlk
  - Day 6: Teat ends: No difference
    Bedding: No difference

Janzen, et al (1982)

- *E. coli*, *Enterobacter* and *Strep.* spp. counts on teat ends were significantly less in cows bedded on crushed limestone vs. DMS or 50:50 mixture.
- *Staph. aureus* and *Staph. epidermis* counts on teat ends were significantly less in cows bedded on crushed limestone vs. DMS or 50:50 mixture.

Natzke and LeClair (1975)

- Large numbers of coliform bacteria were found on teat ends of cows bedded with sawdust artificially contaminated with coliform bacteria as compared to controls (sawdust not contaminated with coliform bacteria).

Zdanowicz (2002)

- There was a significant correlation between the mean “cow-bedding count 1” (time spent lying in a stall multiplied by the bacterial count for the stall) and the bacterial counts on teat swabs for cows housed on sand for coliforms and *Klebsiella* spp.
- There was a significant correlation between the mean “cow-bedding count 1” and the bacterial counts on teat swabs for cows housed on sawdust for coliforms, *Klebsiella* spp. and *Streptococcus* spp.

Zdanowicz, et al (2004)

- There were 2 times more coliforms and 6 times more *Klebsiella* bacteria on teat ends of cows housed on sawdust compared with those housed on sand.
- There were 10 times more *Strep*. spp. bacteria on teat ends of cows when housed on sand compared with sawdust.

### *Studies Showing Counts in Bedding Not Correlated with Counts on Teat Ends*

Hogan, et al (1990) There is a positive correlation when data for all bacteria from each bedding type is pooled, but not necessarily each bacteria separately.

- Correlations between bedding counts and teat skin counts were not significant within bedding type.
- All bacteria: Teat Ends: week 1 > week 2 = week 3
  Bedding: week 1 = week 2 = week 3
- Gram-negative, coliform and *Klebsiella*: Teat ends: chopped newspaper = corn cobs
  Bedding: chopped newspaper = corn cobs

- Gram-negative: Teat ends: newspaper = wood shavings
  Bedding: newspaper > wood shavings
- *Strep.* spp.: Teat ends: newspaper > wood shavings
  Bedding: newspaper = wood shavings
- Appeared that adherence of bedding (due to particle size) had more to do with the difference in teat swab counts than the amount of bacteria in the bedding. (i.e. teat swab counts for gram-negative, coliform and *Klebsiella* differed between cows bedded on newspaper and corn cobs, but the amount of bacteria in the bedding didn't – corn cobs adhered more to the teats because of fine particle size and those cows had higher teat swab counts).

Hogan, et al (1999) – There is a positive correlation when data for all bacteria from each bedding type is pooled, but not necessarily each bacteria separately.

- Recycled Manure: Gram-negative
  - Day 1: Teat ends: DMS = DMSL > DMSAlk = DMSAcid
    Bedding: DMS > DMSL and DMS = DMSAlk = DMSAcid
  - Day 2: Teat ends: DMSL > DMSAlk
    Bedding: DMSL = DMSAlk
- Recycled Manure: *Strep.* species
  - Day 1: Teat ends: DMS > DMSAcid only
    Bedding: DMS > DMSL = DMSAlk = DMSAcid
  - Day 2: Teat ends: DMS > DMSAcid only
    Bedding: DMS = DMSL = DMSAcid > DMSAlk
- Recycled Manure: *Klebsiella*
  - Day 1: Teat ends: DMS = DMSL > DMSAcid = DMSAlk
    Bedding: DMS = DMSL > DMSAcid = DMSAlk
- Sawdust – None of the bacterial counts on teat ends correlated with those in the bedding.

Rendos, et al (1975)

- Total Coliform counts on teats in sawdust > shavings = straw. There were no differences in coliform counts in the different bedding materials.
- *Klebsiella* counts on teats in sawdust > shavings > straw. There were no differences in bedding counts.
- *Strep.* spp. counts on teats in straw > shavings > sawdust. In bedding, straw > sawdust = shavings.
- *Staph.* spp. counts on teats in straw = sawdust > shavings. In bedding, straw > sawdust > shavings.
- Teat swab means between groups of cows (3 different sets in this trial) were significantly different from each other for all bacteria, indicating a cow effect on teat end contamination.

Zdanowicz (2002)

- There was no significant correlation for "cow-bedding counts 1" and teat end streptococci counts for cows bedded on sand.

# Relationship of Bacteria in Bedding and on Teat Ends to Mastitis and Milk Quality

Researchers have generally stated the rule of thumb that bedding materials should be kept below a maximum bacterial count of $10^6$ colony forming units (cfu) per gram of bedding wet weight. This number appears to be based on one study where there were no new cases of coliform mastitis when bedding counts were at $10^4$ and $10^5$ one summer, but there were several new cases the following summer when bedding counts were at $10^7$ cfu/g wet weight (Bramley and Neave, 1975). This paper does not claim that $10^6$ colony forming units (cfu) per gram of bedding wet weight is a critical level and it represents data from only two summers on one farm. A few studies show a correlation between the number of bacteria in the bedding and/or the number on the teat ends and mastitis while a number of studies show no correlation. Few studies examined the relationship between bedding pathogens and milk quality.

### *Counts in Bedding and Mastitis*

Bramley (1982)

- Large numbers of *Strep. uberis* were isolated from samples of straw bedding for cattle from farms which suffered a high incidence of *S. uberis* mastitis, but the results did not demonstrate a direct relationship between exposure to *S. uberis* from straw bedding and udder disease.

Fairchild (1982)

- Coliform counts > $10^6$ in sawdust, but no new infections
- Unable to demonstrate a direct relationship between bacterial counts in bedding and rates of coliform or environmental IMI.
- High populations of coliforms will not necessarily cause infection under good management conditions.
- Type of bedding may be just one link in a chain of possible situations that promote mastitis.

Hogan, et al (1989a)

- Neither percentages of quarters infected at calving nor mean rates of clinical mastitis during the first 7 days of lactation were correlated with long straw bacterial counts (maternity area bedding).
- Linear relationships were significant among total rates of clinical mastitis during lactation and counts of gram-negative bacteria and Klebsiella species in lactating cow bedding.

Hutton, et al (1990)

- Prevalence of cows' environmental pathogen IMI was similar between high and low SCC herds as was the number of environmental organisms in bedding materials.

Todhunter, et al (1995)

- In recycled manure bedding, no correlation existed between the rate of environmental streptococcal IMI during the dry period and streptococcal numbers in bedding by season of the year.

Munoz, et al (2006)

- In a 5-mo study in a NY dairy herd performed during the summer of 2005, all of 9 samples of unused sand bedding tested negative for *Klebsiella.*
- 14 of 18 samples of used sand bedding contained *Klebsiella* at a median level of $10^{4.6}$ cfu/g
- It is hypothesized that fecal shedding of *Klebsiella* by dairy cows contributes to the presence of *Klebsiella* in the environment regardless of bedding type.

### *Counts on Teat Ends and Mastitis*

Hogan, et al, (1990)

- IMI status of the quarters had no effect on teat swab counts

Neave and Oliver (1962)

- If teats are experimentally contaminated (> 30,000 colonies) with *Staph. aureus* (contagious mastitis pathogen) at the end of lactation, the quarters are much more likely to become infected than if the teats are lightly contaminated (30,000 colonies or less).
- The association of large numbers ($15 \times 10^6$) of *Staph. aureus* at the apex and infection of the quarter was highly significant ($P < 0.001$) ($15 \times 10^6 > 30{,}000 = 60 =$ none).
- *Strep. uberis* was not recovered from either teats or orifices at the end of lactation, but was present in large numbers in six orifices 21 days later. All of these were associated with infected quarters. As *Strep uberis* was not applied to the teats at drying-off, it was assumed that those udders found to harbor it became contaminated from the environment of the dry cow.

Natzke and LeClair (1975)

- No new coliform IMI despite large numbers on teat ends

### *Counts in Bedding Correlated with Counts in Milk*

Hogan, et al (1988) (dry weight study).

- Gram-negative, coliform, and streptococcal counts in bulk tank milk were associated with bacterial counts in bedding materials
- Significant correlations among bacterial counts in bulk tank milk and bacterial counts in bedding were: gram-negative and gram-negative, coliform and coliform, coliform and *Klebsiella* species, and streptococcal and streptococcal.

### *Counts on Teat Ends Correlated with Counts in Milk*

Janzen, et al (1982)

- *E. coli*, *Enterobacter* and *Strep.* spp. counts on teat ends and in the milk were significantly less in cows bedded on crushed limestone than in DMS or 50:50 mixture
- *S. aureus* counts on teat ends and in the milk were less in crushed limestone than DMS or 50:50 mixture.

## Hygiene and Mastitis

The impact of bedding, cleanliness of the udder and/or legs on the mastitis rate of a herd is unclear. Bedding may play a role in the cleanliness of the udder, and pre-milking udder hygiene may play a role in the amount of mastitis seen.

### *Housing Hygiene and Mastitis*

Barrett, et al (2005)

- Herds with prolonged periods on straw bedding in yards (exposed to rain, cleaned less frequently) were more likely to acquire environmental mastitis (12 herds in Ireland).

Bartlett, et al (1992)

- General sanitation in lactating cow housing was an important disease determinant of both coliforms and environmental streptococci.
- Improving general sanitation by 1 unit (scores of 1 – above average, 2 – approximately average and 3 – worse than average) was associated with a 57% reduction in the prevalence of coliform infection.

Howell, (1972)

- Survey of 50 herds in England having trouble with environmental mastitis (comparison of management)
- Cause of *E. coli* infection is believed to be the feces and infection is due to gross fecal contamination of the teat orifice. *E. coli* mastitis was rare in summer when cattle are pastured and only occurred in herds where zero grazing was practiced or where cows were kept for long periods in dirty yards during milking. Where *E. coli* occurred in cubicle herds, it was when there were obvious faults of the cubicles (i.e. wrong length, so dung fell in cubicle rather than alleyway and cows lay in it).

Peeler, et al (2000)

- Survey of management practices of British dairy herds with low somatic cell count (average 76,000 cells/ml) showed the following bedding variables lead to increased rate of clinical mastitis: straw in milking cow accommodations and mucking out the calving area less than once/month.
- The following bedding variables were shown to decrease the rate of clinical mastitis: cleaning out dry cow accommodation at least once/week, sawdust/wood shavings in the calving area and sawdust/wood shavings in dry cow accommodations.

Ward, et al (2002)

- Looked at 4 dairy farms that used straw for bedding.
- The farm with the lowest incidence of mastitis had the cleanest cows and the most satisfactory beds.

- Counts of E. coli and S. uberis were much higher in the beds of early lactation cows than in those of dry cows. Many of the early lactation cows were heavily and persistently contaminated with feces. Dry cows were much cleaner.

Barkema, et al (1999b)

- *E. coli* incidence higher if lactating cows are not allowed to graze at night.
- *S. aureus* and *S. dysgalactiae* incidence lower with thicker layer of straw in calving pen
- *S. dysgalactiae* incidence lower with thicker layer of straw in cubicles of dry cows
- *S. uberis* incidence higher with disinfection of cubicles of lactating cows.

Schukken, et al (1991)

- *E. coli* mastitis incidence lower if cubicles cleaned of manure, and with rubber mats at calving site, higher with complete cleaning of dry cow cubicles.
- *S. aureus* incidence lower with higher amount of bedding in cubicles.

Elbers, et al (1998)

- The following risk factors were associated with a higher rate of clinical mastitis caused by *E. coli*: no disinfection of the maternity area after calving, use of a thick layer of bedding in the stall.
- The following risk factors were associated with a higher rate of clinical mastitis caused by *S. aureus*: no regular disinfection of the stall, no regular replacement of stall bedding.

### *Animal Hygiene and Mastitis*

Neave, et al (1969)

- Herds using a full hygiene milking routine (use of disinfectants, paper towels, or boiled cloths for washing each individual udder, the wearing of rubber gloves by the milker, and the pasteurization of teat cup clusters before each cow is milked, together with post-milking disinfectant teat dips) had a 45% reduction in new udder infection in one trial and a 58% reduction in the 2nd trial when compared with herds that practiced only washing with water and a shared cloth.
- Herds using a partial hygiene milking routine (same as full, but without the pasteurization of teat cup clusters) showed a 44% reduction in new udder infection when compared to control cows.

Pankey, et al (1987)

- Rate of IMI by major mastitis pathogens was reduced significantly by pre-dipping plus good udder preparation compared with good udder preparation alone.
- Pre-dipping reduced IMI due to environmental pathogens in each herd. Reduction in IMI with environmental pathogens ranged from 47% to 56%.
- This study suggests that the environmental pathogens cause new infections during milking. The inference is that the number of environmental pathogens on teats prior to milking is reduced significantly by pre-dipping with an effective germicide, and consequently, the rate of new infections is reduced. It appears that environmental pathogens contaminate teat skin between mlkings but may or may not cause new infections between milkings.

Schreiner and Ruegg (2003)

- Udder hygiene scores (UHS) were significantly associated with leg hygiene scores (LHS).
- Linear somatic cell scores increased as UHS increased (dirtier udders).
- Significant differences in somatic cell scores were observed for clean (UHS scores of 1 [completely free of or has very little dirt] and 2 [slightly dirty]) versus dirty (UHS of 3 [mostly covered in dirt] and 4 [completely covered, caked-on dirt]) udders.
- There was a significant association between the prevalence of intra-mammary contagious pathogens in the milk and UHS but not LHS.
- The prevalence of intra-mammary environmental pathogens was significantly associated with UHS but not associated with LHS.
- Cows with UHS of 3 and 4 were 1.5 times more likely to have major pathogens (both contagious and environmental) isolated from milk samples compared with cows with hygiene scores of 1 and 2.
- The type of surface of the free-stall bed and the type of bedding used on that surface are likely to have a large influence on UHS but probably have less influence on LHS.

- Manure management systems, frequency of cleaning of barn alleys, and the ease of movement of cattle are likely factors that have a larger influence on LHS than on UHS.

Zarkower and Scheuchenzuber (1977)

- Pre-milking washing and drying of teats with iodine solution had no effect on total colonies, staphylococci, streptococci, gram-negative lactose fermenters and gram-negative lactose non-fermenters on the teat apex as compared to unwashed teats.
- When washed and dried thoroughly (with special care to include the teat orifice area), total number of colony-forming units was decreased significantly.

Zdanowicz, et al (2004)

- Udders of cows housed on sand had higher grid counts (dirtier udders) than those on sawdust.
- No clear correlation between udder cleanliness and teat end bacterial counts.

# Somatic Cell Count (SCC) and Mastitis

Several studies have been conducted on the differences between herds that have low average SCC counts and herds that have high average SCC counts. Other studies look at the value of SCC count in determining intra-mammary infection status in herds. High SCC is correlated with decreased milk production. SCC is measured both with a bulk tank sample (BTSCC) and with individual milk samples from each cow. BTSCC can be a good indicator of a herd's general udder health status, with high BTSCC generally indicating a problem with contagious mastitis. Herds with lower BTSCC have lower subclinical mastitis and better general udder health. However, the presence of leucocytes in the udder helps protect it from getting other mastitis, therefore low SCC appears to predispose cows to getting environmental mastitis. By looking at individual cow SCC over a period of several months, patterns can be established for each cow. Spikes in individual cow SCC usually indicate environmental mastitis and are often short in duration. When SCC is done on a monthly or other low frequency basis, these spike may be missed. Thus typical BTSCC cannot generally be used to diagnose environmental mastitis at the herd level unless it is pervasive and persistent.

### *SCC and Milk Yield*

Barkema, et al (1998b)

- As bulk milk somatic cell count (BTSCC) decreased, milk production increased ($P<0.0001$). Herds with a low BTSCC had a mean cumulative fat corrected milk production during 305 d of lactation of 8589 kg compared with 8072 kg for herds with a high BTSCC.

Deluyker, et al (1993)

- Both elevated SCC and clinical mastitis were associated with milk yield losses.
- The milk yield loss associated with clinical mastitis represented 5% of yield in the first 119 d postpartum.
- A 6% yield loss was associated with a mean SCC of 383,370 cells/ml, compared with a mean SCC of 47,465 cells/ml.

Raubertas and Shook (1982)

- Regression coefficients for the average $\log_e$ of SCC were negative and highly significant for all lactations, indicating that increased average log cell count is associated with reduction in yield. Coefficients become larger with lactation number through the first three lactations.
- Yield loss per unit increase in average $\log_e$ cell count was 135 +/- 20 kg in first lactation and 270 +/- 30 kg for all other lactations.
- These relationships were linear indicating that loss per unit increase in actual cell count is greatest when cell count is low.

Hortet and Seegers (1998)

- At test-day level (milk production on the day of testing), the average trend was a loss of 0.4 kg of milk in primiparous cows and 0.6 kg in multiparous, by each 2-fold increase of SCC above 50,000 cells/ml.

- At the lactation level (cumulative milk production over the lactation), the average trend was a loss of 80 kg of milk in primiparous and 120 kg in multiparous, by each 2-fold increase of the geometric mean of SCC above 50,000 cells/ml.
- Protein content of milk showed a small increase of 0.15 g/kg (at the test-day level) while fat content showed a small decrease of 0.20 g/kg (both at the test-day and at the lactation level), by each 2-fold increase of SCC.

Salsberg, et al (1984)

- One unit increase in the $\log_e$ of the geometric mean of the somatic cell count was associated with a loss of 247 kg of 305 day milk production.
- One unit increase in the $\log_e$ of the 24 hour somatic cell count was associated with a decrease of 0.65 kg of test day milk production.

Dohoo, et al (1984)

- A unit increase in the log count of SCC resulted in a loss of 1.44 kg of milk at test day.

### *The Value of SCC in Determining Intramammary Infection Status*

DeHaas (2004)

- Clinical mastitis can be predicted better by SCC patterns than by the average of 200,000 cells/ml in lactation.
- Short peaks in SCC are associated with clinical *E. coli.*
- Long increased SCC is associated with *Staph. aureus.*
- No pattern for streptococcus was shown.

Deluyker, et al (1993)

- In a low SCC herd free of *Staph. aureus, Strep. agalactiae* or *Strep. dysgalctiae,* cows with clinical mastitis were characterized by a high SCC prior to clinical mastitis diagnosis; SCC increased further around the time of diagnosis and returned to high pragmatists counts after about 10 d following the end of treatment.

Hogan, et al (1988)

- Rates of total clinical mastitis were significantly correlated with bulk tank milk SCC (82.3% were environmental).

Smith, et al (1985b)

- SCC counts from individual or bulk tank counts are of questionable value for surveillance of environmental mastitis. This is because IMI are of short duration, and percent quarters infected at any time is generally not great.

Suriyasathaporn, et al (2000a)

- Very low somatic cell counts during the udder inflammation-free state (no mastitis) are associated with increased risk of clinical mastitis.

Peeler, et al (2003)

- The association between quarter somatic cell counts (QSCC) of milk and the risk of clinical mastitis (CM) was investigated in a one year study on three dairy herds in Somerset, UK.
- QSCC was categorized and the risk of CM occurring in the month after the QSCC was examined.
- When all cases of CM were considered, quarters with SCC 21,000 – 100,000 cells/ml had reduced odds and quarters with SCC > 200,000 cells/ml had over three times the odds of CM compared with QSCC 1,000 – 20,000 cells/ml.
- When only coliform CM were investigated, quarters with SCC 6,000 – 200,000 cells/ml had reduced odds of coliform CM compared with QSCC 1,000 – 5,000 cells/ml, and SCC > 200,000 cells/ml were not significantly different from the baseline.
- When *S. uberis* CM were investigated, quarters with SCC > 200,000 cells/ml had more than three times the odds of *S. uberis* CM compared with QSCC 1,000 – 20,000 cells/ml.
- QSCC < 21,000 and > 200,000 cells/ml are associated with increased odds of CM in the following 4 – 6 weeks: this association may be pathogen specific.

Zadoks et al, 2001.

- SCC was not associated with the risk of infection with S. uberis
- low SCC was associated with a lower risk of infection with S. aureus

### *Differences in Mastitis Between Low and High SCC Herds – Types of Bacteria*

Barkema, et al (1998a)

- The mean incidence rate of clinical mastitis (IRCM) was approximately equal for herds in the low (SCC <=150,000/ml), medium (SCC 150,000 to 250,000) and high (SCC 250,000 to 400,000) bulk milk somatic cell count (BTSCC), but the pathogens were different and the severity of the disease was higher at the lowest BTSCC.
- The IRCM caused by *Strep. agalactiae, Strep. dysgalactiae* or *Staph. aureus* was lower for herds in the low BTSCC category than for herds in the medium or high BTSCC categories.
- Mixed cultures and contaminated samples were found less often in herds in the low BTSCC category than in herds in the high BTSCC category.
- The IRCM caused by *E. coli, Klebsiella* spp., *Pseudomonas* spp., and culture negative was higher for herds in the low BTSCC category than in the medium or high categories.
- The IRCM for cows that were reported by the farmer to be systemically ill was higher for herds in the low BTSCC category than for herds in the medium and high BTSCC categories.

Erskine, et al (1988)

- The incidence of clinical coliform (environmental) mastitis was significantly higher in the low SCC herds, but the incidence of clinical mastitis attributable to *Str. agalactiae* and *S. aureus* (contagious IMI) was significantly higher in the high SCC herds.

Hogan, et al (1989b)

- In a study of nine well managed herds with low somatic cell counts, a total of 646 clinical cases of mastitis were diagnosed. Coliforms, bacteriologically negative and environmental streptococci accounted for 82.3% of these cases, while contagious mastitis pathogens accounted for only 3.4% of the clinical cases.

Hutton, et al (1990)

- The only significant difference in the prevalence of intra-mammary infection major pathogens between high and low SCC herd groups was the pathogen *Staph aureus*. Eight times more cows had *S. aureus* in high than in low herds.

Jasper, et al (1975)

- Case histories of herds in California with coliform mastitis problems showed varying probable reasons for the problem.
- One herd's coliform mastitis problem coincided with their decrease in contagious mastitis problems.

### *Differences in Mastitis between Low and High SCC Herds – Management*

Barkema, et al (1998b)

- Post milking teat disinfection and dry cow therapy were practiced most frequently with herds with low bulk milk somatic cell count (BMSCC).
- For herds with a low BMSCC, more attention was paid to hygiene and detail than was paid to these areas for herds with medium or high BMSCC.
- Cubicles, drinking buckets and cows were cleaner in herds with a low BMSCC

Barkema, et al (1999)

- 300 Dutch dairy herds were studied for management style and its association with BMSCC.
- Cluster analysis was used to identify groups of farmers who had similar management styles for the prevention of mastitis – two management styles (clusters) were identified as clean and accurate, and quick and dirty.

- The relationship between clusters and BMSCC was high, but the relationship between clusters and mastitis was weak.
- Farms with herds that had a low bulk milk SCC had better hygienic conditions than those farms with herds that had a high bulk milk SCC.

Hutton, et al (1990)

- Low SCC herds (greatest % of animals with SCC <= 283,000 cells/ml) had lower moisture content of cow bedding than "high" SCC herds, however the prevalence of non-contagious mastitis was similar between low and high groups, thus it is not clear how drier bedding relates to lower SCC.

Schukken, et al (1990)

- Risk factors associated with the mastitis rate in herds with low bulk tank SCC included the use of mats in cubicles, and the percentage of dirty cubicles. Rubber mats were generally associated with a moist surface giving an environment that may support bacterial growth. Percentage of dirty cubicles was correlated to the rate of mastitis and also correlated to the cleanliness score of the cows.
- A high frequency of cubicle disinfection per month (with formalin) was associated with higher mastitis, possibly by causing skin irritation and lesions which are predisposing to clinical mastitis.

Schukken, et al (1991)

- Presence of rubber mats in herds with low bulk tank SCC was associated with an increase in the incidence rate of both *E. coli* and *S. aureus* mastitis.
- More frequent cleaning of manure by hand from the cubicle was associated with lower incidence rate of *E. coli* mastitis.
- Greater amount of bedding in cubicles of the lactating herd was associated with lower incidence rate of both *E. coli* and *S. aureus* mastitis.

# Other Mastitis Issues

Other issues that may affect intramammary infection in dairy herds include stage of lactation and the dry period, parity (number of lactations), milking and milking machine factors including the use of post milking dips, teat end roughness and callosity, seasons of the year, nutrition, and housing conditions other than bedding.

### *Stage of Lactation*

Barkema, et al (1998a)

- The highest incidence rate of clinical mastitis (IRCM) was in early lactation. Peak incidence around calving was higher in heifers than in older cows: >30% of the cases of clinical mastitis in heifers occurred during the first 14 d of lactation, but, in cows, this prevalence was at 13%. After the 2$^{nd}$ wk of lactation, the IRCM was higher in cows than in heifers.

Bartlett, et al (1992)

- A greater prevalence of environmental streptococcal infection was associated with herds that had increased number of days dry.

Hogan, et al (1989b)

- Rates of clinical mastitis were highest the first 90 d and decreased throughout lactation.
- Rates of clinical cases was highest the week following calving for each of coliform, environmental streptococcal and bacteriologically negative clinical cases.

Erskine, et al (1988)

- Low SCC herds had a high incidence of clinical mastitis during the first month of lactation, while clinical mastitis in high SCC herds tended to be uniform during the entire lactation period.

Peeler, et al, (2000)

- The rate of clinical mastitis decreased with a dry period of <40 days.

Smith, et al (1985a)

- Dry treatment significantly influenced the rate of environmental streptococcal IMI during the dry period. Rate of strep IMI was highest in cow groups not dry treated (6 to 7 times higher).

- However, for coliform mastitis, after adjusting for parity and season, there was little or no indication that any of the treatments (dry cow therapy, immunization, artificial infusion and combinations thereof) including immunization significantly altered the rate of coliform IMI during the dry period.

Smith, et al (1985b)

- Rate of coliform IMI was highest in first 76 days of lactation and decreased progressively as lactation advanced.
- Rate of streptococcal IMI was twice as high as coliform IMI and decreased as lactation advanced, but not as markedly as coliform IMI.
- Rate of coliform IMI in the dry period was 3 to 4 times higher than the rest of lactation.
- Rate of streptococcal IMI in the dry period was 1.6 times higher than rest of lactation.
- Dry cow therapy had an effect on streptococcal IMI, but not coliform.

Todhunter, et al (1995)

- Rate of new environmental streptococcal IMI was highest during the 1st month of lactation, and were highest in that period for cows in lactation >= 4 and heifers.
- The rate of IMI declined from 31 to 150 DIM for all cows.
- The rate of IMI further declined from 151 DIM to drying off for cows in 1st or 2nd lactation, but rates of new infection in late lactation increased for cows in 3rd and 4th lactation compared with rates at 31 to 150 DIM.

### *Parity*

Barkema, et al (1998a)

- The incidence rate of clinical mastitis increased as parity increased.

Smith, et al (1985a)

- Parity group had an influence on IMI. Heifers had less coliform IMI than 2nd and 3rd lactation.

Smith, et al (1985b)

- Rate of coliform IMI was approx 3x as high in multiparous cows as heifers in first lactation.
- Parity had an effect on both coliform and streptococcal IMI. Rate of both increased approximately 5 times from 1st lactation to lactation 6 or greater.

Zadoks, et al (2001)

- Rate of IMI by *S. uberis* and *S. aureus* are lower in first and 2nd parity than in older cows.

### *Milking and Milking Machine Factors*

Barkema, et al (1999a)

- Milking machine factors were associated with the incidence rate of clinical mastitis (IRCM) caused by *E. coli, Streptococcus dysgalactiae,* and *Streptococcus uberis.* As milking vacuum pressure increased, prevalence of IMI increased.
- Post milking teat disinfection was associated with an increased overall IRCM and IRCM caused by *E. coli*, especially in herds in the low BTSCC category.

Bartlett, et al (1992)

- A greater prevalence of coliform infection was associated with herds that had a comparatively large amount of milk left in the udders after being milked, herds with longer milking times, herds that used running water to clean cows before milking and herds with more liner slippage.
- A lower prevalence of environmental streptococcal infection was associated with herds that used individual rags or cloths for drying udders.

Eberhart and Buckalew, (1977)

- The level of infections with streptococcal species other than *Str. agalactiae*, which was initially low (1.8%), has increased to 6.3% over the years since post-milking teat dipping and dry-cow therapy were introduced in the Pennsylvania State University dairy herd.

- Comparison of incidence of clinical mastitis over several years indicates that the incidence was not appreciably reduced by the use of teat dipping and dry cow therapy, but that there were changes in the types or organisms isolated. Streptococcal species other than *Strep agalactiae* and gram-negative organisms became the cause of about two-third of the clinical mastitis.

Hogan, et al (1988)

- Bulk tank milk bacterial counts were associated with the number of quarter-milkings that liners were used. Liners used greater than 1200 quarter-milkings were associated with higher total bacterial and staphylococcal counts than were liners used less than 1200 quarter-milkings. This could be caused by teat skin bacteria adhering to the worn surface of the liners.

Jasper, et al (1975)

- Case histories of herds in California with coliform mastitis problems showed varying probable reasons for the problem.
- Two years after virtually eliminating contagious mastitis problems, one herd began to have trouble with acute coliform mastitis. In this case, a batch of liners was defective and rapidly became cracked. The problem disappeared almost immediately after the liners were replaced.
- The problem in another herd illustrates that bacterial build-up and infection can also occur through the efforts of man that change the ecologic environment. In this instance, chlorhexidine of unknown and imprecise concentrations was being used to disinfect teat cup clusters between cows and between milkings. The chlorhexidine had effectively eliminated the natural microbial competition and had left the field free for abundant growth of pseudomonas. Exposure to the heavily colonized liner during milk was sufficient to bring about quarter infections.

Neave, et al (1969)

- Large differences in new infection rates between herds using full hygiene systems to control mastitis were most probably due to milking machine differences that result in an increase in infection during milking, i.e. vacuum reserve, air bleed, pulsation characteristic, milk lift and inflation design.

Peeler, et al, (2000)

- Survey of management practices of British dairy herds with low somatic cell count (average 76,000 cells/ml)
- The following milking variables were associated with increased rate of clinical mastitis:
  - Herds that always practiced post milking teat disinfection
  - Herds that changed the teat liner at > 6000 or more milkings
  - Herds where there were cows leaking milk on entering the parlor
- The following milking variables were associated with decreased rate of clinical mastitis
  - Herds that used a rotary parlor
  - Herds that used a confinement yard (loafing) after milking
  - Herds using automatic cluster removal.

Zarkower and Scheuchenzuber (1977)

- Use of a post-milking iodophor teat dip significantly reduced the total bacterial and staphylococcal populations but no effects were noticed on the streptococcal bacteria counts.

### *Teat Ends*

Neave, et al (1969)

- In herds practicing full hygiene a significant relationship was found between the new infection rate and the number of cows with teat lesions.

Neijenhuis, et al (2001)

- In the within-cow analysis (teat end callosity thickness - TECT and roughness - TECR compared between quarters with mastitis and lateral quarters of the same cow without mastitis), TECT was significantly higher in the mastitic quarters than in those without clinical mastitis. There was no difference in TECR.
- In the between cow analysis (cows with mastitis were paired with similar cows without mastitis based on parity and date of calving), clinical mastitis cows had thicker, and more frequently rough,

callous rings on their teat ends than cows that did not have clinical mastitis, both before and after the clinical mastitis occurred, if it occurred between the 1st and 6th month of lactation. On the other hand, cows with clinical mastitis in the first month of lactation showed less TECT and TECR during lactation than other cows.

- Clinical mastitis cases which were culture-negative or caused by less frequently found pathogens like yeast, *K. pneumoniae* and *E. aerogenes* were associated with higher teat end callosity, while clinical *E. coli* mastitis was associated with less TECT.

Zadoks, et al (2001)

- Teat end roughness and extreme teat end callosity increased the rate of *S. aureus* mastitis but not *S. uberis* mastitis.

### *Seasonality*

Hogan, et al (1988)

- Rates of clinical mastitis differed among seasons of the year and were associated with bulk tank milk somatic cell counts.
- Rates of total and coliform clinical cases were higher during summer than spring.

Hogan, et al (1989b)

- Mean rate of clinical mastitis cases was highest during summer and decreased throughout fall and winter to a low in spring.
- Rates of coliform and bacteriologically negative clinical cases were highest during summer, lowest during spring.
- Rates of clinical mastitis caused by environmental streptococci did not differ among seasons of the year.

Erskine, et al (1988)

- The peak incidence of clinical coliform mastitis was recorded during August. Peak percentages of clinical mastitis caused by other environmental mastitis organisms were recorded in July or August, and the peak incidence of contagious pathogens was in June, July and August.

Smith, et al (1985a)

- Season of the year has an influence on IMI. Coliform IMI was lower in winter (Dec, Jan, Feb) and fall (Sep, Oct, Nov) than in spring (Mar, Apr, May) and summer (Jun, Jul, Aug).
- Parity group had an influence on IMI. Heifers had less coliform IMI than 2nd and 3rd lactation.
- After adjusting for parity and season, there was little or no indication that any of the treatments (dry cow therapy, immunization, artificial infusion and combinations thereof), including immunization significantly altered rate of coliform IMI during the dry period.

Smith, et al (1985b)

- Rate of coliform IMI was elevated by a factor of 3 during summer and the effect was primarily associated with multiparous cows.

Todhunter, et al (1995)

- Rates of environmental streptococcal IMI during the dry period and during lactation were greatest during summer.

### *Nutrition*

Barkema, et al (1999a)

- Nutrition was associated with the incidence rate of clinical mastitis (IRCM) caused by *E. coli*, *Streptococcus dysgalactiae*, and *Streptococcus uberis.* The presence of minerals in the diets of lactating cows was associated with a decreased IRCM caused by *S. dysgalactiae* and *S. uberis.* When lactating cows were fed corn silage, a lower overall IRCM and IRCM caused by *S. uberis*, and a higher IRCM caused by *E. coli* were observed.

Peeler, et al, (2000)

- Offering fresh feed after both milkings decreased the rate of clinical mastitis.

Suriyasathaporn, et al (2000b)

- A review of the role of ketosis resulting from negative energy balance in the risk of mastitis.
- Udder defense mechanisms are reduced in cows with ketosis, resulting in increased risk of mastitis.

Weiss, et al (1997)

- Cows were assigned to one of three treatments at 60 d before anticipated calving:
  - Treatment 1 – 100 IU/d of supplemental vitamin E during the dry period and 100 IU/d during the first 30 d of lactation.
  - Treatment 2 – 1000 IU/d of vitamin E during the dry period and 500 IU/d during lactation.
  - Treatment 3 – 1000 IU/d of vitamin E during the first 46 d of the dry period, 4000 IU/d during the last 14 d of the dry period, and 2000 IU/d during lactation.
- The percentage of quarters with new infections at calving was not different (32.0%) between cows receiving treatments that contained low and intermediate concentrations of vitamin E but was reduced (11.8%) in cows receiving the high vitamin # treatment.
- Clinical mastitis affected 25.0, 16.7, and 2.6% of the quarters during the first 7 d of lactation for cows receiving the low, intermediate, and high vitamin E treatments, respectively.

### *Housing Other than Bedding*

Barkema, et al (1999a)

- A lower incidence rate of clinical mastitis caused by *E. coli* was associated with complete slatted floors and alleys, and lower animal density.

Barrett, et al (2005)

- Herds with less than 110 cubicles per 100 cows were more likely to experience environmental mastitis.

Bartlett, et al (1992)

- A greater prevalence of coliform infection was associated with herds that used freestalls in the winter.
- A greater prevalence of environmental streptococcal infection was associated with herds that housed animals in tie stalls.

Peeler, et al, (2000)

- Survey of management practices of British dairy herds with low somatic cell count (average 76,000 cells/ml) showed the following housing variables lead to increased rate of clinical mastitis: lactating cows housed in straw yards compared with cubicles, dry cows housed in straw yards compared with cubicles and access of milking cows to outdoor yards (when housed).

## References Cited


Barkema, H.W., Schukken, Y.H., Lam, T.J.G.M., Beiboer, M.L., Wilmink, H., Benedictus, G., & Brand, A. (1998a). Incidence of clinical mastitis in dairy herds grouped in three categories by bulk milk somatic cell counts. *Journal of Dairy Science* 81:411-419.

Barkema, H.W., Schukken, Y.H., Lam, T.J.G.M., Beiboer, M.L., Benedictus, G., & Brand, A. (1998b). Management practices associated with low, medium, and high somatic cell counts in bulk milk. *Journal of Dairy Science* 81:1917-1927.

Barkema, H.W., Schukken, Y.H., Lam, T.J.G.M., Beiboer, M.L., Benedictus, G., & Brand, A. (1999a). Management practices associated with the incidence rate of clinical mastitis. *Journal of Dairy Science* 82:1643-1654.

Barkema, H.W., Van der Ploeg, J.D., Schukken, Y.H., Lam, T.J.G.M., & Brand, A. (1999b). Management style and its association with bulk milk somatic cell count and incidence rate of clinical mastitis. *Journal of Dairy Science,* 82:1655-1663.

Barrett, D., Doherty, M.L., & Healy, A.M. (2005). A descriptive epidemiological study of mastitis in 12 Irish dairy herds. *Irish Veterinary Journal* 58(1):31-35**.**

Bartlett, P.C., Miller, G.Y., Lance, S.E., & Heider, L.E. (1992). Managerial determinants of intramammary coliform and environmental streptococci infections in Ohio dairy herds. *Journal of Dairy Science* 75:1241-1252.

Bishop, J.R., Janzen, J.J., Bodine, A.B., Caldwell, C.A., & Johnson, D.W. (1981). Dairy waste solids as a possible source of bedding. *Journal of Dairy Science*, 64:706-711.

Bramley, J. (1982). Sources of *Streptococcus uberis* in the dairy herd. *Journal of Dairy Research* 49:369-373.

Bramley, A.J., & Neave, F.K. (1975). Studies on the control of coliform mastitis in dairy cows. *British Veterinary Journal*, 131, 160-169.

Brim, M., & Timms, L.L. (1989). In vitro growth of environmental mastitis pathogens in various bedding materials. *Journal of Dairy Science* 72(Suppl 1):14.

Carroll, E.J., & Jasper, D.E. (1978). Distribution of *Enterobacteriaceae* in recycled manure bedding on California dairies. *Journal of Dairy Science*, 61:1498-1508.

De Haas, Y., Veerkamp, R.F., Barkema, H.W., Grohn, Y.T., & Schukken, Y.H. (2004). Associations between pathogen-specific cases of clinical mastitis and somatic cell count patterns. *Journal of Dairy Science*, 87:95-105.

Deluyker, H.A., Gay, J.M., & Weaver, L.D. (1993). Interrelationships of somatic cell count, mastitis, and milk yield in a low somatic cell count herd. *Journal of Dairy Science* 76:3445-3452.

Dohoo, I.R., Meek, A.H., & Martin, S.W. (1984). Somatic cell counts in bovine milk: relationships to production and clinical episodes of mastitis. *Canadian Journal of Comparative Medicine*, 48:130-135.

Eberhart, R.J. & Buckalew, J.M., (1977). Intramammary infections is a dairy herd with a low incidence of *Streptococcus agalactiae* and *Staphylococcus aureus* infections. *JAVMA* 171(7):630-634.

Elbers, A.R.W., Miltenburg, J.D., De Lange, D., Crauwels, A.P.P., Barkema, H.W., & Schukken, Y.H. (1998). Risk factors for clinical mastitis in a random sample of dairy herds from the southern part of The Netherlands. *Journal of Dairy Science*, 81:420-426.

Erskine, R.J., Eberhart, R.J., Hutchinson, L.J., Spencer, S.B., & Campbell, M.A., (1988). Incidence and types of clinical mastitis in dairy herds with high and low somatic cell counts. *JAVMA* 192(6):761-765.

Fairchild, T.P., McArthur, J., Moore, J.H., & Hylton, W.E. (1982). Coliform counts in various bedding materials. *Journal of Dairy Science*, 65:1029-1035.

Gabler, M.T., Reneau, J.K., & Farnsworth, R.J. (2001). Comparison of number of *Streptococcus uberis* calculated on a volume or weight basis in sand and sawdust bedding. *AJVR* 62(2):171-173.

Hogan, J.S., Hoblet, K.H., Smith, K.L., Todhunter, D.A., Schoenberger, P.S., Hueston, W.D., Pritchard, D.E., Bowman, G.L., Heider, L.E., Brockett, B.L., & Conrad, H.R., (1988). Bacterial and somatic cell counts in bulk tank milk from nine well managed herds. *Journal of Food Protection.* 51(12):930-934.

Hogan, J.S., Smith, K.L., Hoblet, K.H., Todhunter, D.A., Schoenberger, P.S., Hueston, W.D., Pritchard, D.E., Bowman, G.L., Heider, L.E., Brockett, B.L., & Conrad, H.R. (1989a). Bacterial counts in bedding materials used on nine commercial dairies. *Journal of Dairy Science*, 72:250-258.

Hogan, J.S., Smith, K.L., Hoblet, K.H., Schoenberger, P.S., Todhunter, D.A., Hueston, W.D., Pritchard, D.E., Bowman, G.L., Heider, L.E., Brockett, B.L., & Conrad, H.R., (1989b). Field survey of clinical mastitis in low somatic cell count herds. *Journal of Dairy Science.* 72:1547-1556.

Hogan, J.S., Smith, K.L., Todhunter, & D.A., Schoenberger, P.S. (1990). Bacterial counts associated with recycled newspaper bedding. *Journal of Dairy Science*, 73:1756-1761.

Hogan, J.S., & Smith, K.L. (1997). Bacterial counts in sawdust bedding. *Journal of Dairy Science*, 80:1600-1605.

Hogan, J.S., Bogacz, V.L., Thompson, L.M., Romig, S., Schoenberger, P.S., Weiss, W.P. & Smith, K.L. (1999). Bacterial counts associated with sawdust and recycled manure bedding treated with commercial conditioners. *Journal of Dairy Science*, 82:1690-1695.

Hortet, P., & Seegers, H. (1998). Calculated milk production losses associated with elevated somatic cell counts in dairy cows: review and critical discussion. *Veterinary Research,* 29:497-510.

Howell, D., (1972). Survey on mastitis caused by environmental bacteria. *The Veterinary Record.* 90:654-657.

Hutton, C.T., Fox, L.K., & Hancock D.D. (1990). Mastitis control practices: Differences between herds with high and low milk somatic cell counts. *Journal of Dairy Science*, 73:1135-1143.

Janzen, J.J., Bishop, J.R., Bodine, A.B., Caldwell, C.A., & Johnson, D.W. (1982). Composted dairy waste solids and crushed limestone as bedding in free stalls. *Journal of Dairy Science*, 65:1025-1028.

Jasper, D.E., Dellinger, J.D., & Bushnell, R.B. (1975). Herd Studies on Coliform Mastitis. *JAVMA* 166(8):778--780.

Kristula, M.A., Rogers, W., Hogan, J.S. & Sabo, M. (2005). Comparison of bacteria populations in clean and recycled sand used for bedding in dairy facilities. *Journal of Dairy Science,* 88:4317-4325.

LeJeune, J.T., & Kauffman, M.D. (2005). Effect of sand and sawdust bedding materials on the fecal prevalence of *Escherichia coli* O157:H7 in dairy cows. *Applied and Environmental Microbiology,* 71:1, 326-330.

Mote, C.R., Emerton, B.L., Allison, J.S., Dowlen, H.H., & Oliver, S.P. (1988). Survival of coliform bacteria in static compost piles of dairy waste solids intended for freestall bedding. *Journal of Dairy Science,* 71:1676-1681.

Munoz, M.A., Ahlstrom, C., Rauch, B.J., & Zadoks, R.N. (2006). Fecal shedding of *Klebsiella pneumoniae* by dairy cows. *Journal of Dairy Science,* 89:3425-3430.

Natzke, R.P., & LeClair, B.J. (1975). Coliform contaminated bedding and new infections. *Journal of Dairy Science,* 59:2152-2154.

Neave, F.K., Dodd, F.H., Kingwill, R.G., & Westgarth, D.R. (1969). Control of mastitis in the dairy herd by hygiene and management. *Journal of Dairy Science* 52(5):696-707.

Neave, F.K. & Oliver, J. (1962). The relationship between the number of mastitis pathogens placed on the teats of dry cows, their survival, and the amount of intramammary infection caused. *Journal of Dairy Research* 29:70-93.

Neijenhuis, F., Barkema, H.W., Hogeveen, H., & Noordhuizen, J.P.T.M. (2001). Relationship between teat-end callosity and occurrence of clinical mastitis. *Journal of Dairy Science* 84:2264-2672.

Newman, L.E. & Kowalski, J.J. (1973). Fresh sawdust bedding – A possible source of *Klebsiella* organisms. *Am. J. Vet. Res.* 34(7):979-980.

Pankey, J.W., Wildman, E.E., Drechsler, P.A., & Hogan, J.S. (1987). Field trial evaluation of premilking teat disinfection. *Journal of Dairy Science.* 70:867-872.

Peeler, E.J., Green, M.J., Fitzpatrick, J.L., Morgan, K.L., & Green, L.E. (2000). Risk factors associated with clinical mastitis in low somatic cell count British dairy herds. *Journal of Dairy Science.* 83:2464-2472.

Peeler, E.J., Green, M.J., Fitzpatrick, J.L., & Green, L.E. (2003). The association between quarter somatic-cell counts and clinical mastitis in three British dairy herds. *Preventive Veterinary Medicine,* 59:169-180.

Raubertas, R.F., & Shook, G.E. (1982). Relationship between lactation measures of somatic cell concentration and milk yield. *Journal of Dairy Science.* 65:419-425.

Rendos, J.J., Eberhart, R.J., & Kesler, E.M. (1975). Microbial populations of teat ends of dairy cows, and bedding materials. *Journal of Dairy Science*, 58:1492-1499.

Salsberg, E., Meek, A.H., & Martin, S.W. (1984). Somatic cell counts: associated factors and relationship to production. *Canadian Journal of Comparative Medicine,* 48:251-257.

Schreiner, D.A., & Ruegg, P.L. (2003). Relationship between udder and leg hygiene scores and subclinical mastitis. *Journal of Dairy Science*, 86:3460-3465.

Schukken, Y.H., Grommers, F.J., Van de Geer, D., Erb, H.N., & Brand, A. (1990). Risk factors for clinical mastitis in herds with a low bulk milk somatic cell count. 1. Data and risk factors for all cases. *Journal of Dairy Science*, 73:3463-3471.

Schukken, Y.H., Grommers, F.J., Van de Geer, D., Erb, H.N., & Brand, A. (1991). Risk factors for clinical mastitis in herds with a low bulk milk somatic cell count. 1. Risk factors for *Escherichia coli* and *Staphylococcus aureus*. *Journal of Dairy Science*, 74:826-832.

Smith, K.L., Todhunter, D.A., & Schoenberger, P.S. (1985a). Environmental pathogens and intramammary infection during the dry period. *Journal of Dairy Science*, 68:402-417.

Smith, K.L., Todhunter, D.A., & Schoenberger, P.S. (1985b). Environmental mastitis: Cause, prevalence, prevention. *Journal of Dairy Science*, 68:1531-1553.

Suriyasathaporn, W., Schukken, Y.H., Nielen, M., & Brand, A. (2000a). Low somatic cell count: a risk factor for subsequent clinical mastitis in a dairy herd. *Journal of Dairy Science.* 83:1248-1255.

Suriyasathaporn, W., Heuer, C., Noordhuizen-Stassen, E.N., & Schukken, Y.H. (2000b). Hyperketonemia and the impairment of udder defense: a review. *Veterinary Research,* 31:397-412.

Todhunter, D.A., Smith, K.L., & Hogan, J.S. (1995). Environmental streptococcal intramammary infections of the bovine mammary gland. *Journal of Dairy Science*, 78:2366-2374.

Ward, W.R., Hughes, J.W., Faull, W.B., Cripps, P.J., Sutherland, J.P., & Sutherst, J.E. (2002). Observational study of temperature, moisture, pH and bacteria in straw bedding, and faecal consistency, cleanliness and mastitis in cows in four dairy herds. *Veterinary Record,* 151:199-206.

Zadoks, R.N., Allore, H.G., Barkema, H.W., Sampimon, O.C., Grohn, Y.T., & Schukken, Y.H. (2001). Analysis of an outbreak of *Streptococcus uberis* mastitis. *Journal of Dairy Science*, 84:590-599.

Zarkower, A., & Scheuchenzuber, W.J. (1977). Teat apex microflora: Influence of washing and dipping procedures. *Cornell Vet*, 67:404-412.

Zdanowicz, M. (2002). Sand and sawdust bedding affect populations of Coliforms, *Klebsiella* Spp. and *Streptococcus* Spp. on teat ends of dairy cows housed in freestalls. MS Thesis, The University of British Columbia. Retrieved 7/18/06 at http://www.landfood.ubc.ca/animalwelfare/publications/documents/zdanowicz_thesis15.pdf

Zdanowicz, M., Shelford, J.A., Tucker, C.B., Weary, D.M., & von Keyserlingk, M.A.G. (2004). Bacterial populations on teat ends of dairy cows housed in free stalls and bedded with either sand or sawdust. *Journal of Dairy Science*, 87:1694-1701.

Zehner, M.M., Farnsworth, R.J., Appleman, R.D., Larntz, K., & Springer, J.A. (1986). Growth of environmental mastitis pathogens in various bedding materials. *Journal of Dairy Science*, 69:1932-1941.

## APPENDIX B

## FARM DESCRIPTIONS

The descriptions of each farm here are from single interviews with the farm owner prior to the start of the study on the date indicated for each farm.

### Farm A

2/16/06

They have 2000 milkers. All are bedded on DMS. Manure is scraped from the 3 barns and flows into a cement "pond" with agitators. It is then pumped up to 2 Fan separators one on top of each of 2 Fan drum composters. About 1/3 goes through these, 2/3 can't be handled by these separators and composters, so it goes to a third Fan separator and that manure is land spread.

The liquid separation system has resulted in about 30% reduction in P in the liquid stream.

The manure is in the composters ~ 24 hours. It gets to ~60 deg C and dries down about an additional 5-6% to about 35-40% solids. It can be too dry and blow around in the summer.
Compost sits ~ 1 day before being spread in barn.

Cows love this bedding – lie down more than sand or sawdust.
Were previously spending ~$300,000/yr on sawdust.
Most cows are not on mattresses (groups 4 and 5 do have mattresses).

They started using DMS directly from separator in Nov 05. At first saw a drop in SCC. Then in summer 06 got mastitis and saw SCC go from ~200,000 to 480,000, so decided to compost. SCC is now at 220,000. Current mastitis is 60% gram neg, 10-15% *Streptococcus* and *Staphylococcus.*

Bed MWF takes all day from 7-4. Mix some lime into it in the spreader for the non-Zorbisan bedded areas. They scrape out manure by hand from stalls 3x/day at milking. Then once a week a mechanical scraper scrapes out the end of each stall.

There are 9 groups of cows. All are on DMS. There is 1 barn dry cows, 1 fresh and pre-fresh, 1 lactating high. Once fresh, all are fed the same. Diet is a moving target.

They have made major changes in milking to reduce teat end damage. Have done teat end scoring.

**Farm B**

2/10/06

All 850-900 milkers are on DMS and have been for ~2 years in April.
They think there may have been some rise in SCC to ~300,000 which has caused them to readdress cow preparation.
All milkers on DMS except for the pen of those ready to freshen, which are on straw.

They use a Vincent separator. Bedding material is stockpiled in windrows undercover for ~ 10day prior to use. Plan for all of bedding to go through it (they also have a Fan separator)
Separate before digester (so solids are not digested). Main reason is odor control. Did not want plug flow. Mixed vat is simpler to build and operate. Hope to get down to 6 day hydraulic retention.

DHI comes monthly. Everything is computerized.
Conductivity is measured and recorded and used as a tool for mastitis control.

Dry Cows are on DMS except for close-up cows.
Heifers are in bare stalls (older) and sawdust (younger).

They have had Johnes, so no DMS in younger heifers.
They have a regular hoof trimmer and felt that this farm has historically had more hoof problems than "normal" (warts, abscesses). They are not sure if the DMS has caused any changes but they do not think so.
All hoof health information is recorded in Dairy Comp.

They re-bed MWF around noon.
Use 2:1 bags of lime:chlorine powder, about a 5 gallon pail for 100 stalls.
Spread 1-3 inches of DMS in the stalls.
Stall surface is rubber mattresses – may replace some.
They think there is less hock abrasion than with sawdust.

They are milking in a double 20 parlor with auto ID of cows.
When they have clinical mastitis, they take a milk sample and freeze it and send monthly for culture to QMPS if deemed necessary. They do not necessarily treat with antibiotics if oxytocin and milking works.

After the 1$^{st}$ month of sampling, they switched their re-bedding scenario to 6 days per week (every day but Sunday).

**Farm C**

2/10/06

This farm uses Dairy Comp. DHI comes monthly and does SCC by individual cow.
If there is mastitis, they follow up to find bacterial cause.

They have 1350 milking cows.
One barn has 2 groups of 200 fresh cows bedded on DMS. They are moved according to lactation stage.
They stay in the fresh pen ~60-70 days.
There are 4 other 200 cow groups in another barn bedded on a mix of paper byproduct and sawdust.

Manure goes as liquid to digester for ~ 21 days.
They use a Vincent screw press to ~26% solids.
DMS is used as bedding right out of the press.

Some dried manure is aged and exported to a facility that pelletizes it. They plan to stop exporting when it is dry enough for bedding.

The DMS is re-bedded on Tuesdays, Thursdays and Saturdays at about noon.
Some hydrated lime is thrown at the end of the stall before bedding is added. About 1 inch or 30-40 lbs/stall of DMS is added with side delivery spreader.
Experience is that DMS stays in stall better than sawdust.
Stalls have cut tire mattresses.
There are activity meters on the cows, but not auto recording of cows in the parlor.

**Farm D**

3/3/06

They use Dairy Comp. DHI comes monthly and does SCC by individual cow.
If there is mastitis, they follow up to find bacterial cause but do not enter it into Dairy Comp.
Hoof health recorded in Dairy comp

1000 milkers
122/group except one with 160. All stock bedded on DMS that are 7-10 days old stored in piles 7'-10' high. They are trying to dry material a bit more for young stock, they will force air through. They are moved according to lactation stage. Stay in the fresh pen ~60-70 days.

Manure goes as liquid to digester for ~ 16 days.
Vincent screw press to ~30% solids.
Used as bedding at 7-10 days

They are assessing bedding volume as they have just added the digester 10/05

The DMS is re-bedded M, W and F starting at 6am.
Some hydrated lime is thrown at the end of the stall before bedding is added. About 3-4 inches of DMS is added with side delivery spreader. They have some mattresses still most have been removed. When they took mattresses out of a barn recently and filled what is equal to a sand bed structure, cows really responded - great cow comfort.
Experience is that DMS stays in stall better than sawdust. They use sawdust as a back up when something breaks down.

**Farm E**

12/19/05

1600 milking cows, alley scraper system

Expect to transition from sand in March

Currently bedding weekly on Monday AM add sand. They have only removed the sand once. Sand costs $10/ton and they spend $14,000/month

Key is deep beds

Discussed 3 treatments – sand, separated solids, separated and composted using in-vessel composter for bedding.

Could sample out of screw press; mix before entering composter; out of composter

One barn is divided into 6 parts – could do 3 treatments.

They used a U WI system – screw press directly to bedding, but had problem with screw press. Did not have SCC or cow problems.

They are now looking at Fan.

Fan screw press, expect 27-35% solids. About 75% will be land applied, 25% will go to mixer wagon to mix with calf bedded pack (straw) and moldy feed, then compost in vessel.

They feel that teat ends are key. They implemented a new inflation system in their parlor in May.

Johnes is low – 6% of the 35% culls are Johnes = 1.7% of herd.

Records – good hoof health data for past 5 years. Data are in Dairy Comp

They generally have QMPS look at mastitis cases.

They are part of NYCHAPS

Had QMPS do pathogens on all 4 quarters of each cow in 8/05.

Have bedding samples from 8/05

DHI coming monthly, but may drop back to quarterly.

QMPS scores teat ends quarterly

*Fusarium mycotoxin* is an issue. There is 500 ppb in silage. Erodes cow's immune system. Grows better in conservation tillage, cool (30 deg C is optimal). Can see 80% reduction if 53 deg C for > 3 days. Expect digester (thermophillic) to deal with it. Once they have a digester, won't compost.

**Farm F**

2/22/06

They use DMS on all but the young heifers and have used it for >5.5 years. They use bedded pack for pre-fresh.

Liquid manure all goes through one Fan separator.
DMS is conveyed to a shed that has capability of forced air but air is not used.
DMS sits in tall big pile for ~a week before use. About 1/3 is excess and is land spread (1 ten wheel truck/day), 2/3 used for bedding
They re-bed every 6th night starting about 5:30 PM

They have a digester that is not working. When it works, they will digest before separation. They hope to have it working by summer. Problem was cover and corrosion.

They think "the drier the better" for DMS bedding. The cows are very comfortable in the DMS. The beds look quite deep with DMS. Maybe 3-4 inches spread each time.
They level the beds every other day and add some hydrated lime. They add lime before they re-bed.

Use hoof dip. Hoof health is a struggle. Trimmer comes every Wednesday. Foot bath – have recently changed from copper sulfate to "concentrated copper". In the summer they use formaldehyde.

Diet – all the same except pre fresh and fresh.

DHI records location in barn when cows are monitored, but they do not track movement in Dairy Comp

Milking procedures are being worked on. 13.6 vacuum. Considering inflators. Teat ends not so good. Parlor is double 16 parallel.

1075 adult cows, 957 milkers.
2 milking barns, 1 dry cow barn. 1 barn has 4 milk groups of about 130. 1 barn has 3 high groups and one fresh group.

SCC about 250,000-300,000. They did not see much mastitis last summer, 2005, despite the heat.

Quality milk tested bedding in 2005.

After we started sampling in March, they changed their re-bedding to MWF

**APPENDIX C**

**BEDDING SAMPLING PROCEDURE**

## Bedding Sampling Procedure for Using Manure Solids as Bedding

**Supplies:**

- 7 one-gallon zipper style storage bags appropriately labeled for each AIC farm and 21 for ERDA farm for compositional analysis
- 7 sandwich size zipper style storage bags appropriately labeled for each AIC farm and 21 for ERDA farm for bacterial analysis and dry matters
- 3 fecal cups appropriately labeled for each AIC farm and 9 for ERDA farm for Johnes testing
- Gloves
- Styrofoam coolers and ice packs large enough to hold samples
- 1 Garbage bag for each cooler that will be shipped for compositional analysis
- Bucket
- Accession forms and mailing label
- Extra bags of both sizes, sharpie.

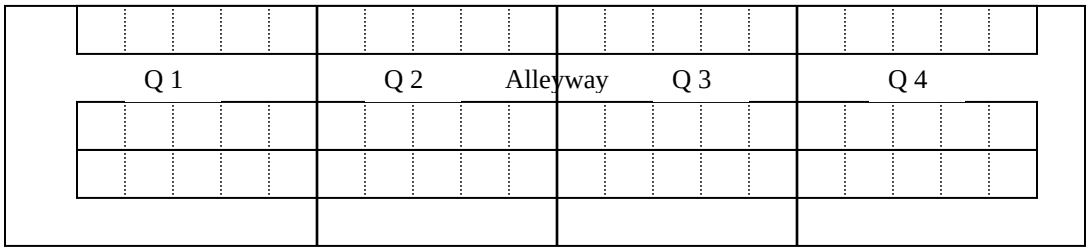
**General:**

- Sampling should be done at a time that will maximize bedding use:
  - Farm D, Farm A, Farm B, Farm F: Monday mornings just before re-bedding (3 days use)
  - Farm C: Tuesday mornings just before re-bedding (3 days use)
  - Farm E: Tuesday mornings just before re-bedding (4 days use).
- Used bedding will be sampled from the back of the stalls, unused bedding will be sampled from the pile
- All samples will be taken from the fresh cow pen at each AIC farm. Samples from Farm E will be taken from 3 specified pens using Composted DMS, sand and Uncomposted DMS
- 3 samples of used bedding and 1 sample of unused will be taken for compositional analysis. In addition, a $4^{th}$ sample of used and 2 samples of unused will be taken for dry matter, Solvita ($NH_4$, $CO_2$, and maturity) and particle size only.
- 4 samples of used bedding and 3 samples of unused will be taken for bacterial analysis
- 3 samples of unused bedding will be taken for Johnes testing
- Farm, bedding type, month of collection and sample # have been coded (see attached farm and sample code sheet)

**Procedure:**

1. Start with the unused bedding.

2. Divide the pen into 4 quadrants. Standing in the feed alley, looking at the pen:
    - Quadrant 1 (Q1) = All of the beds on the far left side
    - Quadrant 2 (Q2) = All of the beds in the middle left side
    - Quadrant 3 (Q3) = All of the beds in the middle right side
    - Quadrant 4 (Q4) = All of the beds on the far right side

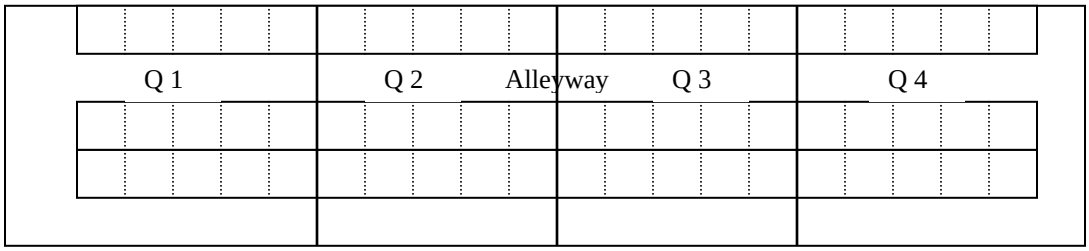



3. Visually divide the bed portion of the stalls (that area between the end of the stall and the beginning of the brisket board) into 3 equal portions.
4. The back third represents the area where the udder will rest when the cow is lying down.
5. In a randomly selected stall in quadrant 1, with a gloved hand, scoop bedding from the back third in a straight line across the stall and put into the gallon size Ziploc bag labeled "Used bedding Q 1 Brookside". If there is manure present in the line of collection it should be included in the sample. Repeat this procedure in approximately 4-5 more stalls in the same quadrant until the bag is approximately ¾ full. Mix the contents of the bag and put a handful or 2 of it into the sandwich bag labeled "Used bedding Q 1 – QMPS". Seal the bags (removing the air) and put on ice in Styrofoam cooler or bucket.
6. Using a new glove for each sample, repeat steps 3 - 5 in the 3 other quadrants of the pen depositing a portion of each sample in the correct "Used bedding – QMPS" bag, leaving the rest in the "Used bedding Brookside" bag.
7. For unused bedding, with a clean glove, collect several grab samples from one portion of the pile and deposit in one of the gallon bags labeled "Unused bedding – Brookside", until the bag is ¾ full. Seal and mix. When thoroughly mixed, pull out a representative sample and put in the correspondingly numbered sandwich bag labeled "Unused bedding – QMPS". Seal the bag (removing the air) and put bag on ice in Styrofoam cooler or bucket with the used samples. Using a new glove for each one, from 2 other spots, fill the other 2 sets of bags for Brookside and QMPS.
8. Put all 7 QMPS bags in a gallon size storage bag and label with farm name, date and QMPS. Put QMPS accession form in a sandwich bag and add to the gallon bag. Put the whole bag on ice. Deliver/mail to: Quality Milk Promotion Services (QMPS), 22 Thornwood Dr., Ithaca, NY 14853.
9. Put all of the Brookside bags that are labeled for DM, Solvita and Particle size only (1 used and 2 unused) in a garbage bag and put the accession form for DM, Solvita and Particle size only in the bag and tie. Put the rest of the Brookside bags (3 used and 1 unused) in a garbage bag and put the accession form for Z001, pH, particle size, maturity, extractable P, copper in the bag and tie. Place both garbage

bags in a cooler (no ice is necessary in cold weather). Seal and label the cooler with UPS 2nd day air label and mail to: Brookside Laboratories, Inc., 308 S. Main St., New Knoxville, OH 45871.

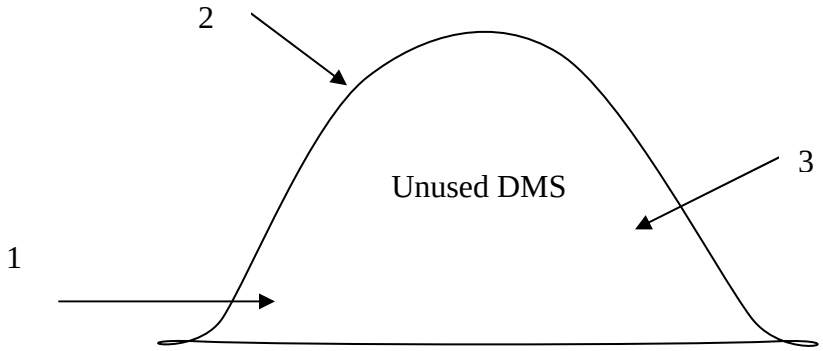
10. Using a new glove each time, take a grab sample from 3 different spots on the unused bedding pile and deposit in the fecal cups labeled "Unused bedding – Johnes", close the cup and put on ice.
11. Put all 3 samples in a gallon size storage bag and label with farm name, date and Johnes. Put Johnes accession form in a sandwich bag and add to the gallon bag. Put the whole bag on ice. Deliver to Johnes Laboratory, Warren Road, Ithaca, NY.

Picture of pen lay-out – One at each of the AIC farms and 3 at the ERDA farm.




**Used bedding sampling regime:**

- QMPS – 4 samples from each of 4 quadrants of the fresh cow pen at AIC farms and 4 samples from each of 4 quadrants in 3 pens bedded with composted DMS, sand and DMS from the separator (not composted) at the ERDA farm.
- Brookside – 3 of the 4 samples collected (1 from each quadrant) will get the full compositional analysis (% moisture, % OM, % Total N, % Ammonia N, % Nitrate N, % Organic N, % P and as $P_2O_5$, % K and as $K_2O$, ppm Cu, pH, ppm water extractable P, Solvita ($NH_4$, $CO_2$ and maturity), and particle size. The 4th sample will be analyzed for % moisture, Solvita ($NH_4$, $CO_2$ and maturity), and particle size only. The quadrant that will get the abbreviated analysis will change each time samples are taken.



**Unused bedding sampling regime:**

- QMPS – 3 samples from 3 different portions of the Unused DMS pile at AIC farms and 3 samples from 3 different portions of each of 3 unused composted DMS, sand and DMS from the separator (not composted) at the ERDA farm.
- Brookside – 1 of the 3 samples collected (1 from each quadrant) will get the full compositional analysis (% moisture, % OM, % Total N, % Ammonia N, % Nitrate N, % Organic N, % P and as $P_2O_5$, % K and as $K_2O$, ppm Cu, pH, ppm water extractable P, Solvita ($NH_4$, $CO_2$ and maturity), and particle size. The other 2 samples will be analyzed for % moisture, Solvita ($NH_4$, $CO_2$ and maturity), and particle size only.
- Johnes – 3 samples from 3 different portions of the Unused DMS pile at AIC farms and 3 samples from 3 different portions of each of 3 unused composted DMS, sand and DMS from the separator (not composted) at the ERDA farm.

**APPENDIX D**

**MASS NUTRIENT BALANCE FOR FARMS USING MANURE SOLIDS**

Note: The notations of Farm A, B, C, etc in this appendix do not necessarily reflect the same farms that are coded as A, B, C, etc in the body of this report.

# Mass Nutrient Balances of Six New York State Dairy Farms Using Manure Solids as Bedding

July 3, 2007

Caroline Rasmussen and Quirine Ketterings
Nutrient Management Spear Program

A mass nutrient balance (MNB) analysis was done on 6 farms in cooperation with the Cornell Waste Management Institute project studying the use of manure solids for dairy barn bedding. Mass nutrient balances (MNB) provide a useful and achievable metric for assessing nutrient loadings and potential losses on farms. A mass nutrient balance is calculated by summing the nutrients in imported feeds, fertilizers, animals, and purchased bedding for a farm and subtracting exported nutrients in milk, meat, crops, and manure.

Data were collected for the 2006 calendar year. A data collection questionnaire was developed to collect nitrogen (N), phosphorus (P) and potassium (K) farm import and export data. An MS Excel© spreadsheet ("Mass Nutrient Balance", downloadable from http://nmsp.css.cornell.edu/projects/massbalance.asp) was used to analyze the mass balance data. Farm financial records and crop and dairy production records were used as data sources and additional information was provided by nutritional consultants, feed and fertilizer company representatives.

The MNB of the 6 farms was conducted within a broader, multiple year study of nutrient management on NYS livestock farms. Of the 53 New York State dairy farms that submitted 2006 mass balance data, imported bedding constituted only 1% of all N imports, 1% of all P imports, and 2% of all K imports (Table 1).

Table 1. The average distribution of nitrogen, phosphorus and potassium imports and exports for 53 New York State dairy farms in 2006.

| Annual imports | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|
| Feed | 76% | 72% | 66% |
| Fertilizer | 23% | 26% | 32% |
| Animals purchased | 0% | 1% | 0% |
| Bedding & misc. | 1% | 1% | 2% |
| Annual exports | Nitrogen | Phosphorus | Potassium |
| Milk | 76% | 75% | 75% |
| Animals sold | 9% | 12% | 2% |

| | | | |
|---|---|---|---|
| Crops sold | 13% | 11% | 20% |
| Manure, compost | 2% | 1% | 2% |

It is not surprising the percentage nutrients imported via bedding is this low:

- Of the 53 farms, 19 did not import any bedding material nutrients (used sand or all farm-produced bedding).
- For those that purchased bedding material, materials have a very low N, P and K content such as sawdust, straw and paper waste, were most commonly used. The quantity and nutrient content of other imports (purchased feed and fertilizer. etc.) greatly exceed the nutrients imported as bedding.

Farm "C" imported food waste which was added to a methane digester and land-applied. The nutrients in this imported food waste are *not* included in the values presented in Tables 2 and 3. The percentage of N imported with bedding was less than 0.5% on 5 of the 6 manure solids study farms, lower than the average for the other 47 dairy farms (1%). The percentage of P imported as bedding was slightly lower than the average for all 6 of the manure solids study farms but as mentioned before, bedding material only contributes a very small fraction of total N and P imported on most New York dairy farms.

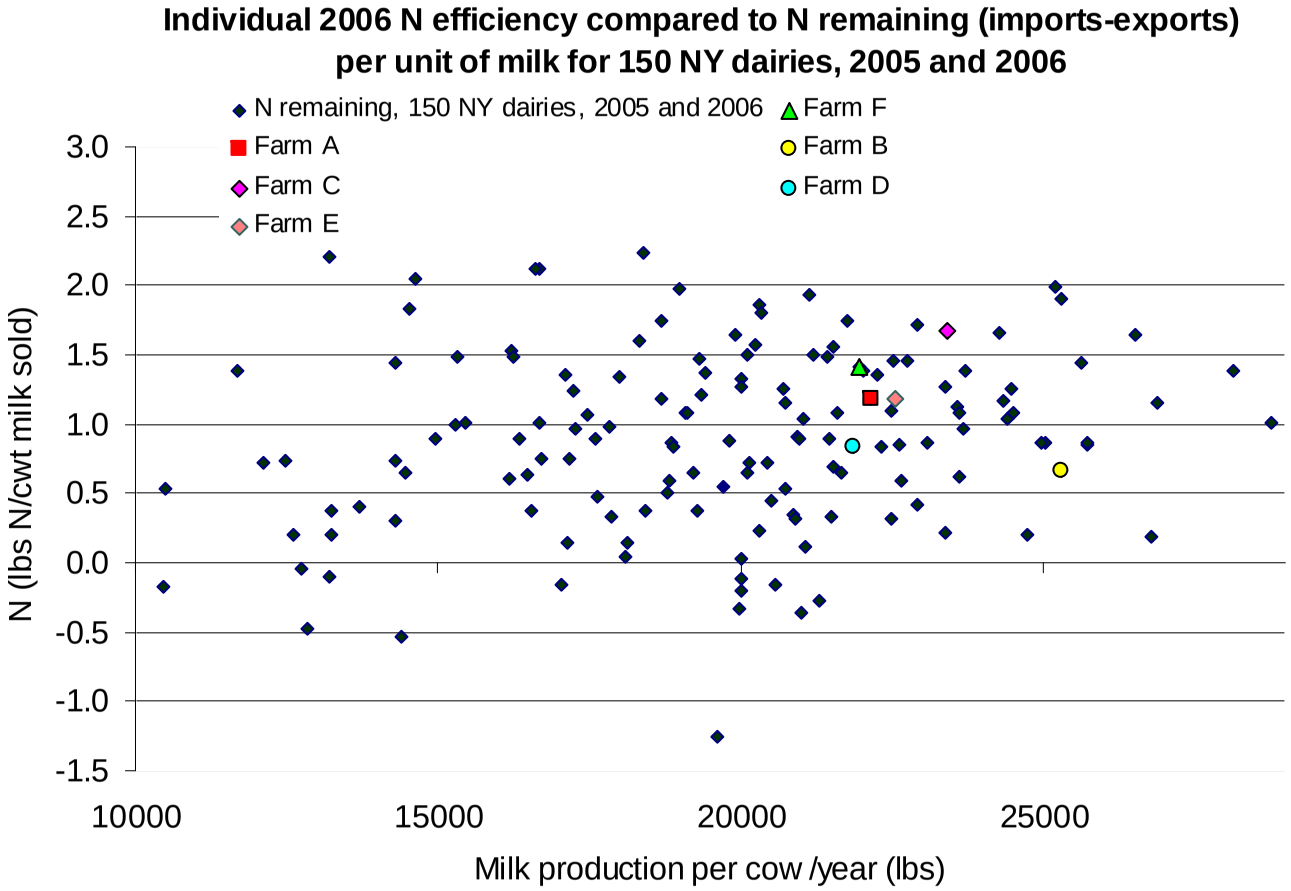
Table 2. The distribution of nitrogen imports and exports for manure solids study participants and 53 New York State dairy farms (2006).

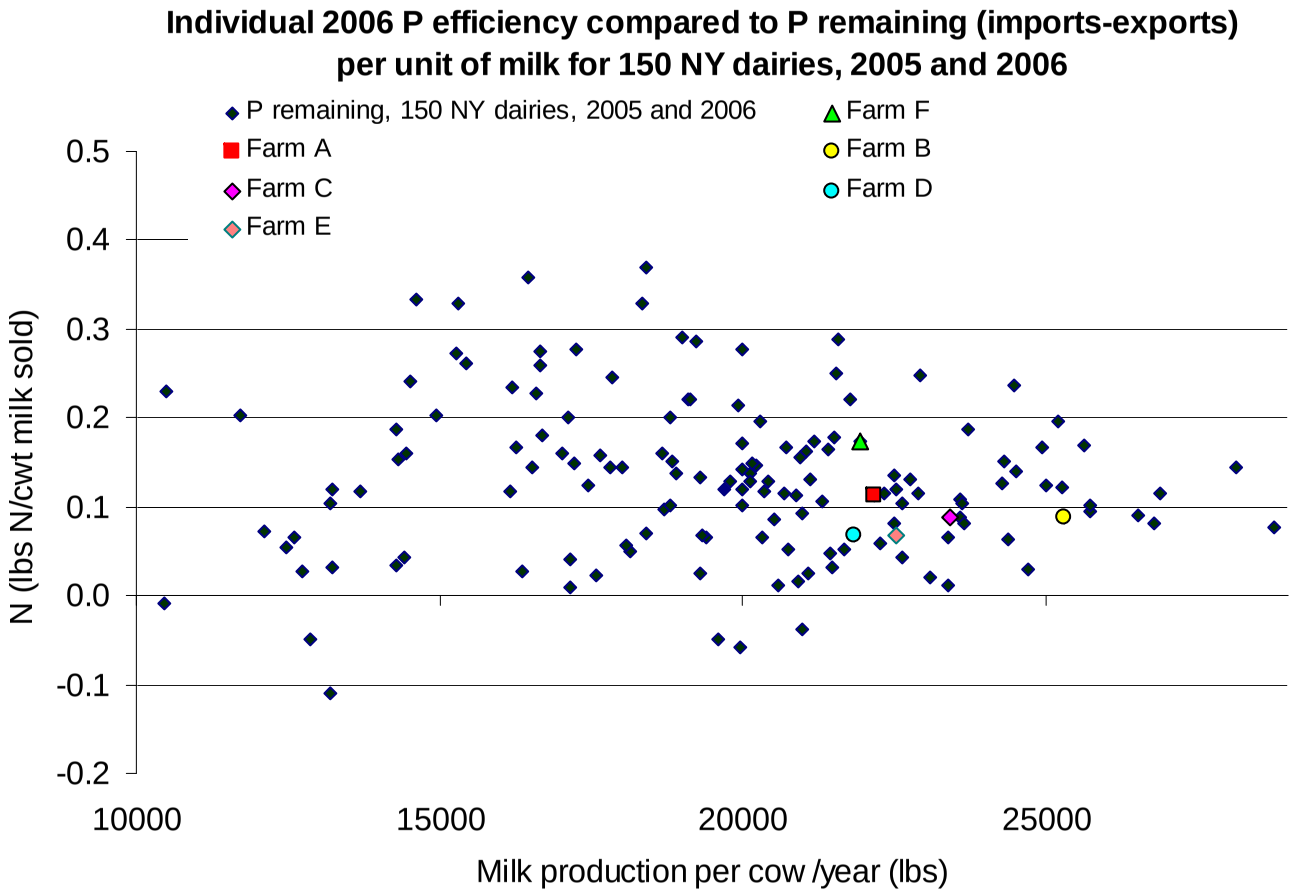
| Annual imports | 47 farms | Farm A | Farm B | Farm C | Farm D | Farm E | Farm F |
|---|---|---|---|---|---|---|---|
| Feed | 76% | 80% | 79% | 77% | 87% | 60% | 70% |
| Fertilizer | 23% | 20% | 21% | 23% | 12% | 31% | 28% |
| Animals purchased | 1% | 0% | 0% | 0% | 0% | 9% | 1% |
| Bedding & misc. | 1% | 0% | 0% | 0% | 0% | 0% | 1% |
| Annual exports | | | | | | | |
| Milk | 76% | 86% | 77% | 75% | 73% | 74% | 79% |
| Animals sold | 9% | 8% | 14% | 8% | 12% | 14% | 17% |
| Crops sold | 12% | 6% | 9% | 7% | 6% | 12% | 4% |
| Manure, compost | 3% | 0% | 0% | 10% | 9% | 0% | 0% |

Table 3. The distribution of phosphorus imports and exports for manure solids study participants and 53 New York State dairy farms (2006).

| | 47 farms | Farm A | Farm B | Farm C | Farm D | Farm E | Farm F |
|---|---|---|---|---|---|---|---|
| Annual imports | | | | | | | |
| Feed | 73% | 89% | 71% | 74% | 94% | 57% | 70% |
| Fertilizer | 26% | 11% | 29% | 25% | 5% | 23% | 28% |
| Animals purchased | 1% | 1% | 0% | 0% | 0% | 20% | 2% |
| Bedding | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| Annual exports | | | | | | | |
| Milk | 75% | 83% | 73% | 70% | 68% | 70% | 74% |
| Animals sold | 12% | 11% | 18% | 11% | 16% | 18% | 22% |
| Crops sold | 11% | 6% | 9% | 11% | 6% | 12% | 4% |
| Manure, compost | 1% | 0% | 0% | 8% | 11% | 0% | 0% |

An important measure of environmental impact is a firm's productive efficiency. The efficiency with which the participating dairy farms use N and P to produce milk is presented in Figures 1 and 2. In each of these figures, the nutrients remaining (import-export) are divided by the total quantity of milk sold (lbs nutrient per hundred weight of milk sold). The farms are ranked by the quantity of milk per cow. The 6 dairy farms varied greatly in nutrient use efficiency. Work is ongoing to determine inefficiency indicators and management options for improvement of whole farm nutrient imbalances but it is obvious from this dataset that bedding management does not greatly impact overall farm nutrient balances on New York dairy farms.


Individual 2006 N efficiency compared to N remaining (imports-exports) per unit of milk for 150 NY dairies, 2005 and 2006
N remaining, 150 NY dairies, 2005 and 2006
Farm A
Farm C
Farm E
Farm F
Farm B
Farm D
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
N (lbs N/cwt milk sold)
10000
15000
20000
25000
Milk production per cow /year (lbs)


Individual 2006 P efficiency compared to P remaining (imports-exports) per unit of milk for 150 NY dairies, 2005 and 2006
P remaining, 150 NY dairies, 2005 and 2006
Farm A
Farm C
Farm E
Farm F
Farm B
Farm D
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
N (lbs N/cwt milk sold)
10000
15000
20000
25000
Milk production per cow /year (lbs)

## APPENDIX E

## ECONOMIC ANALYSIS DATA

**Farm B**

### Bedding Production Costs

***Machinery and Services Operating Costs per Hour for Construction***

| | |
|---|---|
| Site Preparation | $50.00 |
| Grading | $70.00 |
| Rolling | $70.00 |
| Design | $100.00 |

***Machinery Operating Costs per Hour for Operations (includes all costs)***

| | |
|---|---|
| Skid Steer | $22.00 |
| Payloader | $32.00 |
| Material Pickup | $30.00 |
| Spreader/Mixer | $28.00 |
| Dump Truck | $25.00 |
| Turner | $22.00 |

***Personnel Costs per Hour***

| | |
|---|---|
| Management | $25.00 |
| Labor | $20.00 |

***Start up Costs in Hours***

| | |
|---|---|
| Contract Acquisition | 0 |
| Process Evaluation | 100 |

***Annual Equipment Operating Hours***

| | |
|---|---|
| Skid Steer | 78 |
| Payloader | 0 |
| Material Pickup | 0 |
| Spreading | 0 |
| Dump Truck | 0 |
| Turner | 0 |

***Total Facility Capitalized Costs***

| | |
|---|---|
| Construction | $50,000.00 |

***Total Equipment Capitalized Costs***

| | |
|---|---|
| Pumps and Separator | $75,000.00 |

| | |
|---|---|
| *Total Project Cost* | $125,000.00 |

***Annual Personnel Hours***

| | |
|---|---|
| Record Keeping | 0 |
| Marketing | 0 |
| General Labor | 85 |
| Bagging | 0 |

***Other Factors***

| | |
|---|---|
| Opportunity Cost of Capital | 5.00% |
| Salvage Value of Facility | $10,000.00 |
| Salvage Value of Equipment | $0.00 |
| Yards of Product Produced | 6,900 |
| Facility Capitalization Time | 20 |
| Equipment Capitalization Time | 7 |
| Pounds of Milk Sold per Year | 24,000,000 |

**Farm B**

***Costs and Returns from Composting***

| **Annual Income Received** | | |
|---|---|---|
| Compost Sales | | |
| Total Income | $0.00 | |
| | | |
| **Reduced Expenses** | | |
| Manure Hauling | $5,490.00 | |
| Wood Shavings - Bedding | $57,200.00 | |
| Total Reduced Expenses | $62,690.00 | |
| | | |
| **Annual Variable Expenses** | | **Per Yard Expenses** |
| Skid Steer | $1,716.00 | $0.25 |
| Payloader | $0.00 | $0.00 |
| Material Pickup/Delivery | $0.00 | $0.00 |
| Spreading/Mixing | $0.00 | $0.00 |
| Dump Truck | $0.00 | $0.00 |
| Turner | $0.00 | $0.00 |
| Record Keeping | $0.00 | $0.00 |
| Marketing | $0.00 | $0.00 |
| Electricity | $4,745.00 | $0.69 |
| Repairs | $3,000.00 | $0.43 |
| Bagging | $0.00 | $0.00 |
| Labor | $1,700.00 | $0.25 |
| Lost Quality Premiums | $24,000.00 | $3.48 |
| *Total Variable Expenses* | $35,161.00 | $1.62 |
| | | |
| **Annual Fixed Expenses** | | **Per Yard Expenses** |
| Insurance | $500.00 | $0.07 |
| Facility Depreciation | $2,000.00 | $0.29 |
| Composting Equipment Depreciation | $10,714.29 | $1.55 |
| Average Annual Interest on Investment | $3,375.00 | $0.49 |
| *Total Fixed Expenses* | $16,589.29 | $2.40 |
| | | |
| **Total Economic Cost to Farm** | $51,750.29 | $4.02 |
| (Total Fixed and Variable Expenses) | | |
| | | |
| **Annual Cost to Farm** | -$10,939.71 | |
| (less Savings and Generated Income) | | |
| **Annual Cost per Hundred Weight of Milk** | -$0.05 | |

**Farm C**

## Bedding Production Costs

***Machinery and Services Operating Costs per Hour for Construction***

| | |
|---|---|
| Site Preparation | $50.00 |
| Grading | $70.00 |
| Rolling | $70.00 |
| Design | $100.00 |

***Machinery Operating Costs per Hour for Operations (includes all costs)***

| | |
|---|---|
| Skid Steer | $22.00 |
| Payloader | $32.00 |
| Material Pickup | $30.00 |
| Spreader/Mixer | $28.00 |
| Dump Truck | $25.00 |
| Turner | $22.00 |

***Personnel Costs per Hour***

| | |
|---|---|
| Management | $25.00 |
| Labor | $20.00 |

***Start up Costs in Hours***

| | |
|---|---|
| Design | 10 |
| Process Evaluation | 25 |

***Annual Equipment Operating Hours***

| | |
|---|---|
| Skid Steer | 0 |
| Payloader | 130 |
| Material Pickup | 0 |
| Spreading | 0 |
| Dump Truck | 0 |
| Turner | 0 |

***Total Facility Capitalized Costs***

| | |
|---|---|
| Building | $63,000.00 |

***Total Equipment Capitalized Costs***

| | |
|---|---|
| Pumps and Separator | $31,700.00 |

| | |
|---|---|
| *Total Project Cost* | $94,700.00 |

***Annual Personnel Hours***

| | |
|---|---|
| Record Keeping | 2 |
| Marketing | 0 |
| General Labor | 197.5 |
| Bagging | 0 |

***Other Factors***

| | |
|---|---|
| Opportunity Cost of Capital | 5.00% |
| Salvage Value of Facility | $10,000.00 |
| Salvage Value of Equipment | $0.00 |
| Yards of Product Produced | 3,200 |
| Facility Capitalization Time | 20 |
| Equipment Capitalization Time | 7 |
| Pounds of Milk Sold per Year | 36,500,000 |

**Farm C**

***Costs and Returns from Composting***

| | | |
|---|---|---|
| **Annual Income Received** | | |
| Compost Sales | | |
| Total Income | $0.00 | |
| **Reduced Expenses** | | |
| Manure Hauling | $8,450.00 | |
| Sawdust Bedding | $44,800.00 | |
| Total Reduced Expenses | $53,250.00 | |
| **Annual Variable Expenses** | | **Per Yard Expenses** |
| Skid Steer | $0.00 | $0.00 |
| Payloader | $4,160.00 | $1.30 |
| Material Pickup/Delivery | $0.00 | $0.00 |
| Spreading/Mixing | $0.00 | $0.00 |
| Dump Truck | $0.00 | $0.00 |
| Turner | $0.00 | $0.00 |
| Record Keeping | $50.00 | $0.02 |
| Marketing | $0.00 | $0.00 |
| Electricity | $299.95 | $0.09 |
| Repairs | $3,000.00 | $0.94 |
| Bagging | $0.00 | $0.00 |
| Labor | $3,950.00 | $1.23 |
| Lost Quality Premiums | $0.00 | $0.00 |
| *Total Variable Expenses* | $11,459.95 | $3.58 |
| **Annual Fixed Expenses** | | **Per Yard Expenses** |
| Insurance | $980.00 | $0.31 |
| Facility Depreciation | $2,650.00 | $0.83 |
| Composting Equipment Depreciation | $4,528.57 | $1.42 |
| Average Annual Interest on Investment | $2,617.50 | $0.82 |
| *Total Fixed Expenses* | $10,776.07 | $3.37 |
| **Total Economic Cost to Farm** (Total Fixed and Variable Expenses) | $22,236.02 | $6.95 |
| **Annual Cost to Farm** (less Savings and Generated Income) | -$31,013.98 | |
| **Annual Cost per Hundred Weight of Milk** | -$0.08 | |

**Farm D**

## Bedding Production Costs

***Machinery and Services Operating Costs per Hour for Construction***

| | |
|---|---|
| Site Preparation | $50.00 |
| Grading | $70.00 |
| Rolling | $70.00 |
| Design | $100.00 |

***Machinery Operating Costs per Hour for Operations (includes all costs)***

| | |
|---|---|
| Skid Steer | $22.00 |
| Payloader | $32.00 |
| Material Pickup | $30.00 |
| Spreader/Mixer | $28.00 |
| Dump Truck | $25.00 |
| Turner | $22.00 |

***Personnel Costs per Hour***

| | |
|---|---|
| Management | $25.00 |
| Labor | $20.00 |

***Start up Costs in Hours***

| | |
|---|---|
| Contract Acquisition | 0 |
| Process Evaluation | 10 |

***Annual Equipment Operating Hours***

| | |
|---|---|
| Skid Steer | 0 |
| Payloader | 0 |
| Material Pickup | 0 |
| Spreading | 0 |
| Dump Truck | 0 |
| Turner | 0 |

***Total Facility Capitalized Costs***

| | |
|---|---|
| Construction | $80,000.00 |

***Total Equipment Capitalized Costs***

| | |
|---|---|
| Pumps and Separator | $77,100.00 |

| | |
|---|---|
| *Total Project Cost* | $157,100.00 |

***Annual Personnel Hours***

| | |
|---|---|
| Record Keeping | 156 |
| Marketing | 0 |
| General Labor | 1000 |
| Bagging | 0 |

***Other Factors***

| | |
|---|---|
| Opportunity Cost of Capital | 5.00% |
| Salvage Value of Facility | $20,000.00 |
| Salvage Value of Equipment | $5,000.00 |
| Yards of Product Produced | 1,560 |
| Facility Capitalization Time | 20 |
| Equipment Capitalization Time | 7 |
| Pounds of Milk Sold per Year | 22,478,997 |

**Farm D**

***Costs and Returns from Composting***

**Annual Income Received**

| | |
|---|---|
| Compost Sales | |
| Total Income | $0.00 |

**Reduced Expenses**

| | |
|---|---|
| Manure Hauling | $8,325.00 |
| Wood Shavings - Bedding | $53,082.00 |
| Total Reduced Expenses | $61,407.00 |

| **Annual Variable Expenses** | | **Per Yard Expenses** |
|---|---|---|
| Skid Steer | $0.00 | $0.00 |
| Payloader | $0.00 | $0.00 |
| Material Pickup/Delivery | $0.00 | $0.00 |
| Spreading/Mixing | $0.00 | $0.00 |
| Fuel | $0.00 | $0.00 |
| Lubrication | $0.00 | $0.00 |
| Record Keeping | $3,900.00 | $2.50 |
| Marketing | $0.00 | $0.00 |
| Electricity | $7,679.00 | $4.92 |
| Repairs | $18,097.00 | $11.60 |
| Bagging | $0.00 | $0.00 |
| Labor | $22,000.00 | $14.10 |
| Lost Quality Premiums | $0.00 | $0.00 |
| *Total Variable Expenses* | $51,676.00 | $33.13 |

| **Annual Fixed Expenses** | | **Per Yard Expenses** |
|---|---|---|
| Insurance | $752.00 | $0.48 |
| Facility Depreciation | $3,000.00 | $1.92 |
| Composting Equipment Depreciation | $0.00 | $0.84 |
| Average Annual Interest on Investment | $4,427.50 | $2.84 |
| *Total Fixed Expenses* | $8,179.50 | $5.24 |

| | | |
|---|---|---|
| **Total Economic Cost to Farm** (Total Fixed and Variable Expenses) | $59,855.50 | $38.37 |
| **Annual Cost to Farm** (less Savings and Generated Income) | -$1,551.50 | |
| **Annual Cost per Hundred Weight of Milk** | -$0.01 | |

**Farm E**

## Bedding Production Costs

***Machinery and Services Operating Costs per Hour for Construction***

| | |
|---|---|
| Site Preparation | $50.00 |
| Grading | $70.00 |
| Rolling | $70.00 |
| Design | $100.00 |

***Machinery Operating Costs per Hour for Operations (includes all costs)***

| | |
|---|---|
| Skid Steer | $22.00 |
| Payloader | $32.00 |
| Material Pickup | $30.00 |
| Spreader/Mixer | $28.00 |
| Dump Truck | $25.00 |
| Turner | $22.00 |

***Personnel Costs per Hour***

| | |
|---|---|
| Management | $25.00 |
| Labor | $20.00 |

***Start up Costs in Hours***

| | |
|---|---|
| Contract Acquisition | 0 |
| Process Evaluation | 10 |

***Annual Equipment Operating Hours***

| | |
|---|---|
| Skid Steer | 624 |
| Payloader | 0 |
| Material Pickup | 0 |
| Spreading | 0 |
| Dump Truck | 0 |
| Turner | 0 |

***Total Facility Capitalized Costs***

| | |
|---|---|
| Construction | $80,000.00 |

***Total Equipment Capitalized Costs***

| | |
|---|---|
| Pumps and Separator | $110,000.00 |

| | |
|---|---|
| *Total Project Cost* | $190,000.00 |

***Annual Personnel Hours***

| | |
|---|---|
| Record Keeping | 100 |
| Marketing | 0 |
| General Labor | 1000 |
| Bagging | 0 |

***Other Factors***

| | |
|---|---|
| Opportunity Cost of Capital | 5.00% |
| Salvage Value of Facility | $40,000.00 |
| Salvage Value of Equipment | $0.00 |
| Yards of Product Produced | 18,625 |
| Facility Capitalization Time | 20 |
| Equipment Capitalization Time | 7 |
| Pounds of Milk Sold per Year | 38,325,000 |

**Farm E**

***Costs and Returns from Composting***

| **Annual Income Received** | | |
|---|---|---|
| Compost Sales | | |
| Total Income | $0.00 | |
| | | |
| **Reduced Expenses** | | |
| Manure Hauling | $8,425.00 | |
| Wood Shavings - Bedding | $156,114.75 | |
| Total Reduced Expenses | $164,539.75 | |
| | | |
| **Annual Variable Expenses** | | **Per Yard Expenses** |
| Skid Steer | $13,728.00 | $0.74 |
| Payloader | $0.00 | $0.00 |
| Material Pickup/Delivery | $0.00 | $0.00 |
| Spreading/Mixing | $0.00 | $0.00 |
| Dump Truck | $0.00 | $0.00 |
| Turner | $0.00 | $0.00 |
| Record Keeping | $2,500.00 | $0.13 |
| Marketing | $0.00 | $0.00 |
| Electricity | $4,599.00 | $0.25 |
| Repairs | $22,100.00 | $1.19 |
| Bagging | $0.00 | $0.00 |
| Labor | $20,000.00 | $1.07 |
| Lost Quality Premiums | $0.00 | $0.00 |
| *Total Variable Expenses* | $62,927.00 | $3.38 |
| | | |
| **Annual Fixed Expenses** | | **Per Yard Expenses** |
| Insurance | $770.00 | $0.04 |
| Facility Depreciation | $2,000.00 | $0.11 |
| Composting Equipment Depreciation | $15,714.29 | $0.84 |
| Average Annual Interest on Investment | $5,750.00 | $0.31 |
| *Total Fixed Expenses* | $24,234.29 | $1.30 |
| | | |
| **Total Economic Cost to Farm** | $87,161.29 | $4.68 |
| (Total Fixed and Variable Expenses) | | |
| | | |
| **Annual Cost to Farm** | -$77,378.46 | |
| (less Savings and Generated Income) | | |
| **Annual Cost per Hundred Weight of Milk** | -$0.20 | |

**Farm F**

## Bedding Production Costs

***Machinery and Services Operating Costs per Hour for Construction***

| | |
|---|---|
| Site Preparation | $50.00 |
| Grading | $70.00 |
| Rolling | $70.00 |
| Design | $100.00 |

***Machinery Operating Costs per Hour for Operations (includes all costs)***

| | |
|---|---|
| Skid Steer | $22.00 |
| Payloader | $32.00 |
| Material Pickup | $30.00 |
| Spreader/Mixer | $28.00 |
| Dump Truck | $25.00 |
| Turner | $22.00 |

***Personnel Costs per Hour***

| | |
|---|---|
| Management | $25.00 |
| Labor | $20.00 |

***Start up Costs in Hours***

| | |
|---|---|
| Contract Acquisition | 0 |
| Process Evaluation | 10 |

***Annual Equipment Operating Hours***

| | |
|---|---|
| Skid Steer | 650 |
| Payloader | 0 |
| Material Pickup | 0 |
| Spreading | 0 |
| Dump Truck | 0 |
| Turner | 0 |

***Total Facility Capitalized Costs***

| | |
|---|---|
| Construction | $212,000.00 |

***Total Equipment Capitalized Costs***

| | |
|---|---|
| Pumps and Separator | $70,000.00 |

| | |
|---|---|
| *Total Project Cost* | $282,000.00 |

***Annual Personnel Hours***

| | |
|---|---|
| Record Keeping | 10 |
| Marketing | 0 |
| General Labor | 730 |
| Bagging | 0 |

***Other Factors***

| | |
|---|---|
| Opportunity Cost of Capital | 5.00% |
| Salvage Value of Facility | $40,000.00 |
| Salvage Value of Equipment | $0.00 |
| Yards of Product Produced | 8,030 |
| Facility Capitalization Time | 20 |
| Equipment Capitalization Time | 7 |
| Pounds of Milk Sold per Year | 25,520,000 |

**Farm F**

***Costs and Returns from Composting***

| **Annual Income Received** | | |
|---|---|---|
| Compost Sales | $15,000.00 | |
| Total Income | $15,000.00 | |
| | | |
| **Reduced Expenses** | | |
| Manure Hauling | $50,000.00 | |
| Wood Shavings - Bedding | $81,600.00 | |
| Total Reduced Expenses | $131,600.00 | |
| | | |
| **Annual Variable Expenses** | | **Per Yard Expenses** |
| Skid Steer | $14,300.00 | $1.78 |
| Payloader | $0.00 | $0.00 |
| Material Pickup/Delivery | $0.00 | $0.00 |
| Spreading/Mixing | $0.00 | $0.00 |
| Dump Truck | $0.00 | $0.00 |
| Turner | $0.00 | $0.00 |
| Record Keeping | $250.00 | $0.03 |
| Marketing | $0.00 | $0.00 |
| Electricity | $8,687.00 | $1.08 |
| Repairs | $14,000.00 | $1.74 |
| Bagging | $0.00 | $0.00 |
| Labor | $14,600.00 | $1.82 |
| Lost Quality Premiums | $0.00 | $0.00 |
| *Total Variable Expenses* | $51,837.00 | $6.46 |
| | | |
| **Annual Fixed Expenses** | | **Per Yard Expenses** |
| Insurance | $770.00 | $0.10 |
| Facility Depreciation | $8,600.00 | $1.07 |
| Composting Equipment Depreciation | $10,000.00 | $1.25 |
| Average Annual Interest on Investment | $8,050.00 | $1.00 |
| *Total Fixed Expenses* | $27,420.00 | $3.41 |
| | | |
| **Total Economic Cost to Farm** | $79,257.00 | $9.87 |
| (Total Fixed and Variable Expenses) | | |
| | | |
| **Annual Cost to Farm** | -$67,3443.00 | |
| (less Savings and Generated Income) | | |
| **Annual Cost per Hundred Weight of Milk** | -$0.26 | |