Management Practices, Milk Yield, and Feed Cost on Confinement Dairy Farms in Minnesota

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Lee A Kloeckner

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Literature Review

INTRODUCTION

The trend in the dairy industry is for a shift to larger farms. This is the result of the ability to earn higher returns per hundredweight of milk produced (MacDonald et al., 2016). Feed represents a majority of the cost of producing milk (56% of 2015 production cost; USDA ERS, 2016b). The feed costs in Minnesota were slightly below the national average as 44% (USDA ERS, 2016b) and 50% (FINBIN, 2016) of the cost of production was attributed to feed. Feed cost per cow per day, feed cost per kg of dry matter (**DM**), income over feed costs (**IOFC)**, and feed cost per 45.4 kg of milk are some of the many possible ways to evaluate the economics of feeding programs. Hutjens (2007) identifies feed cost per 45.4 kg of milk as the best method for comparing between groups and farms within a region because milk yield is standardized and the value is impacted by milk yield per cow and feed costs.

As herd size increases, cows are fed as a group with a totally mixed ration (**TMR**), where forages and concentrates are mixed together to provide a diet that will meet the cows nutritional requirements for optimal milk production. Larger herds have the ability to group cows by stage of lactation or production to formulate a diet more precise to their nutritional requirements (USDA-APHIS VS, 2016). Formulating a properly balanced diet can provide cows with the correct nutrients, but there are several factors that can impact what the cow actually consumes; including frequency of fresh feed delivery, particle size of the TMR, and target refusal rate (DeVries et al., 2005; Endres and Espejo, 2010; Sova et al., 2013). Behavior of dairy cows can be altered by the stocking density and the design of the feed barrier (Huzzey et al., 2006). Feed shrink, or the amount of feedstuff dry matter that was purchased but not consumed by the cow, can add up to substantial losses if feed is not properly stored or handled (Stone et al., 2015).

Several factors impacting milk production have been identified. The use of bovine somatotropin (**bST**) and increased milking frequency from 2 to 3 times per day has the greatest impact on milk production (Bewley et al., 2001b; Cabrera et al., 2010). Other factors impacting milk production include: frequency of fresh feed delivery, particle size of the TMR, feeding for refusals, water space per cow, stocking density, and the use of sprinklers to cool cows (Bewley et al., 2001b; Bach et al., 2008; Sova et al., 2013; Nasrollahi et al., 2015). Pushing up feed has a positive association with milk production; however, the frequency of feed push-up has no association with milk production (DeVries et al., 2003; Bach et al., 2008).

Feed costs can also be impacted by several factors including region, access to byproduct feeds, and current milk prices. In tough economic conditions, producers may try to minimize their feed cost per cow; however, Buza et al. (2014) found that minimizing feed cost per cow per day did not result in the highest IOFC. Kalantari et al. (2016) found the overall average gain in IOFC was the greatest going from 1 lactating group diet to 2 lactating group diets in addition to a post-fresh group diet, and the gain was further emphasized in tough economic conditions. Lactation number, confirmed pregnancy, level of milk production, and body condition score (**BCS**) should be the primary criteria for grouping cows (Krohn and Konggaard, 1979; Grant and Albright, 2001).

In the past decade, there have been several studies investigating dairy management practices on confinement dairy herds in the United States (e.g. Brotzman et al., 2015; Cook et al., 2016; and USDA-APHIS VS, 2016). Fewer studies have focused on feeding management practices and their associated economic impact (Winsten et al., 2010; Buza and Holden, 2016) in the Northeastern U. S. and the most recent study in the Midwest was Endres and Espejo (2010) on 50 freestall dairy farms in Minnesota.

The objectives of this project were to 1) describe housing and management practices of dairy farms using confinement housing primarily in the form of freestalls, 2) compare housing and management practices between 2 farm sizes, and 3) identify management factors for energy corrected milk yield (**ECM**) per cow per day and feed cost per 45.4 kg of ECM. The following sections will provide a summary of previous work on housing and management practices in dairy herds in North America.

FACILITY DESIGN

Pen Design

As farms increase in size, loose housing becomes more common, primarily in the form of freestalls. The use of a freestall barn is associated with reduced labor, increased cow comfort, and increased efficiency (Bewley et al., 2001a). In a survey of 1261 U.S. dairy operations, 20.0 ± 1.1% of all operations housed lactating cows in freestalls with no access to open or dry lots. Freestalls with no pasture or dry lot access were used on 39.4 ± 2.6% and 51.1 ± 1.8% of farms from 100-499 cows and 500 or more cows, respectively (USDA-APHIS VS, 2016). Mayer and Kammel (2008) found that of the 99 Wisconsin dairy farms that had recently modernized their housing for the lactating cows to loose housing, 79% used freestalls and 21% used bedded pack barns.

Compared to 2 rows of freestalls in a pen, having 3 rows allows producers to have more cows in a pen leading to reduced labor; however, feed bunk space per cow is usually reduced. Two or 3 rows of freestalls in a pen were the most common design for freestall barns. Endres and Espejo (2010) reported 38% of farms utilized 2-row pens and 62% of farms utilized 3-row pens. Brotzman et al. (2015) reported that 47.7% of farms utilized 2-row pens and 48.8% of farms utilized 3-row pens. Cook et al. (2016) reported that 61% of farms used 2-row pens. Bewley et al. (2001a) found that 7, 25, 39, and 23% of new freestall barns in recently modernized herds were constructed with a 2-, 3-, 4-, or 6-row design, respectively.

Freestalls

Nordlund and Cook (2003) identified 4 critical points for evaluating freestalls: 1) surface cushion, 2) body resting space, 3) lunge space, and 4) neck rail position. Stall surfaces have evolved over the years from loose bedding on concrete surfaces, to different types of rubber surfaces on concrete, to deep bedded stalls. Several studies reported negative associations between lameness, lesions, or swellings and the use of soft mats, mattresses, or deep bedded freestalls (e.g. Brenninkmeyer et al., 2013; Chapinal et al., 2013; Cook et al., 2016). When comparing mattresses and deep bedding, Cook et al. (2004), Ito et al. (2010), and Cook et al. (2016) reported higher prevalence of lame cows in herds with mattresses. Cook et al. (2004) found that cows spent 1.61 more hours per day standing, lame cows spent 4.31 more hours per day standing in the stall, and feeding time was reduced by 0.57 hours per day in mattress herds compared to sand herds. The use of deep bedded freestalls was reported on 59, 52, 49, 68, and 70% of herds (Bewley et al., 2001a; Mayer and Kammel, 2008; von Keyserlingk et al., 2012; Brotzman et al., 2015; Cook et al., 2016; respectively). The use of rubber surfaces was reported on 28, 27, 30, and 32% of herds (Bewley et al., 2001a; Mayer and Kammel, 2008; von Keyserlingk et al., 2012; Brotzman et al., 2015; respectively).

The primary bedding type used for lactating cows can vary depending on the geographical location and size of the farm. Regardless of bedding type, the bedding material should be clean and dry to provide a comfortable lying surface for the cows and minimize the spread of contagious mastitis pathogens. Surveys by von Keyserlingk et al. (2012), Rowbotham and Ruegg (2015), and USDA-APHIS VS (2016) showed that 33, 9, and 6% of farms used dried or composted manure, 17, 60, and 22% of farms used sand, respectively. Surveys by von Keyserlingk et al. (2012) and USDA-APHIS VS (2016) found that 38 and 22% of herds used sawdust or other wood products as primary bedding material, respectively. Straw and hay were used by 29.7% of operations (USDA-APHIS VS, 2016). Rowbotham and Ruegg (2015) reported that 19% of herds used non-manure organic bedding. Sand bedding has advantages because it is inorganic, allowing it to drain well and is less likely to maintain high levels of mastitis causing organisms

(Bewley et al., 2001a). Rowbotham and Ruegg (2015) found that Wisconsin dairies that used inorganic bedding, such as sand, had greater rolling herd average (**RHA**) milk production and better milk quality than farms that used organic bedding. Sand bedding is also less abrasive than mattresses and results in fewer hock lesions, an indicator of cow comfort. Bewley et al. (2001a) found that in new freestall barns, herds using sand had lower culling rates than herds using mattresses.

The body-resting space is determined by the length and width of the freestalls. Brisket boards are commonly used to help position the cows within the stall to reduce fecal contamination of the back of the stall. Cook and Nordlund (2005) recommended that the distance from the rear of the curb to the brisket locator should be 178 to 183 cm depending on cow lactation and size, and not higher than 10.2 cm above the stall surface. They recommend the width of the stalls to be 122 to 127 cm for lactating cows. Espejo and Endres (2007) found an association between brisket board height greater than 15.2 cm and higher prevalence of lameness.

Providing adequate lunge space allows for a cow to naturally 'bob' her head when she stands up. Lunge space can be impacted by the height of the brisket locator, bedding build-up behind the brisket locator, a horizontal mounting bar for the dividers, or a wall (Nordlund and Cook, 2003). Espejo and Endres (2007) found an association between more lameness and the presence of an area behind the brisket board filled with concrete.

The location of the neck rail helps position the cow while she is standing in the stall so she does not defecate in the back of the stall. Cook and Nordlund (2005) recommended that the height of the neck rail be 112 to 127 cm above the bedded surface and 158 to 183 cm from the rear of the curb depending on the stall surface (deep bedded versus mattress), the size of the cow, and the height of the neck rail.

Freestall Stocking Density

Having more cows than freestalls in a pen appears to be a common practice for freestall herds as it gives producers the ability to reduce the cost per freestall. A herd budget-simulation model by De Vries et al. (2016) found that the average optimal stall-stocking density across 2,187 combinations of inputs was 1.2 cows per freestall and the average maximum increase in profit was $99 per stall per year. Although overstocking freestalls can increase net returns, cows can experience negative effects on behavior and performance. When cows were overcrowded, decreased feeding times and reductions in milk production have been reported (Huzzey et al., 2006; Bach et al., 2008).

Reported stocking densities for high-production pens were 1.14, 1.09, and 1.2 cows per freestall (Boterman and Bucholtz, 2005; Schefers et al., 2010; Cook et al., 2016; respectively). Fulwider et al. (2008) and von Keyserlingk et al. (2012) reported stocking densities ranging from 0.61 and 0.71 to 1.56 and 1.97 cows per freestall, respectively. Fulwider et al. (2008) also reported that 60% of high-producing groups had stocking rates over 1 cow per freestall, and von Keyserlingk et al. (2012) reported that 50% of high-producing groups were stocked at or above 1.02 cows per freestall. Bewley et al. (2001a) found that the average stocking rates were 1.11 and 1.04 cows per freestall in 4-row and 6-row barns, respectively.

Flooring

Solid flooring in the pens for the lactating cows is the most common; Bewley et al. (2001a) reported that 20% of new 6-row and 2% of new 4-row barns use slatted flooring and USDA-APHIS VS (2016) reported that slatted concrete was used on 2.2 ± 0.5% of farms. Rubber flooring was used on 4.6% and 21.0 ± 1.5% of herds (Cook et al., 2016; USDA-APHIS VS, 2016; respectively). Cook and Nordlund (2009) found that rubber flooring may reduce hoof trauma and wear. Grooved or textured concrete was used on 47.9 ± 1.7% of herds and smooth concrete was used on 11.5 ± 1.2% of herds (USDA-APHIS VS, 2016).

Feed Barrier

Cows accessing feed via a post and rail barrier spent more time eating (Batchelder, 2000; Endres et al., 2005; Huzzey et al., 2006); however, they were more likely to be displaced than cows accessing feed via a headlock barrier (Huzzey et al., 2006). Headlocks were used as the primary feed barrier for the high-producing groups on 66, 28, 70, and 26% of herds (Caraviello et al., 2006; Endres and Espejo, 2010; Brotzman et al., 2015; USDA-APHIS VS, 2016; respectively). Post and rail was used as the primary feed barrier for the high-producing groups on 60, 26, 15% of herds (Endres and Espejo, 2010; Brotzman et al., 2015; USDA-APHIS VS, 2016; respectively). A combination of headlock and post and rail was used on 8 and 3.5% of high-producing groups (Endres and Espejo, 2010; Brotzman et al., 2015; respectively). An elevated feed bunk in the high-producing pen was used by 13.6% of herds (USDA-APHIS VS, 2016).

Feed Bunk Stocking Density

It is recommended that lactating cows have 0.46 m of bunk space per cow when feed is always available (Holmes et al., 2013). Increased stocking density of the feed bunk can decrease feeding time (Olofsson, 1999; DeVries et al., 2004; Huzzey et al., 2006); however, contrasting results have been found investigating production as a result of the stocking density of the feed bunk. Sova et al. (2013) reported an association between feed bunk space and milk fat percentage; for every 10 cm increase in bunk space, milk fat percentage increased by 0.06 percentage points. However, Bach et al. (2008) found no relationship between feed bunk space per cow and animal performance, incidence of lameness, or culling rate. Mean linear feed bunk space per cow in the high-producing group was 0.51, 0.53 ± 0.02, 0.45 ± 0.11, 0.54 ± 0.14, and 0.52 ± 0.09 m (Boterman and Bucholtz, 2005; Caraviello et al., 2006; Endres and Espejo, 2010; Schefers et al., 2010; Cook et al., 2016; respectively). Endres and Espejo (2010) reported that linear bunk space was greater in two-row pens than in three-row pens (0.56 ± 0.09 vs. 0.39 ± 0.08 m/cow; P <0.01). In the post-fresh pen Boterman and Bucholtz (2005) and Schefers et al. (2010) reported 0.65 and 0.80 ± 0.29 m/cow, respectively.

Sova et al. (2013) found an association between water trough space and milk yield; milk yield tended to increase by 0.77 kg per day for every 2 cm per cow increase in water trough space. Endres and Espejo (2010) and Cook et al. (2016) reported 4.6 ± 2.1 and 7.8 ± 2.2 cm/cow of linear water space, respectively. Von Keyserlingk et al. (2012) reported 8 and 6 cm/cow of linear water space in California and in the Northeast United States, respectively.

FEEDING MANAGEMENT

Number of Rations

The use of a TMR allows producers to optimize milk production by providing cows with a consistently balanced ration of several different ingredients. The use of TMR is becoming increasingly popular. Winsten et al. (2010) reported that 99% of large, modern, confinement farms (no grazing and ≥300 milking and dry cows) and 57% of traditional farms (less intensive grazing methods or confinement farms <300 milking and dry cows) fed TMR. Buza and Holden (2016) reported that 97.6% of the farms surveyed in Pennsylvania fed a TMR for groups of lactating cows. Several studies show a possible economic advantage to grouping cows for nutritional purposes and providing them with a more precisely formulated diet (e.g. Stallings, 2011; Cabrera et al., 2012; Kalantari et al., 2016). However, Buza and Holden (2016) and USDA-APHIS VS (2016) both reported that only 46.3 and 33.1% of farms fed more than 1 TMR to the lactating cows. Common grouping strategies include grouping cows by production, stage of lactation, and lactation number; grouping is more commonly done by larger farms. USDA-APHIS VS (2016) reported that 24.2% of medium size farms and 51.6% of large farms group cows based on production or stage of lactation and 5.7% and 11.3% of medium and large farms, respectively, group cows based on lactation number.

Feedings

Fresh feed delivery is important for stimulating the feeding activity of dairy cows (DeVries and von Keyserlingk, 2005). Sova et al. (2013) found a positive association between increased frequency of fresh feed delivery and milk yield with twice per day feed delivery being associated with a 2.01 kg per day increase in milk yield per cow than once per day feeding. Endres and Espejo (2010), von Keyserlingk et al. (2012), and Brotzman et al. (2015) reported once per day feeding in 70, 54, and 53% of herds, respectively. The same studies reported twice-per-day feed delivery frequencies of 22, 36, and 45%, and 3 or more feed deliveries of 8, 10, and 3%, respectively.

Feed Push-ups

Feed push-up is important to ensure that cows always have access to feed as they tend to push and throw feed out of reach as they eat. Increasing the number of feed push-ups does not alter feeding activity (DeVries et al., 2003) or milk yield (Bach et al., 2008). However, Bach et al. (2008) reported that pushing up feed had a positive impact on milk production; herds that pushed up feed averaged 3.9 kg per day more milk than herds that did not push up feed. Average frequency of feed push-up was reported to be 6.8 ± 0.4, 3.5, and 5.4 ± 2.3 times daily by Caraviello et al. (2006), Mayer and Kammel (2008) and Endres and Espejo (2010), respectively.

Refusals

Feeding for refusals can be a balancing act of ensuring cows have enough feed to meet their intake requirements without providing too much extra feed, which would result in increased total feed costs. Herds that fed to ensure feed refusals tended to produce more milk (29.1 ± 0.61 kg per day) than those who fed for no feed refusals (27.5 ± 0.73 kg per day; Bach et al., 2008). Sova et al. (2013) found reduced sorting against long particles in herds that fed for lower refusal rates. Caraviello et al. (2006) reported an average target feed refusal rate of 3.5 ± 0.2% of the feed delivered. Boterman and Bucholtz (2005) reported that 33% of farms disposed of the refusals from the lactating groups. The remaining farms either fed the refusals to heifers (34%), low-producing groups (13%), close up dry cows (5%), and steers (15%).

Composition

Feeding a properly balanced diet is essential for optimal milk production. Diet composition can vary for many different reasons. The ratio of forage to concentrate in the diet can impact dry matter intake (**DMI**) as the amount and digestibility of forage fiber can impact rates of passage (NRC 2001). Machado et al. (2014) reported that reducing the forage content of the diet from 65 to 45% linearly increased milk yield and milk production efficiency; however, at the expense of fat and lactose content. They also reported no negative effects on cow body weight or body condition score. Endres and Espejo (2010) reported the average forage content of formulated rations on freestall herds in Minnesota was 52% of the ration DM. Buza and Holden (2016) reported that 58.5 percent of farms used forage to concentrate ratios of 60% forage to 40% concentrates, 14.6% of farms had less than 50% forage in the diet, and 17.1% had 70% forage in the diet.

Three studies reported ration nutrient composition for United States dairy herds. Boterman and Bucholtz (2005) reported 29.1%, 18.5%, and 1.74 Mcal/kg of DM for neutral detergent fiber (**NDF**), crude protein (**CP**), and net energy for lactation (**NE_L**), respectively. Caraviello et al. (2006) reported 30.8 ± 0.6% and 17.8 ± 1.1% of DM for NDF and CP, respectively. Endres and Espejo (2010) reported ration characteristics for both formulated and analyzed diets. Neutral detergent fiber percent of DM was 29.8 ± 1.6% and 30.6 ± 2.3% of the formulated and analyzed diets. Crude protein percent of DM was 17.9 ± 0.5 and 17.5 ± 1.0% of the formulated and analyzed diets, respectively. Net energy for lactation of the formulated diet was 1.71 ± 0.42 Mcal/kg of DM. Each of these studies met the minimum recommended amounts of NDF, CP, and NE_L set by the NRC (2001).

The Penn State Forage Particle Separator is a tool that can be used to measure particle size of forages and total mixed rations. The guidelines described by Heinrichs and Kononoff (2002) recommended that 2 to 8% of the as fed TMR remain on the 19 mm sieve, 30 to 50% of the as fed TMR remain on the 8 mm and 1.18 mm sieves, and less than 20% of particles are smaller than 1.18 mm. Endres and Espejo (2010) found that 52% of farms exceeded the recommended upper limit of 8% on the upper sieve. They also found that 22 and 24% of farms did not meet the recommended amounts for the 8 and 1.18 mm sieves, respectively. All rations observed in their study were below the recommended maximum of 20% for particles smaller than 1.18 mm. Nasrollahi et al. (2015) found that with decreasing forage particle size DMI, milk production, and protein production increased; however, fat percentage decreased.

Feeders

The person mixing and delivering the feed has some control over the consistency or variability of the feed delivered to the cows. James and Cox (2008) reported that the primary feeders were less accurate than feeders that did less than 25% of the feed mixing, because the primary feeder may have developed bad mixing practices. Boterman and Bucholtz (2005) reported that on farms less than 250 cows, generally the main feeder did most of the feeding. Farms larger than 1000 cows had 1 or 2 people who were designated feeders. Farms ranging from 250 to 1000 cows tended to have more people who did a proportion of the feeding.

Feed Nutrient Analysis

Testing feeds for dry matter and nutrient composition helps ensure that the proper diet is being delivered to the cows without over or under feeding any nutrients. Although consistency may be better for cows, several studies have shown that milk yield and DMI were usually not affected by long term differences in TMR dry matter (Leonardi et al., 2005; Fish and DeVries, 2012; McBeth et al., 2013). However, variability in the daily TMR composition was associated with measures of group average DMI, milk yield, and efficiency (Sova et al., 2014). Frequency of DM determination varies by farm size with larger farms testing the DM more frequently (Boterman and Bucholtz, 2005). Buza and Holden (2016) found that 26.8% of farms tested DM weekly and 24.1% of farms tested DM biweekly. They also reported that nutrients were tested in the TMR (37.1% of farms), corn silage (48.8%), haylage (56.1%) and other forages (60.0%) at a feed change, such as switching to a new silo.

FEED INGREDIENTS

Forages

Corn silage is commonly used for forage in the Midwest and across the entire United States with 89.4% of all herds feeding corn silage to lactating or dry cows (USDA-APHIS VS, 2016). Endres and Espejo (2010) reported that corn silage was the most commonly used forage on 48 out of 49 farms in Minnesota with corn silage making up 25.4 ± 7.9% of the ration DM and 48.7 ± 14.2% of the total forage DM. Kellogg et al. (2001) found that 91.2% of dairy herds in the Midwest were using corn silage. Boterman and Bucholtz (2005) reported that 100% of surveyed Michigan herds were using corn silage as a separate ingredient and when choosing corn hybrid variety for corn silage, 66% of producers considered NDF digestibility, 40% of producers considered yield, and 40% of producers used other criteria. Higher DMI and increased milk yield were reported in studies investigating corn silage with high NDF digestibility (Oba and Allen, 1999; Bal et al., 2000; Thomas et al., 2001). However, several studies reported no difference in milk yield between brown midrib (**BMR**) corn hybrids and conventional hybrids (Bal et al., 2000; Ballard et al., 2001; Qui et al., 2003).

Along with corn silage, legume forages are also used by many herds in the United States as 92.0% of all herds feed alfalfa hay or haylage to lactating or dry cows. In the Midwest, 96.5% of farms were using legume haylage and 57.9% of farms were using legume hay. Boterman and Bucholtz (2005) found that 100% of surveyed Michigan herds were using alfalfa silage as a separate ingredient in the lactating cow TMR. Endres and Espejo (2010) reported that 47 of 49 farms included alfalfa haylage in the ration at 22.6 ± 8.3% of the TMR DM and 43.4 ± 14.9% of the total forage. They also found that hay was included in 31 of the rations at 6.9 ± 3.6 of the TMR DM and 13.4 ± 6.9% of the total forage DM. Other forages used in Minnesota were straw in 7 rations, barley silage in 2 rations, and sweet corn silage in 1 ration.

Concentrates

Corn grain is a popular energy source in dairy rations across the United States due to its high availability. Ninety percent of all herds fed corn grain, whole, ground, cracked, or flaked (USDA-APHIS VS, 2016). In the Midwest, 75.4% of herds fed corn and 36.8% of herds fed high-moisture grains (Kellogg et al., 2001). Boterman and Bucholtz (2005) reported that 16 out of 18 herds were using high moisture corn and 8 out of 18 herds were using dry corn. High moisture grains as a major part of the feeding program were found to have an association with higher milk yield and fat content than corn or barley as the primary grain source (Kellogg et al., 2001).

Soybeans are a commonly used protein source. USDA-APHIS VS (2016) found that 76.9 ± 1.4% of producers fed whole soybeans, soybean meal, or soybean hulls to lactating or dry cows. Kellogg et al. (2001) reported that 70.7% of producers across the nation fed soybean meal and 56.6% of producers in the Midwest fed roasted soybeans. Boterman and Bucholtz (2005) reported that half of the surveyed herds used soybean meal as a protein source. Farms that fed roasted soybeans had an association with higher fat content in the milk than farms that did not include roasted soybeans (Kellogg et al., 2001).

The use of cottonseed was reported by 3 studies. Jordan and Fourdraine (1993), Kellogg et al. (2001), and Boterman and Bucholtz (2005) reported the use of whole cottonseed by 72, 71, and 33% of herds, respectively. Other commonly used byproducts include animal proteins, beet or citrus pulp, brewers' grains and yeasts, canola meal, corn gluten meal, cottonseed meal, distillers grains, and molasses (Jordan and Fourdraine, 1993; Kellogg et al., 2001; Boterman and Bucholtz, 2005; Buza and Holden, 2016). The use of byproduct feeds have an advantage of lower cost; however, a high degree of variability in these feeds has been reported (DePeters et al., 2000; DeGroot et al., 2007).

Additives

Ionophores, such as monensin, can help increase milk production efficiency (Elanco, 2016). Brotzman et al. (2015) and Cook et al. (2016) reported the use of monensin on 81.6 and 87.9% of herds, respectively. USDA-APHIS VS (2016) reported its use in 37.0 ±1.6% of all herds, with 56.2 ± 2.7 and 62.7 ± 2.2% of medium and large herds, respectively, feeding ionophores. Other common feed additives include sodium bicarbonate and yeast (Jordan and Fourdraine, 1993; Kellogg et al., 2001).

Storage

As feeds make up a significant portion of the cost of production, it is important for producers to properly store feed in facilities that will minimize feed shrink. Boterman and Bucholtz (2005) reported that 15 out of 18 farms stored corn silage and haylage in bunkers and 10 of the 16 farms that used high moisture corn stored it in upright silos. Mayer and Kammel (2008) reported that silo bags and upright silos were used on 66% of the Wisconsin farms surveyed and bunkers and wrapped bales were used on 35 and 34% of the farms, respectively.

MILKING

Frequency

Herds that milked 3 times per day produced about 15% more milk than herds that milked twice per day (Bewley et al., 2001b; Smith et al., 2002). Smith et al. (2002) also reported significantly lower fat and protein percentages, somatic cell score (**SCS**) and weighted somatic cell count (**SCC**) for herds milking 3 times per day compared with 2 times per day. USDA-APHIS VS (2016) reported that 88.4 ± 0.9% of farms milk twice per day and 10.2 ± 0.7% of farms milked 3 times per day, with 56.8 ± 1.9% of large operations milking 3 times per day.

Milk Production

In 2015, Minnesota averaged 9,334 kg/cow per year (USDA ERS, 2016a). Brotzman et al. (2015) and Cook et al. (2016) reported energy corrected milk production of 39.5 ± 4.6

and 40.1 ± 4.4 kg/cow per day in the upper Midwest. Endres and Espejo (2010) reported management level milk production for the high-production group was 39.9 ± 5.6 kg/day with a milk fat percentage of 3.51 ± 0.36 and milk protein percentage of 2.90 ± 0.20.

OTHER

Bovine Somatotropin (bST)

The use of bST can help improve production and efficiency on dairy herds by allowing healthy cows to produce an average of 4.54 kg more milk per day resulting in a reduction of production cost by about 3 to 5% (Elanco, 2016). Bewley et al. (2001b) found that the use of bST was associated with an increase of 583 kg in RHA milk production. Tauer (2016) found an annual reduction in the cost of producing milk in New York from $0.24 to $3.42 per 100 kg of milk produced over the last 20 years with the use of bST. In the upper Midwest, bST was used by about two-thirds of dairies (Fulwider et al., 2008; Brotzman et al., 2015; Cook et al., 2016). Across the United States 9.7 ± 0.8% of all operations used bST with 14.0 ± 1.8 and 28.6 ± 1.9% of medium and large operations reporting its use (USDA-APHIS VS, 2016).

Technology

The use of technology in the dairy industry is increasing as producers seek more ways to improve efficiency on their farms. Feeding management programs were used on 16.2 ± 1.1% of all operations with 52.3 ± 2.3 and 15.3 ± 2.0% of large and medium herds, respectively, reporting its use (USDA-APHIS VS, 2016). Boterman and Bucholtz (2005) found that daily feed intake was monitored on 17 out of 18 herds; however, only 3 of these herds were using a feeding management program and 3 more herds not using it were planning to purchase it. Borchers and Bewley (2015) found that technologies monitoring milking performance, reproductive performance, udder health and milk components were the most commonly used systems at 52.3%, 41.3%, 41.3 and 25.7% of dairy operations, respectively.

Hoof Health

As previously mentioned, freestall design and flooring type can impact the hoof health of dairy cows. Along with facility design, hoof trimming and footbath use are also important for managing lameness. Brotzman et al. (2015) and Cook et al. (2016) reported that 83.1 and 87.9% of farms in the upper Midwest followed scheduled hoof trimming, respectively, with 50.8 and 65.5% of those herds trimming at least twice per lactation. Espejo and Endres (2007) found that farms who trimmed hooves on a maintenance schedule either once or twice annually had a lower prevalence of lameness than herds who only trimmed hooves when the manager decided that cows needed because of lameness or hoof overgrowth. Footbaths are important for managing infectious causes of lameness. Caraviello et al. (2006) reported that 89% of herds use a footbath and Cook et al. (2016) reported that 98% of surveyed herds used a footbath with a frequency of 4.5 ± 2.2 passes per week.

Heat Abatement

The effects of temperature and relative humidity can be combined to create a temperature humidity index (**THI**); at a THI of 68, subtle, but significant changes in cow behavior were identified (Cook et al., 2007). During heat stress, cows reduced feed intake, decreased activity, increased respiratory rate, and increased both peripheral blood flow and sweating (West, 2003). Because these changes in behavior can have a large impact on milk production, Cook et al. (2007) recommended the use of both fans and soakers when the barn temperature is at or above 21 degrees Celsius and that having fans over the stalls may help reduce the effects of heat stress in lame cattle that prefer to stand in the freestalls.

The use of heat abatement has become more common in recent years. Bewley et al. (2001a) reported that 57% of respondents who had recently modernized their dairy facilities in Wisconsin were not using fans and sprinklers; however, they did find an association with the use of fans, sprinklers, or fans and sprinklers to cool cows and higher RHA milk production. Caraviello et al. (2006) and Cook et al. (2016) had similar findings and reported that over 80% of farms were using either wind tunnel ventilation or recirculation fans and over 70% of farms were using sprinklers. Nationally, 75.7 ± 1.5% of herds were using fans to cool cows and 25.2 ± 1.3% of operations were using misters or sprinklers (USDA-APHIS VS, 2016).

Chapter 2

Feeding and management practices on large and small confinement dairy farms in Minnesota

SUMMARY

The objectives of this study were to evaluate feeding and management practices on freestall dairy farms in Minnesota and compare practices between 2 dairy farm sizes. Eighty-two farms were randomly selected from a list provided by the Minnesota Department of Agriculture that included all dairies in the state. Farms were visited once between May and December to collect on-farm measurements and observations and to inquire about management practices. Farms were blocked by size: large farms (≥425 cows; n=41) and small farms (>140 and <425 cows; n=41). Data were analyzed using the MEANS, TTEST, MIXED, and FREQ procedures of SAS. Mean farm size for the large and small farms was 931 and 293 cows, respectively. Large farms were more likely to use 3 or more separate lactating rations (68.3%) and 2 separate non-lactating rations (73.2%) than small farms (24.4% and 36.6%, respectively). Large farms had more frequent feed push-ups (mean ± SD, 9.1 ± 4.2) and milkings (2.93 ± 0.30) per day than small farms (5.1 ± 2.9 and 2.41 ± 0.50, respectively). The high-production rations on large farms had higher estimated DMI (27.1 ± 2.4 kg/cow) and CP percent of DM (17.0 ± 0.4) and less total forage (48.9 ± 6.0) and legume forage (18.2 ± 4.3) as a percent of DM than small farms (25.1 ± 1.9, 16.6 ± 0.8, 53.7 ± 5.6, and 23.3 ± 6.1, respectively). Small farms were more likely to use upright silos (36.6%) to store high moisture grains and Ag

bags (26.8%) to store forages than large farms (17.1% and 9.8%, respectively). More large herds grouped primiparous and multiparous cows separately in the post-fresh pen (20.0%) and the high-production pen (95.1%) than small farms (0% and 68.3%, respectively). In the high-production pen large farms had less bunk space per cow (0.49 ± 0.12 m/cow) than small farms (0.55 ± 0.14). There were no differences in the usage of bulk bins, commodity bays, bunker silos, and forage piles between each farm size. There were no differences in the type of plastic used to cover forages. Other management practices where no differences were observed included number of feedings per day, target percent refusals, own or hired forage harvesting, type of corn silage hybrids, and feed mixer type. Results of the study indicate that some feeding management practices were influenced by farm size.

INTRODUCTION

The trend in the dairy industry is for a shift to larger farms. This is the result of the ability to earn higher returns per hundredweight of milk produced (MacDonald et al., 2016). Feed represents a majority of the cost of producing milk (56% of 2015 production cost; USDA ERS, 2016b). The feed costs in Minnesota are slightly below the national average as 44% (USDA ERS, 2016b) and 50% (FINBIN, 2016) of the cost of production was attributed to feed.

As herd size increases, cows are fed as a group with a TMR, where forages and concentrates are mixed together to provide a diet that will meet the cows' nutritional requirements for optimal milk production. Larger herds have the ability to group cows by stage of lactation or production to formulate a diet more precise to their nutritional requirements (USDA-APHIS VS, 2016). Formulating a properly balanced diet can provide cows with the correct nutrients, but there are several factors that can impact what the cow actually consumes including frequency of fresh feed delivery, particle size of the TMR, and target refusal rate (DeVries et al., 2005; Endres and Espejo, 2010; Sova et al., 2013). Behavior of dairy cows can be altered by the stocking density and the design of the feed barrier (Huzzey et al., 2006). Feed shrink, or the amount of feedstuff dry matter that was purchased but not consumed by the cow, can add up to substantial losses if feed is not properly stored or handled (Stone et al., 2015).

In the past decade, there have been several studies investigating dairy management practices on confinement dairy herds in the United States (e.g. Brotzman et al., 2015; Cook et al., 2016; USDA-APHIS VS, 2016). Fewer studies have focused on feeding management practices (Winsten et al., 2010; Buza and Holden, 2016) in the Northeastern U. S. and the most recent study in the Midwest was Endres and Espejo (2010) on 50 freestall dairy farms in Minnesota.

The objectives of this observational study were to 1) describe current management practices relating to feeding on confinement dairy farms in Minnesota; and 2) identify whether any of these management practices are influenced by herd size.

MATERIALS AND METHODS

This cross-sectional observational study was performed on 82 dairy farms in Minnesota between May and December 2015. A list of farms was obtained from the Minnesota

Department of Agriculture (St. Paul) and farms with fewer than 150 cows were removed from the list. The remaining farms were randomly selected by a computer to be included in the study. Herd owners were contacted by phone or email and asked about their willingness to participate in the study. The criteria for enrollment were that cows were fed a mixed ration and housed in loose housing; freestall housing was preferred, but not required. Ninety-six farms were contacted and 11 farms did not agree to participate. Three farms housed lactating cows on 2 different sites, but records were combined between the different sites so the farm was counted as 1. The remaining 82 farms were blocked by size, 140 to 424 cows and 425 or more cows. There was a similar number of farms that did not agree to participate within each block. The smaller herds had a mean size of 293 ± 80 cows (range 142-421 cows) and the larger herds had a mean size of 931 ± 441 cows (range 431-2063 cows). Therefore, results from this study would represent Minnesota dairy farms with a herd size ≥140 cows.

Each farm was visited once during the study. Logistical limitations and the goal of visiting all farms in a short period of time to avoid major seasonal variation did not allow for more than 1 visit per farm. Data were collected from an interview with the owner or herd manager addressing all areas of cow management with emphasis on feeding management, direct observation of the feed storage and mixing area, each of the lactating cow pens, and compilation of herd records. On 4 farms, the high-producing group was not housed in a freestall barn. On 2 farms, an automated milking system was used and the cows were fed a partially mixed ration. A total of 82 farms were visited with 41 having less than 425 cows and 41 having 425 or more. A total of 44,634 lactating cows were included in the study.

The storage facility for each forage and concentrate ingredient was identified when observing the feeding and mixing area. If a bunker silo, forage pile, or Ag bag was used, the type of plastic and the ground below the storage facility was noted. It was also noted whether the farm was using a defacer to remove forage from the pile. Information on forage removal rate, feed mixer type, mixing order and time, and processing of hay and corn silage were obtained from the interview with the owner or herd manager.

The group description and the number of cows in each pen were obtained from the owner or herd manager and each pen of lactating cows was observed; if there was a far-off or close-up dry cow pen, they were also observed. Within each pen, pen type (2-row or 3-row configuration or pack), number of crossovers, number of freestalls and bedding material, type of feed barrier (headlocks or post-and-rail), presence or absence of sprinklers, cow brushes, and dead-end alleys, and the location, number, and size of fans, and the spacing between the fans were noted. Freestall measurements included the total length of the stall, distance from the brisket locator to the curb, width (measured from the center of the stall divider to the center of the adjacent divider), distance from the neck rail to the curb, height of the neck rail above the stall surface, and height of the brisket board measured perpendicularly from the surface of the stall. Total linear bunk space and linear accessible water space were also measured in each pen. One-third of the cows in each pen (Endres et al., 2014) were scored for body condition by a single observer using the five-point scale (1=emaciated, 5=obese; 0.25 increments, Ferguson et al., 1994). A total of 19,390 cows were scored.

A fresh sample of TMR from the high-production group from the morning feeding was used for particle size evaluation. Particle size was evaluated by the same person with the 3-sieve (19-, 8-, and 1.18-mm) Penn State Forage Particle Separator and the methodology as described by Kononoff et al. (2003). The procedure was performed in triplicate for each sample and the weight of the mass retained on each screen and the bottom pan was recorded in every replicate.

A copy of the TMR formulation for each diet was obtained from the owner, herd manager, or the nutritionist and the formulated CP and NDF percent of DM and NE_L in Mcal / kg of DM of the high-production group and a weighted-average of the whole herd were used in data analysis. The amount of total forage, corn silage, legume forage, and small grain silage were calculated for each high-production group diet and a weighted average of the whole herd. Feed cost per cow was estimated using the provided diets and standardized feed prices (Feedstuffs, 2015) for the location closest to Minnesota. If an ingredient could not be found from Feedstuffs, prices from the USDA National Agricultural Statistics Service (USDA NASS, 2016) were used, or an average of reported cost from producer and nutritionist were used. Custom grain and protein mixes were the only ingredient that had farm specific prices as reported by the producers or their nutritionists. The price of legume haylage and high moisture grains was adjusted for dry matter, and the price of corn silage was 10 times the price of corn grain as reported by Feedstuffs (2015). Energy corrected milk standardized to 3.5% fat and 3.2% protein was calculated using the formula described by DRMS (2014). Feed price per 45.4 kg of ECM was calculated using the number of cows within each pen as reported from a DairyComp 305 or PC Dart backup file and the diet corresponding with that pen divided by the total amount of ECM sold that day as obtained from daily bulk tank records.

Heat abatement of the high-production pen was classified as mechanical if the pen was located in a tunnel or cross-ventilated barn with or without sprinklers. Heat abatement of the high-production pen was classified as adequate if: 1) sprinklers were present and fans were located over the feed bunk and each row of freestalls; 2) sprinklers were not present, but the fans were located over the feed bunk and each row of freestalls with the distance between the fans less than 10 times the diameter of the fan. Heat abatement of the high-production pen was classified as moderate if fans were located over the feed bunk or the freestalls with the distance between the fans less than 10 times the diameter of the fan with or without sprinklers. Fans were classified as inadequate if they did not fall in 1 of the other 3 categories.

Data Analysis

Descriptive data were analyzed using the MEANS and FREQ procedures of SAS 9.4 (SAS Institute Inc., Cary, NC). The TTEST procedure (SAS Institute Inc.) was used to determine the differences in quantitative data between herd sizes of <425 cows and ≥425 cows. Least square means were determined for qualitative data between herd sizes of <425 and ≥425 cows using the MIXED procedure (SAS Institute Inc.) with a Tukey adjustment. Significant differences were declared at $P < 0.05$ and tendencies at $P < 0.1$.

RESULTS AND DISCUSSION

Milk Production

Cows were milked more frequently on large farms (2.93 ± 0.26 (mean ± SD) times per day) than on small farms (2.41 ± 0.50 times per day; $P < 0.01$) and spent more time out of the pen on large farms (215 ± 60214 ± 59 vs. 182 ± 55 minutes per day; $P = 0.01$). Brotzman et al. (2015) reported the average milking frequency of 2.7 ± 0.5 times per day on herds over 200 cows in the upper Midwest. Cook et al. (2016) and Espejo and Endres (2007) reported daily time spent out of the pen to be 238 ± 70 min/d and 246 min/d, respectively. Espejo and Endres (2007) also found an association between the amount of time that cows spent out of the pen daily and the prevalence of lameness.

Daily milk yield was higher on large farms than on small farms (42.1 ± 4.140.0 ± 3.6 vs. 38.9 ± 4.6 kg/cow; $P < 0.01$). Milk protein percentage was greater on large farms than on small farms (3.12 ± 0.08% vs. 3.08 ± 0.10%; $P = 0.03$). Milk fat percentage and SCS did not differ between farm sizes and averaged 3.77% and 2.48, respectively. Milk production per cow is summarized in Table 1. Feed cost per 45.4 kg of ECM did not differ between farms as large farms averaged $7.08 ± 0.78 and small farms averaged $7.10 ± 0.84 ($P > 0.10$). FINBIN (2016) data, published by the University of Minnesota reported that the average feed cost per 45.4 kg of milk was $8.76 for farms larger than 100 cows and was the lowest for farms larger than 500 cows ($8.34). Price per 45.4 kg of milk sold was lower than FINBIN in the present study because an energy corrected milk value was used and only the lactating cows were included, whereas FINBIN (2016) included non-lactating cows, and did not use a component corrected milk value. The lack of differences we found between farm sizes could likely be explained by the use of standardized feed prices, therefore the advantage of buying feed ingredients in bulk that large farms might have was probably lost.

As farm size increases, it would be expected that farms would gain efficiency in labor. USDA ERS (2016b) reported that the cost of labor increased until the herd size exceeded 1000 cows. There were no differences in labor efficiency as the number of cows and kg of milk produced per full-time employee equivalent (**FTE**, 50 h/wk.) were 52.7 ± 13.1 and 648,279 ± 176,657 on large farms and 50.9 ± 13.3 and 609,791 ± 186,308 on small farms ($P > 0.10$).

Seventy-six percent of large farms used bST compared with only 46% of small farms ($P < 0.01$). Thirty-eight percent of all farms were using bST more frequently than the recommended interval of 14 days. Use of bST is higher in the Midwest than the rest of the nation as several surveys in the Midwest reported that over 60% of operations used bST (Fulwider et al., 2008; Brotzman et al., 2015; Cook et al., 2016). Winsten et al. (2010) reported that only 15% of Northeastern states used bST and USDA-APHIS VS (2016) found that 9.7 ± 0.8% of all operations in the United States used bST with 14 and 29% of medium and large farms reporting its use.

Feeding Management Practices

Ninety-three percent of large farms and 80% of small farms delivered fresh feed once per day ($P > 0.10$). With fewer fresh feed deliveries, it would be expected that farms would push up feed often and large farms pushed up feed more frequently than smaller farms at 9.1 ± 4.2 times per day compared with 5.1 ± 2.9 ($P < 0.01$). Previous studies in the upper Midwest showed that the high-production groups were fed once daily by 70 and 54% of farms (Endres and Espejo, 2010; Brotzman et al., 2015) and feed was pushed up an average of 5.4 ± 2.3 times per day (Endres and Espejo, 2010). Although it is important for cows to always have access to feed, DeVries et al. (2003) found that pushing up feed 2 extra times in the early morning hours did not alter feed alley attendance or increase feeding activity in cows fed twice per day. Bach et al. (2008) found that pushing up feed did have a positive impact on milk production when compared to not pushing up feed, but there was no relationship found between the number of daily feed push-ups and milk yield.

Target refusal rate across all farms was 2.1% of feed delivered (range = 0-10 percent). Feeding for refusals tended to be associated with higher milk yield (Bach et al., 2008). Sova et al. (2013) found that feeding for lower refusal rates was associated with reduced sorting against long ration particles and may have economic benefits because feed wastage would be reduced and cows would be consuming a diet closer to the intended.

Grouping cows by lactation or nutritional requirements has positive impacts on performance and economic efficiency (Krohn and Konggaard, 1979; Kalantari et al., 2016). The present study found large farms fed a greater number ($P < 0.01$) of separate rations to both the lactating and the non-lactating cows. Sixty-eight percent of large farms fed 3 or greater different lactating rations and 73% of large farms used 2 non-lactating rations, whereas 24% of small farms fed 3 or greater different lactating rations and 37% of small farms used 2 non-lactating rations. USDA-APHIS VS (2016) found that 67% of all farms were feeding 1 ration to the lactating cows, but that only 37% of large farms were feeding 1 ration. Grouping cows by production or stage of lactation was used by 29 and 52% of medium and large herds and having a separate ration for first lactation cows was used by 6 and 11% of medium and large herds (USDA-APHIS VS, 2016). Body condition score in the current study did not differ between herd sizes for the high-production group (2.89 ± 0.11) or for all of the lactating cows (2.96 ± 0.09).

Bach et al. (2008) found no relationship between milk production and the use of a close-up dry cow ration in Spanish herds offering the exact same lactating ration. Anionic salts can be used to lower the dietary cation-anion difference (**DCAD**) in the pre-fresh diet and were used on 79% of large farms and 47% of small farms ($P < 0.01$). Lowering the DCAD in non-lactating cow rations to cause metabolic acidosis is effective in decreasing urinary pH and prevalence of clinical milk fever (Charbonneau et al., 2006).

An employee was the primary feeder on 88% of large farms and on 41% of small farms ($P < 0.01$). Boterman and Bucholtz (2005) reported farms with less than 250 cows had 1 feeder that did most of the feeding and farms larger than 1000 cows had 1 or 2 people who were only feeders. Farms ranging from 250 to 1000 cows tended to have multiple people who did a proportion of the feeding along with their other tasks. As feed represents the largest cost of producing milk, owners on smaller farms may believe that they would make fewer errors than their employees while mixing feed resulting in fewer employees as the primary feeder.

Vertical feed mixers were preferred by both farm sizes; 90% of large farms and 80% of small farms were using vertical feed mixers. An on-farm master mix was used by 39% of large farms and 17% of small farms ($P < 0.03$). The use of an on farm master mix can be advantageous to producers because it includes many of the smaller inclusion, generally higher priced ingredients, and is only mixed once per day. This reduces the mixing errors of these ingredients and can help producers save money and provide a more consistent ration to the cows. Some producers expressed concerns about using an on-farm master mix because they did not have the facilities to store it after mixing before adding it to the TMR.

Feed storage facilities are important because they can minimize feed waste and help ensure proper fermentation of feeds if managed correctly. Bulk bins for storing concentrate feed ingredients were used by 66% of all herds and 78% of herds used commodity bays for storing feed ingredients. Only 13% of all herds were storing feed ingredients in uncovered, outside piles. The use of upright silos or Ag bags for storing high moisture grains was 27 and 15%, respectively. Bunker silos and forage piles were most commonly used for forage storage and were used by 41 and 59% of farms, respectively. Upright silos and Ag bags to store forages were used by 2 and 18% of farms, respectively. Ten percent of farms were using wrapped bales to store baleage. The use of a paved base for the feed pad was more common on large herds than small herds (90 vs. 68%; $P = 0.01$). Table 2 summarizes the feed storage facilities used by herd size.

The use of a defacer to remove silage from a forage pile or bunker silo tended to be greater on large farms at 68% compared to 49% on small farms (*P* = 0.07). The use of a defacer or silage rake will help maintain a straight silage face reducing the surface area exposed to oxygen and without disrupting deeper silage layers (Wilkinson and Davies, 2012). The corn silage removal rate was 43.9 ± 69.5 cm per day on large farms and 29.9 ± 26.7 cm per day on small farms (range = 2.5-305 cm/d). Haylage removal rate was 35.6 ± 42.7 cm per day on large farms and 26.6 ± 19.9 cm per day on small farms (range = 7.6-244 cm/d). Wilkinson and Davies (2012) recommended target silage removal rates of 15 to 30 cm per day in the winter and 30 to 60 cm per day in the summer to minimize penetration of air into the face of the silage.

Eleven percent of all farms used 1 layer of black and white plastic to cover forages, 56% of farms used either an oxygen barrier or vapor barrier with black and white plastic or multiple layers of black and white plastic, 21% of farms used a cover that had an oxygen barrier built into the plastic, and 12% of farms used Ag bags. Aerobic stability of silages can be achieved with proper covering and sealing of the plastic. Stone et al. (2015) recommended using plastic with reduced oxygen permeability or 2 layers of quality plastic to reduce top spoilage. Frequency of plastic removal on large farms was 2.9 ± 2.1 times per week compared to 2.0 ± 1.5 times per week on small farms (*P* = 0.03, range = 0.5-7 x/wk.). Removing smaller amounts of plastic more frequently will help minimize the amount of forage that is exposed to oxygen and moisture; however, it is not practical for most farms to remove plastic on a more frequent basis.

Corn hybrids to be used for corn silage on large farms were 58% silage hybrids, 27% grain hybrids, and 15% both silage and grain hybrids. Hybrid selection on small farms was 68% silage hybrids, 27% grain hybrids, and 5% both silage and grain hybrids. Boterman and Bucholtz (2005) found that when selecting hybrid variety for corn silage, 66% of Michigan herds considered NDF digestibility, 40% considered yield, and 40% of herds used other criteria. Forage harvest was done by the farm on 73% of large farms and 68% of small farms; the remainder of the farms hired custom harvesters to complete either some or all of the forage harvesting. Hiring custom harvesters reduces overhead expenses. In addition, custom harvesters can possible harvest a crop faster than the producers could do it themselves, especially for smaller farms. However, sometimes the custom harvester may not be able to come when the crop is ready to harvest and forage yield or quality may be compromised. All farms processed the kernels for corn silage; however, large farms were more likely to use a shredlage processor than small farms (37% vs. 15%; $P = 0.03$). Vanderwerff et al. (2015) found that shredlage processing of BMR corn silage resulted in greater and less variable kernel processing scores and allowed for increased theoretical length of cut than kernel processed BMR corn silage resulting in greater starch digestibility; however, no improvements were found in physically effective NDF. Alfalfa hay tended to be pre-processed more by large farms than small farms (37 vs. 20%; $P = 0.08$). Pre-processing of alfalfa hay helps reduce the particle size to minimize sorting and provide a more consistent TMR to the cows.

Ration Characteristics

Estimated DMI in the high-production pen was 27.1 ± 2.4 kg/cow per day on large farms and 25.1 ± 1.9 kg/cow per day on small farms ($P < 0.01$). Forage content of the formulated high-production group ration was greater on small farms than on large farms (53.7 ± 5.6 vs. 48.9 ± 6.1% of the ration DM; $P < 0.01$). The percentage of corn silage in the formulated ration for the high-production pen was 29.6% of the ration DM. The percentage of legume forage in the formulated ration for the high-production pen was higher on small farms than on large farms (23.3 ± 6.1 vs. 18.2 ± 4.3% of the ration DM; $P < 0.01$). Small grain silage comprised 2.4% of the formulated ration DM for high-producing cows across farms that fed small grain silage (n = 18). Crude protein content of the formulated high-production group ration was 17.0 ± 0.4% (DM basis) on large farms and 16.6 ± 0.7% on small farms ($P = 0.01$). Net energy for lactation of the formulated high-production group ration was 1.68 Mcal/kg (DM basis) across all farms. Neutral detergent fiber content of the formulated high-production group ration was 28.2% (DM basis) across all farms. Formulated ration characteristics of the high pen and herd averages are shown in Table 3. Endres and Espejo (2010) reported similar ration characteristics on freestall herds over 150 cows in Minnesota.

The guidelines described by Heinrichs and Kononoff (2002) recommend that 2 to 8% of the as fed TMR remain on the 19 mm sieve of the Penn State Forage Particle Separator. The average for both large and small farms was above the recommended maximum of 8% (Table 4). Dry matter intake, milk production, and daily production of milk protein increased with decreasing particle size (Nasrollahi et al., 2015). The average weight on the 8.0 mm sieve and the 1.18 mm sieve met the recommendation of 30 to 50% of the total weight of the TMR for both large and small farms; however, some farms were above and below the recommended maximum and minimum. It is recommended that less than 20% of particles are smaller than 1.18 mm and the averages for both the large and small farms met that recommendation; however, the maximum observed proportion of particles on the bottom pan was 22.7 percent. Endres and Espejo (2010) reported similar distributions; however, they reported a mean of 3 percentage units less on the 19.0 mm sieve than was found in the current study. They found an association between greater proportions of longer particle material in the ration and a greater rate of NDF content change.

Cow Grouping and Pen Characteristics

Large farms are at an advantage for grouping strategies simply because they have more cows. Fewer large farms housed pregnant heifers with the far-off dry cows than small farms (24 vs. 59%; $P < 0.01$). However, in the close-up dry cow pen, 73% of large farms and 94% of small farms housed pregnant heifers and dry cows together ($P = 0.03$). Fewer large farms housed primiparous and multiparous cows together in the post-fresh pen than small farms (80 vs. 100%; $P < 0.01$). After leaving the post-fresh pen, more large farms grouped primiparous and multiparous cows separately than small farms (95 vs. 68%; $P < 0.01$). When heifers were separated from older cows there were increases in eating time, meals per day, silage DMI, lying time, and lying periods (Krohn and Konggaard, 1979).

The number of pen moves from when a cow was dried off until she re-entered the high-production pen was 4.5 ± 0.9 on large farms and 3.7 ± 0.8 on small farms ($P < 0.01$; Range = 2-7 pen moves).

Two-row pen configuration was preferred in the far-off dry cow pen (40% of farms using it) and the post-fresh pen (37%) whereas 3-row pen configuration was preferred in the high-production pen (46%), and bedded packs were preferred in the close-up dry cow pen (56%). Other studies in the upper Midwest showed that 3-row pens were more common in high-producing pens than 2-row pens (Endres and Espejo, 2010; Brotzman et al., 2015). Three-row pens allow for more cows in a pen than 2-row pens; however, having more cows per pen can compromise feed bunk space per cow which may explain why farms prefer 2-row pens for the post-fresh pen when dry matter intake is so critical. Large farms had more ($P < 0.01$) cross-alleys in all lactating and non-lactating pens than small farms. The presence of dead-end alleys was greater ($P < 0.01$) in the high-producing pens and tended to be greater in the post fresh pen ($P = 0.09$) on small farms. Deep bedded stalls and inorganic bedding were preferred in each of the observed pen locations as opposed to stalls with a rubber base and manure or organic bedding. In a comparison of deep bedded sand stalls and mattress herds, Cook et al. (2004) found that cows in mattress herds spent more time standing per day and had significantly less feeding time than cows in sand herds. Rowbotham and Ruegg (2015) found Wisconsin dairies that used inorganic bedding had greater RHA milk yield and better milk quality than farms that used organic bedding.

Headlocks were the preferred feed barrier for the lactating pens across all farms; however there were no differences between herd sizes. Endres and Espejo (2010) found contrasting results in their survey of high-production pens on Minnesota freestall dairy farms and reported that post-and-rail barriers were used by 60% of herds and that only 28% of herds used headlocks. It has been shown that the use of headlocks is associated with fewer displacements at the feed bunk (Endres et al., 2005; Huzzey et al., 2006). Rubber flooring in the high-production pen was only used by 7% of all herds and less in other pens. USDA-APHIS VS (2016) found that 21% of operations had rubber flooring over the concrete to provide a softer surface for the cows to stand on. The use of rubber flooring surfaces may reduce the negative impact of concrete on claw health; however, cow time budgets may be altered which could also have a negative effect on lameness (Cook and Nordlund, 2009). Cow brushes were used in the high-production pen by 27% of herds. Table 5 summarizes the characteristics of the far-off dry cow pen, close-up dry cow pen, post-fresh pen, and high-production pen.

Freestall design is critical because providing cows with a comfortable stall that is well designed can maximize resting time and reduce prevalence of lameness (Cook and Nordlund, 2009). Nordlund and Cook (2003) identified body resting space, lunge room, and neck rail position as 3 out of the 4 critical points when evaluating freestalls. Stall lying space and stall width in the high-producing pen (Table 6) tended to be greater (P = 0.07 and 0.10, respectively) on large farms compared to small farms. The height of the brisket locator tended to be greater on small farms than large farms (P = 0.06). Espejo and Endres (2007) found an association between brisket board height greater than 15.2

cm and prevalence of lameness. Neck rails were more likely to be located higher above the stall surface in the high-production pens on large farms than on small farms. There were no differences in stall length and the distance of the neck rail from the rear curb between farm sizes in the high-production pens.

Stall stocking density was the highest in the high-production pens and lowest in the far-off dry cow pens (Table 7) and large farms tended to have greater stall stock density in the high-production pen than small farms. Overstocking pens can have negative effects on cows because they have to compete for resources such as feed, water, and resting space (DeVries et al., 2004; Huzzey et al., 2006; Fregonesi et al., 2007). Schefers et al. (2010) found the average stall stocking densities were 0.81 cows per freestall in the close-up dry cow pen, 0.82 cows per freestall in the post-fresh pen, and 1.09 cows per freestall in the breeding pen on 86 large, commercial dairies. Cook et al. (2016) reported an average stall stocking of 1.2 cows per stall on 66 Wisconsin freestall herds. It is recommended that lactating cows have 0.46 m of bunk space per cow when feed is always available (Holmes et al., 2013); that recommendation was met by all pens. Endres and Espejo (2010) reported 0.45 m/cow of linear feed bunk space and 4.6 cm/cow of liner water space per cow in high-production pens in Minnesota. Cook et al. (2016) reported 0.52 m/cow of linear feed bunk space and 7.8 cm/cow of accessible water trough length on 66 Wisconsin freestall herds. Decreased feeding times and reduced milk production have been reported for cows that were overcrowded (Huzzey et al., 2006; Bach et al., 2008). Hill et al. (2009) found that stocking densities of the freestalls and headlocks greater than 113% altered the resting and standing behavior of lactating dairy cows. From an economic perspective, stall stocking densities of 120% yielded the highest increase in profit per stall per year (De Vries et al., 2016).

Miscellaneous

Adoption of technology was higher on large farms as 61% were using a feeding software program ($P < 0.01$) and 85% were using another technology such as cow activity, daily milk monitoring, or a pasteurizer for feeding whole milk to calves, compared with small farms, where only 5% of farms were using a feeding software program and 63% were using another technology ($P = 0.02$). An online survey by Borchers and Bewley (2015) found the most common technologies were those used to monitor milking performance, reproductive performance, and udder health.

Feed shrink can be defined as the amount of feedstuff dry matter that was purchased, but not consumed by the cow. Having an estimate of feed shrink was greater on large farms than on small farms (22 vs 5%; $P = 0.02$). Having an awareness of feed shrink and identifying ways to minimize it could result in large savings for producers. For example, on a 600 cow dairy averaging 25 kg of DMI at $0.24 per kg of DM, each percentage point of TMR shrink is worth about $13,000.

Automated estrus detection was reported by 41% of large herds and 39% of small herds. Borchers and Bewley (2015) reported that 41% of herds used technology for monitoring cow activity. Thirty-seven percent of large herds and 32% of small herds were using visual aids for heat detection. The remaining herds were using either timed insemination or visual estrus detection without visual aids. Two herds were using herd bulls to inseminate cows. Estrous synchronization with hormones was used on 90% of large farms and 83% of small farms. The use of hormonal estrous synchronization was reported on about 90% of herds by Caraviello et al. (2006) and Cook et al. (2016). Presynch ovsynch was the most common synchronization program and was used by 66% of large herds and 41% of small herds. The use of ovsynch, double ovsynch, and CIDR synchronization were also reported. Synchronized estrus can help producers inseminate cows earlier in lactation with higher conception rates. The voluntary waiting period (**VWP**) for insemination was 57.3 ± 6.3 days on large farms and 57.4 ± 8.3 days on small farms (range = 40-80 days). Caraviello et al. (2006) found that the average VWP was 52 days for primiparous and 53 days for multiparous cows.

As previously mentioned, there are several factors associated with the prevalence of lameness in dairy cows and lameness can cause economic loss on a dairy farm. Footbaths to help control infectious causes of lameness were used 4.1 ± 2.0 days per week on large farms and 2.5 ± 2.0 days per week on small farms ($P < 0.01$). Caraviello et al. (2006) reported that 89% of herds used a footbath and Cook et al. (2016) reported that 98% of surveyed herds used a footbath with the average frequency of 4.5 passes per week. Farms often used multiple different products in the footbath and rotated between these products. Copper products were the most common and used by 88% of all farms. Formaldehyde was used on 18% of farms, and 61% of farms used other chemicals. Espejo and Endres (2007) reported that all but 2 farms used copper sulfate in a study of freestall herds in Minnesota. Scheduled hoof trimming was used on 90% of large farms and 73% of small farms as opposed to farms that only trimmed hooves when the herd manager decided a cow needed to be trimmed due to hoof overgrowth or lameness. One scheduled trim per lactation with additional trims as needed was used by 34% of large and 49% of small herds and 2 or more scheduled trims per lactation with additional trims as needed were used by 56% of large and 24% of small farms. Brotzman et al. (2015) and Cook et al. (2016) reported that 83.1 and 87.9% of farms in the upper Midwest followed scheduled hoof trimming, respectively, with 50.8 and 65.5% of those herds trimming at least twice per lactation. Espejo and Endres (2007) found that farms who trimmed hooves on a maintenance schedule either once or twice annually had a lower prevalence of lameness than herds who only trimmed hooves when the manager decided that cows needed because of lameness or hoof overgrowth.

Mechanical heat abatement was present on 27% of large farms and 7% of small farms. Adequate heat abatement was present on 20% of large farms and 27% of small farms. Moderate heat abatement was present on 29% of large farms and 12% of small farms. Inadequate heat abatement was present on 24% of large farms and 54% of small farms. Caraviello et al. (2006) and Cook et al. (2016) had somewhat similar findings and reported that over 80% of farms were using either wind tunnel ventilation or recirculation fans and over 70% of farms were using sprinklers. Nationally, 75.7 ± 1.5% of herds were using fans to cool cows and 25.2 ± 1.3% of operations were using misters or sprinklers (USDA-APHIS VS, 2016). The effects of temperature and relative humidity can be combined to create a THI; at a THI of 68, subtle, but significant changes in cow behavior were identified (Cook et al., 2007). During heat stress, cows reduced feed intake, decreased activity, increased respiratory rate, and increased both peripheral blood flow and sweating (West, 2003). Because these changes in behavior can have a large impact on milk production, Cook et al. (2007) recommended the use of both fans and soakers when the barn temperature is at or above 21 degrees Celsius and that having fans over the stalls may help reduce the effects of heat stress in lame cattle that prefer to stand in the freestalls.

As of January 1, 2017, the FARM Program will no longer allow tail docking on U.S. dairy herds (NMPF, 2016). In the current study, we found that 85% of large farms and 59% of small farms were docking tails. Fulwider et al. (2008) reported that tail docking was observed on 83% of dairy farms for the reported reasons of cow hygiene and worker comfort. Tail docking is a welfare concern of dairy industry stakeholders (Ventura et al., 2015). Several studies have shown that tail docking has no production or health benefits for cows (Eicher et al., 2001; Tucker et al., 2001; Schreiner and Ruegg, 2002).

CONCLUSIONS

Information collected in this observational study indicates that some management practices were influenced by herd size. Having more cows allows larger herds to implement different grouping strategies and formulate multiple diets for different groups of cows. Higher milk yield could be attributed to increased milking frequency, higher DMI, and differing TMR compositions. Although higher stocking densities were observed in the high-production pens on large farms, they appear to be trying to minimize lameness and heat stress by implementing hoof health protocols and providing adequate heat abatement. More research is needed to determine an association between these management practices and cost efficiency.

Chapter 3

Management factors associated with milk yield and feed cost per 45.4 kg of energy corrected milk on freestall dairy farms in Minnesota

SUMMARY

The objectives of this cross-sectional study were to investigate the association between on-farm, herd-level variables and energy corrected milk yield per cow per day and feed cost per 45.4 kg of ECM on 67 randomly selected freestall dairy farms in Minnesota. Farms were visited once between May and November 2015 to collect on farm measurements and observations and to inquire about management practices. Feed cost was estimated using rations provided by the producer or the nutritionist. Daily bulk tank records were also obtained from the producer. Herd-level variables were used to explain the variation in milk yield and feed cost among herds. Among the variables tested, use of an on-farm master mix, linear water space per cow, use of a post-fresh cow pen, neck rail position, corn silage removal rate, and corn silage percent of the ration DM did not show any association with either of the outcomes of interest in the univariate analysis screening tests and were not included in the multivariate models. Herd size, number of cows per full time employee equivalent, feeding frequency, number of lactating and non-lactating rations, anionic salts in the pre-fresh diet, frequency of feed push up, haylage removal rate, pre-processing of alfalfa hay, time out of pen for milking, dry period length, transition period pen moves, separation of mature cows from young cows and heifers, footbath frequency, heat abatement, feed barrier type, linear bunk space per cow, freestall

length and width, average body condition score of the high-production pen, particle size of the TMR, estimated DMI, and total forage, legume forage, crude protein percent, neutral detergent fiber percent, and net energy for lactation of the formulated rations were eliminated from their respective multivariate models in the backwards stepwise procedure. Energy corrected milk yield per cow per day was associated with milking frequency, use of bST, stocking density of the high-production pen, feed cost per cow, and feed mixer type. Feed cost per 45.4 kg of ECM was associated with percent target refusals, corn silage hybrid variety, hoof trimming schedule, stocking density of the high-production pen, freestall type, and brisket board height.

INTRODUCTION

Feed represents a majority of the cost of producing milk (56% of 2015 production cost; USDA ERS, 2016b). The feed costs in Minnesota were slightly below the national average as 44% (USDA ERS, 2016b) and 50% (FINBIN, 2016) of the cost of production was attributed to feed. Feed cost per cow per day, feed cost per kg of DM, income over feed cost, and feed cost per 45.4 kg of milk are some of the many possible ways to evaluate the economics of feeding programs. Hutjens (2007) identified feed cost per 45.4 kg of milk as the best method for comparing between groups and farms within a region because milk yield is standardized and the value is impacted by milk yield per cow and feed costs.

Several factors impacting milk yield have been identified. Using bST and increasing milking frequency (from 2 to 3 times per day) have the greatest impact on milk yield

(Bewley et al., 2001b; Cabrera et al., 2010). Other factors impacting milk yield include frequency of fresh feed delivery, particle size of the TMR, feeding for refusals, water space per cow, stocking density, and the use of sprinklers to cool cows (Bewley et al., 2001b; Bach et al., 2008; Sova et al., 2013; Nasrollahi et al., 2015). Pushing up feed has a positive association with milk yield; however, the frequency of feed push-up has no association with milk yield (DeVries et al., 2003; Bach et al., 2008).

Feed costs can also be impacted by several factors including region, access to byproduct feeds, and current milk prices. In tough economic conditions, producers may try to minimize their feed cost per cow; however, Buza et al. (2014) found that minimizing feed cost per cow per day did not result in the highest IOFC. Kalantari et al. (2016) found the gain in IOFC was the greatest going from 1 lactating group diet to 2 lactating group diets in addition to a post-fresh group diet and the gain was further emphasized in tough economic conditions. Lactation number, confirmed pregnancy, level of milk production, and body condition score should be the primary criteria for grouping cows (Krohn and Konggaard, 1979; Grant and Albright, 2001).

The objectives of this study were to investigate the association of herd-level factors with energy corrected milk yield per cow and feed cost per 45.4 kg of energy corrected milk on 67 randomly selected dairy farms having freestall barns in Minnesota.

MATERIALS AND METHODS

This study was performed on 67 freestall farms in Minnesota between May and November 2015. Dairy farms were selected randomly from a list of farms obtained from the Minnesota Department of Agriculture (St. Paul) having 150 or more cows. Herd owners were contacted by phone or email and asked their willingness to participate in the study. The criteria for enrollment were that cows were fed a mixed ration and the high-production group was housed in a freestall barn. Ninety-six farms were contacted and 85 agreed to participate. Average herd size was 633 ± 468 cows (range = 176-2063 cows). Therefore, results from this study would represent freestall dairy farms in Minnesota with a herd size ≥150 cows.

Each farm was visited once during the study. Logistical limitations and the goal of visiting all farms in a short period to avoid major seasonal variation did not allow for more than 1 visit per farm. Data were collected from an interview with the owner or herd manager addressing all areas of herd management with an emphasis on feeding management, direct observation of the feed storage and mixing area, high-production pens, and compilation of herd records. On 3 farms, the lactating cows were housed and milked on 2 different sites so both sites were visited and the farm was still considered as 1 farm. On 4 farms, the high-producing groups were not housed in a freestall barn and were removed from analyses. On 2 farms, an automated milking system was used and the cows were fed a partial mixed ration. Eleven farms were removed due to failure to provide lactating cow diets or bulk tank records. Sixty-seven farms with a total of 42,382 cows were included in the current study.

The location of the high-producing pen and the number of cows in that pen were obtained from the owner or herd manager and that pen was observed. Freestall measurements included the total length of the stall, distance from the brisket locator to the curb, width (measured from the center of the stall divider to the center of the adjacent divider), distance from the neck rail to the curb, height of the neck rail above the stall surface, and height of the brisket board measured perpendicularly from the surface of the stall. Freestalls were classified into 3 categories: 1) deep bedded freestalls with inorganic bedding, 2) deep bedded freestalls with manure solids for bedding, and 3) mattresses (non-deep bedded stalls including mattresses, waterbeds, or other solid surface with organic bedding). Total bunk space and accessible water space were also measured in the high-producing pen. One-third of the cows in each high-producing pen (Endres et al., 2014) were scored for body condition by a single observer using a five-point scale (1=emaciated, 5=obese; 0.25 increments, Ferguson et al., 1994). A total of 3,147 cows were scored.

A fresh sample of TMR from the high-production group from the morning feeding was used for particle size evaluation. Particle size was evaluated by the same person with the 3-sieve (19-, 8-, and 1.18-mm) Penn State Forage Particle Separator and the methodology as described by Kononoff et al. (2003). The procedure was performed in triplicate for each sample and the weight of the mass retained on each screen and the bottom pan was recorded in every replicate.

A copy of the TMR formulation for each diet was obtained from the owner, herd manager, or the nutritionist and the formulated CP and NDF percent of DM and NE_L in Mcal/kg of DM of each ration were used in data analysis. A weighted average for the farm was calculated using the number of cows within each pen as reported from a DairyComp 305 (Valley Ag Software, Tulare, CA) or PC Dart (DRMS, Raleigh, NC) backup file and the diet corresponding with that pen. The amount of total forage, corn silage, and legume forage were calculated as a weighted average of the whole herd. Feed cost per cow was estimated using the provided diets and standardized feed prices (Feedstuffs, 2015) for the location closest to Minnesota. If an ingredient could not be found from Feedstuffs, prices from the USDA National Agricultural Statistics Service (USDA NASS, 2016) were used, or an average of reported cost from producers and nutritionists were used. Custom grain and protein mixes were the only ingredient that had farm specific prices as reported by the producers or their nutritionists. The price of legume haylage and high moisture grains were adjusted for dry matter, and the price of corn silage was 10 times the price of corn grain as reported by Feedstuffs. Energy corrected milk standardized to 3.5% fat and 3.2% protein was calculated using the formula described by DRMS (2014). Feed price per 45.4 kg of ECM was calculated using the number of cows within each pen as reported from a DairyComp 305 or PC Dart backup file and the diet corresponding with that pen divided by the total amount of ECM sold that day as obtained from daily bulk tank records.

Heat abatement of the high-production pen was classified as mechanical if the pen was located in a tunnel or cross-ventilated barn with or without sprinklers. Heat abatement of the high-production pen was classified as adequate if: 1) sprinklers were present and fans were located over the feed bunk and each row of freestalls; 2) sprinklers were not present, but the fans were located over the feed bunk and each row of freestalls with the distance between the fans less than 10 times the diameter of the fan. Heat abatement of the high-production pen was classified as moderate if fans were located over the feed bunk or the freestalls with the distance between the fans less than 10 times the diameter of the fan with or without sprinklers. Fans were classified as inadequate if they did not fall in 1 of the other 3 categories.

Data Analysis

Two outcomes of interest were used in the data analyses: milk yield per cow (kg of ECM/cow per day) and feed cost per 45.4 kg of ECM. Association between each variable and outcome of interest was evaluated with a univariate model as a screening test, using a mixed model procedure (PROC MIXED; SAS Institute Inc., Cary, NC). Farm and month were used as random variables in the analysis. Those variables identified in the univariate screening test ($P < 0.3$) were used to build a multivariate model for feed cost per 45.4 kg of ECM using a mixed model procedure (SAS Institute Inc.). The mixed model procedure could only use a maximum of 20 variables so the variables with the 20 lowest *P*-values ($P < 0.09$) from the univariate screening were used to build the multivariate model for milk yield per cow. In each multivariate model, variables that showed least association with each outcome of interest were eliminated using a backwards stepwise procedure until all the remaining variables included in the multivariate model were significant ($P < 0.05$). The assumption of random distribution of the residuals was visually evaluated on a residual chart for the final model. Bonferroni contrast *t*-test was used to compare least squares means of categorically distributed variables.

RESULTS AND DISCUSSION

Univariate Screening Test

Tables 8 and 9 show the distribution of the variables analyzed in the current study, including overall frequency and means. Variables that were unrelated ($P > 0.3$) to either of the outcomes of interest in the univariate analysis of association were: use of an on-farm master mix, linear water space per cow, corn silage removal rate, corn silage percent of the ration DM, the use of a post-fresh pen separate from the lactating pens, and neck rail height and distance from the curb. Therefore, these variables were not included in either of the multivariate models. Variables showing association to either of the outcomes of interest in the univariate analysis of association are shown in Table 10.

Energy Corrected Milk Yield per Cow

Number of cows per FTE equivalent, corn silage hybrid variety, haylage removal rate, average dry period length, transition period pen moves, separation of pregnant nulliparous and dry cows, separation of primiparous and multiparous cows in the post-fresh and high-production groups, feed bunk space per cow, freestall length and width, brisket board height, average BCS, and CP and NDF percent of the formulated ration showed some association ($P < 0.3$) with ECM per cow per day, but were not included in the multivariate model as only 20 variables could be included. Herd size, number of different lactating rations, using anionic salts in the pre-fresh diet, feed push-ups per day, feed mixer type, milking frequency, use of bST, separation of pregnant heifers and close-up dry cows, hoof trimming schedule, footbath frequency, heat abatement category, stall stocking density, feed barrier and freestall type, proportion of as-fed TMR >19 mm in length, estimated DMI, forage and legume forage percent of the ration DM, NE_L content of the formulated rations, and feed cost per cow per day were eligible for inclusion in the multivariate model for ECM yield per cow.

Variables included in the final model for ECM yield per cow were feed mixer type, milking frequency, use of bST, freestall stocking density, and feed cost per cow (Table 11).

The use of a horizontal feed mixer was associated with less ECM per cow per day than the use of a vertical feed mixer ($P < 0.01$). To the knowledge of the authors, there has been no research comparing vertical and horizontal feed mixers, thus indicating a need for research on this topic. There was no correlation between the proportion of particles > 19 mm and feed mixer type leading the authors to the conclusion that there may be some differences in the consistency of the TMR between vertical and horizontal feed mixers.

Milking twice per day was associated with less ECM per cow per day than milking three times per day ($P < 0.01$). Similar findings have been reported by Bewley et al. (2001b) and Smith et al. (2002) who found that herds milking 3 times per day produced about 15% more milk than herds milking twice per day. In the current study, 33% of herds were milking twice per day which is much fewer than the national average of 88% reported by USDA-APHIS VS (2016).

Using bST was associated with more ECM per cow per day ($P = 0.04$). Bovine somatotropin can help improve production and efficiency on dairy herds by allowing healthy cows to produce an average of 4.54 kg more milk per day (Elanco, 2016). Bewley et al. (2001b) found that the use of bST was associated with an increase of 583 kg in rolling herd average milk production. In the current study, 66% of farms were using bST which is similar to what other studies in the upper Midwest have reported (Fulwider et al., 2008; Brotzman et al., 2015; Cook et al., 2016). Nationally, the use of bST is much lower with only 10% of all operations reporting its use (USDA-APHIS VS, 2016).

Freestall stocking density was positively associated with ECM yield per cow ($P < 0.01$). Having more cows than freestalls in a pen appears to be a common practice for freestall herds as it gives producers the ability to reduce the cost per freestall. Although overstocking freestalls can increase net returns, the cows can experience negative effects on behavior and performance. When cows were overcrowded, decreased feeding times and reductions in milk production have been reported (Huzzey et al., 2006; Bach et al., 2008). A herd budget-simulation model by De Vries et al. (2016) found that the average optimal stall stocking density across 2,187 combinations of inputs was 1.2 cows per freestall and the average maximum increase in profit was $99 per stall per year. In the current study, 48% of farms stocked their high-producing pen between 1.0 and 1.2 cows per freestall and 13% of farms stocked their high-producing pen between 1.2 and 1.3 cows per freestall. Only 12% of farms stocked their high-production pens above 1.3 cows per freestall with the highest stocking density being 1.38 cows per freestall. Increased milk yield with higher stocking densities could indicate that producers may be doing a better job of managing their cows in freestall barns with greater stocking density than 1.0 cow per freestall.

Feed cost per cow was positively associated with ECM yield per cow ($P < 0.01$). Higher feed costs could be attributed to the addition of feed additives which may improve cow health which could result in increased milk yield. Higher feed costs could also be the result of utilizing higher quality feed ingredients that generally have higher costs. Although IOFC was not used in the current study, Buza et al. (2014) found that minimizing feed cost per cow per day did not result in the highest IOFC. These findings help show the importance of a high quality ration for dairy cows.

Feed Cost per 45.4 kg of ECM

Feeding frequency, the number of different lactating and non-lactating rations, target percent refusals, corn silage hybrid variety, feed mixer type, pre-processing of alfalfa hay, time out of the pen, separation of primiparous and multiparous cows in the high-production pen, hoof trimming schedule, stall stocking density, freestall type, brisket board height, average BCS, and CP and NDF percent of the formulated diets were eligible for inclusion in the multivariate model for feed cost per 45.4 kg of ECM.

Variables included in the final model for feed cost per 45.4 kg of ECM were target percent refusals, corn silage hybrid variety, hoof trimming schedule, freestall stocking density, freestall type, and brisket board height (Table 12).

Target percent refusals were negatively associated with feed cost per 45.4 kg of ECM (P = 0.05). Bach et al. (2008) found herds that fed to ensure feed refusals tended to produce more milk than those that fed for no feed refusals. Sova et al. (2013) found reduced sorting against long particles in herds that fed for lower refusal rates. They reported an average refusal rate of 3.5% whereas in the current study the average target refusal rate was 2.1% indicating that not limiting DMI may have been a more important factor than selective refusal of long particles in the association between target percent refusals and feed cost per 45.4 kg of ECM.

Using silage hybrids or grain hybrids for corn silage was associated with lower feed cost per 45.4 kg of ECM than using both silage and grain hybrids for corn silage ($P < 0.05$). Other studies found similar results that there were no differences in milk yield between BMR corn hybrids and conventional hybrids (Bal et al., 2000; Ballard et al., 2001; Qui et al., 2003). However, higher DMI and increased milk yield were reported in studies investigating corn silage with high NDF digestibility (Oba and Allen, 1999; Bal et al., 2000; Thomas et al., 2001). In the current study, we suggest that the higher feed cost per 45.4 kg of ECM associated with using both silage and grain hybrids for corn silage on the same farm could be the result of inconsistences in corn silage quality due to variable fiber digestibility and starch content.

Trimming hooves only when cows needed it due to hoof overgrowth or lameness was associated with lower feed cost per 45.4 kg of ECM than following a schedule of either 1 or 2 hoof trimmings per lactation plus when cows needed it ($P < 0.01$). This relationship is difficult to explain. Faye and Lescourret (1989) reported that preventive hoof trimming had no effect on lameness incidence. However, Manske et al. (2002) and Espejo and Endres (2007) reported contrasting results and found that following a hoof trimming schedule with 1 or 2 trimmings per lactation was favorable for reducing lameness incidence.

Freestall stocking density was negatively associated with feed cost per 45.4 kg of ECM ($P = 0.01$). The association between freestall stocking density and feed cost per 45.4 kg of ECM can be explained by the relationship between freestall stocking density and milk yield per cow as previously mentioned.

Deep bedded stalls with manure bedding were associated with higher feed cost per 45.4 kg of ECM than deep bedded stalls with inorganic bedding and stalls with mattresses ($P = 0.01$). When comparing mattresses and deep bedding, Cook et al. (2004), Ito et al. (2010), and Cook et al. (2016) reported higher prevalence of lame cows in herds with mattresses and lameness can have a negative impact on milk production. Inorganic bedding, such as sand, is advantageous because it drains well and is less likely to have high concentrations of mastitis causing organisms (Bewley et al., 2001a). Rowbotham and Ruegg (2015) found that Wisconsin dairies that used inorganic bedding had greater RHA milk yield and better milk quality than farms that used organic bedding. Although freestall type did not remain in the final model for milk yield per cow, we hypothesize that deep bedded freestalls with manure solids may be associated with higher mammary infections and lower milk quality which may reduce milk yield. In the current study, only 13% of farms were using deep bedded freestalls with manure solids bedding therefore, more research with a larger sample size of herds using deep bedded stalls with manure solids is needed to investigate the relationship between freestall type and feed cost per 45.4 kg of ECM.

Height of the brisket board was positively associated with feed cost per 45.4 kg of ECM ($P < 0.01$). Cook and Nordlund (2005) recommend that the height of the brisket board is not higher than 10.2 cm because it can impact the ability of a cow to naturally ‘bob’ her head when she stands up in a stall and to lunge forward naturally. This is more of a problem in lame cows that already have problems lying down and standing up in freestalls. Espejo and Endres (2007) found an association between brisket board height and the prevalence of lameness and recommended that the brisket board height be less than 15.2 cm. Although there was no assessment of lameness prevalence taken in the current study, we suggest that the association between brisket board height and lameness could result in decreased milk yield and in turn, increase feed cost per 45.4 kg of ECM.

CONCLUSIONS

The objectives of this cross-sectional study were to investigate the association between on-farm herd-level variables and energy corrected milk yield per cow per day and feed cost per 45.4 kg of ECM. Energy corrected milk yield per cow per day was associated with milking frequency, use of bST, stocking density of the high-production pen, feed cost per cow, and feed mixer type. Feed cost per 45.4 kg of ECM was associated with target refusals, corn silage hybrid variety, hoof trimming schedule, freestall stocking density, freestall type, and brisket board height. More research is needed to investigate the association between feed mixer type and ECM per cow and deep bedded freestalls with manure bedding and feed cost per 45.4 kg of ECM.

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APPENDIX I – Tables

Table 1: Daily milk yield and composition of 82 dairy herds in Minnesota

Item	Mean	Minimum	Maximum	Large[1]	SD	Small[1]	SD
Daily ECM yield, kg/cow	40.5	29.6	49.4	42.1[a]	4.13.6	38.9[b]	4.6
Milk fat, %	3.77	3.10	4.55	3.79	0.23	3.75	0.21
Milk protein, %	3.10	2.88	3.30	3.12[a]	0.08	3.08[b]	0.10
Somatic cell score	2.46	1.25	3.77	2.56	0.52	2.40	0.52

[a, b] Means within a row with different superscripts differ ($P < 0.05$)

[1] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 2: Feed storage facility used for concentrates and forages on 82 dairy herds in Minnesota

Item[1]	Total	Large[2]	Small[2]
Concentrates			
Bulk bins	65.9	63.4	68.3
Bays	78.1	82.9	73.2
Outside pile	13.4	17.1	9.8
Upright silo	26.8	17.1[b]	36.6[a]
Ag bag	14.6	12.2	17.1
Forage			
Bunker silo	41.5	36.6	46.3
Forage pile	58.6	65.6	51.2
Upright silo	2.4	0.0	4.9
Ag bag	18.3	9.8[b]	26.8[a]
Wrapped bales	9.8	9.8	9.8
Paved base[3]	79.3	90.2[a]	68.3[b]

[a, b] Means within a row with different superscripts differ ($P < 0.05$).

[1]Percent of farms using the storage facility.

[2] Large = farms with more than 425 cows; small = farms with less than 425 cows

[3]Concrete or asphalt below the corn silage source currently in use.

Table 3: Characteristics of the TMR provided to the high-producing group and the entire herd on 82 dairy farms in Minnesota

Item	Mean	Minimum	Maximum	Large[1]	SD	Small[1]	SD
DMI, kg/cow per day							
High pen	26.1	20.8	29.5	27.1[a]	2.4	25.1[b]	1.9
Herd average	25.0	21.2	29.0	25.5[a]	1.6	24.5[b]	1.7
Forage content, % of DM							
High pen	51.3	41.0	65.1	48.9[b]	6.1	53.7[a]	5.6
Herd average	51.6	36.7	65.1	49.6[b]	5.8	53.7[a]	5.1
Corn silage content, % of DM							
High pen	29.6	17.0	46.1	29.9	5.2	29.3	7.0
Herd average	29.8	17.0	46.1	30.3	5.0	29.3	7.0
Legume forage content, % of DM							
High pen	20.7	13.1	36.7	18.2[b]	4.3	23.3[a]	6.1
Herd average	20.6	9.2	35.3	18.1[b]	4.3	23.2[a]	6.0
Small grain silage content, % of DM							
High pen	2.4	0.0	7.0	1.8	0.8	2.9	2.4
Herd average	0.6	0.0	7.0	0.5	0.9	0.7	1.7
CP, % of DM							
High pen	16.8	15.0	17.9	17.0[a]	0.4	16.6[b]	0.8
Herd average	16.8	15.0	17.9	17.0[a]	0.4	16.6[b]	0.8
NE_L, Mcal/kg of DM							
High pen	1.68	1.50	1.88	1.68	0.07	1.68	0.09
Herd average	1.68	1.51	1.88	1.67	0.07	1.69	0.09
NDF, % of DM							
High pen	28.2	24.1	32.8	28.0	1.4	28.5	2.0
Herd average	28.4	24.1	32.8	28.2	1.5	28.6	2.0

[a, b] Means within a row with different superscripts differ ($P < 0.05$)

[1] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 4: Particle size distribution of the TMR of on 82 dairy herds in Minnesota

Particle size[1, 2]	Mean	Minimum	Maximum	Large[3]	SD	Small[3]	SD
> 19.0 mm, %	13.8	1.7	37.8	12.0[d]	8.5	15.5[c]	7.9
19.0 to 8.0 mm, %	40.8	21.6	55.7	41.9	7.1	39.6	5.8
8.0 to 1.18 mm, %	32.5	19.6	43.9	32.6	4.9	32.4	5.5
< 1.18 mm, %	13.0	3.5	22.7	13.5	4.0	12.5	3.6

[c, d] Means within a row with different superscripts tend to differ ($P < 0.10$)

[1] Measured with the Penn State Forage Particle Separator (Kononoff et al., 2003).

[2] Values show in percentage of the material as fed retained on the sieve.

[3] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 5: Characteristics of 4 critical pen groups on 82 dairy herds in Minnesota

	Far Off Dry		Close-Up Dry		Post Fresh		High-Producing	
Item[1]	Large[3]	Small[3]	Large	Small	Large	Small	Large	Small
N Observed[2]	25	32	32	23	39	26	41	41
Pen configuration								
Two row	40.0	40.6	40.6[a]	4.4[b]	53.9[c]	34.6[d]	43.9	46.3
Three row	32.0[c]	9.4[d]	18.8[a]	8.7[b]	28.2	34.6	51.2[c]	41.5[d]
Other	4.0[d]	12.5[c]	0.0[b]	8.7[a]	2.6[d]	11.5[c]	4.9	4.9
Pack	24.0[d]	37.5[c]	40.6[b]	78.3[a]	15.4	19.2	0.0[d]	7.3[c]
Number of cross-alleys	1.9[a]	1.0[b]	1.9[a]	0.8[b]	2.2[a]	1.2[b]	3.1[a]	2.4[b]
Presence of dead ends	19.2	21.9	9.4	13.0	27.0[d]	48.0[c]	2.4[b]	22.0[a]
Stall base								
Deep	84.2	76.5	73.7	50.0	78.8	61.9	72.5	60.5
Rubber	15.8	23.5	26.3	50.0	21.2	38.1	27.5	39.5
Bedding material								
Inorganic	73.7	76.5	63.2[c]	25.0[d]	60.6	52.4	55.0	55.3
Manure	21.1	11.8	26.3	25.0	27.3[c]	14.3[d]	27.5[a]	7.9[b]
Organic	5.3	11.8	10.5[d]	50.0[c]	12.1[d]	33.3[c]	17.5[b]	36.8[a]
Feed barrier type								
Headlock	64.0[c]	40.6[d]	50.0	33.3	71.1	57.7	63.4	53.7
Post and rail	36.0[d]	59.4[c]	50.0	66.7	28.9	42.3	36.6	46.3
Presence of rubber floor	3.9	3.1	0.0	4.6	2.6	7.7	7.3	7.3
Presence of brushes	8.0	0.0	12.9[c]	0.0[d]	23.1	11.5	26.8	26.8

[a, b] Means within a row within a column with different superscripts differ ($P < 0.05$)

[c, d] Means within a row within a column with different superscripts tend to differ ($P < 0.10$)

[1] Percent of farms within each category.

[2] Some farms housed far-off dry cows off-site and were not observed, other farms did not have close-up dry or post-fresh pens.

[3] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 6: Stall dimensions of 4 critical pens on 82 dairy herds in Minnesota

	Far Off Dry		Close-Up Dry		Post Fresh		High-Producing	
Item	Large[1]	Small[1]	Large	Small	Large	Small	Large	Small
Stall length, cm	232.2[b]	244.4[a]	259.2	249.8	241.7	235.1	242.1	238.1
Lying space, cm	185.3[a]	172.0[b]	211.5	187.3	181.6[a]	173.4[b]	183.7[c]	177.0[d]
Brisket locator height, cm	16.9	15.3	14.0	15.2	13.7	15.1	12.4[d]	15.3[c]
Stall width, cm	121.8	120.9	129.2	118.7	121.0	121.7	122.3[c]	120.7[d]
Neck rail height, cm	120.8	118.0	117.7	116.2	116.2	114.0	119.6[a]	114.4[b]
Neck rail distance from curb, cm	175.4[a]	166.8[b]	174.0[a]	157.5[b]	170.0	171.2	172.5	169.5

[a, b] Means within a row within a column with different superscripts differ ($P < 0.05$)

[c, d] Means within a row within a column with different superscripts tend to differ ($P < 0.10$)

[1] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 7: Measures of stocking density in 4 critical pens on 82 dairy farms in Minnesota

	Far Off Dry		Close-Up Dry		Post Fresh		High-Producing	
Item	Large[1]	Small[1]	Large	Small	Large	Small	Large	Small
Stocking density, cows/freestall	0.92	0.89	0.93	1.15	1.00	0.94	1.14[c]	1.08[d]
Bunk space, m/cow	0.68	1.07	0.76	0.95	0.63	0.79	0.49[b]	0.55[a]
Water space, cm/cow	6.1	5.6	8.3	7.7	7.7	8.9	5.7	6.5

[a, b] Means within a row within a column with different superscripts differ ($P < 0.05$)

[c, d] Means within a row within a column with different superscripts tend to differ ($P < 0.10$)

[1] Large = farms with more than 425 cows; small = farms with less than 425 cows

Table 8: Distribution of the quantitative herd-level variables for 67 freestall dairy farms in Minnesota

Variable	Mean	SD	Q1	Median	Q3
Herd size	633	468	295	444	837
Number of cows per FTE equivalent[1]	51.4	13.5	43.6	49.6	56.5
Feed push-ups per day	7.3	4.1	4.0	6.0	12.0
Target refusals, %	2.1	2.0	0.5	1.5	3.0
Haylage removal rate, cm/d	31.3	35.7	15.2	19.1	30.5
Corn silage removal rate, cm/d	35.9	47.6	15.2	21.6	30.5
Time out of pen, min/milking	73.9	26.6	60.0	75.0	90.0
Average dry period length	56.4	6.4	53.0	57.0	59.0
Transition period pen moves	4.1	0.9	4.0	4.0	4.0
Footbath frequency, d/wk.	3.4	2.0	2.0	3.0	5.0
Stocking density, cows/freestall	1.09	0.16	0.98	1.09	1.20
Linear feed bunk space, m/cow	0.53	0.13	0.42	0.52	0.60
Liner accessible water space, cm/cow	6.3	2.9	4.2	5.7	7.4
Freestall length	239.9	15.9	228.6	233.7	248.9
Freestall width	121.8	4.3	119.4	121.9	121.9
Brisket board height	12.7	4.8	10.0	10.2	15.2
Neck rail height	118.5	9.1	111.8	119.4	124.5
Neck rail distance from curb	171.8	8.4	167.6	172.7	177.8
Average body condition score	2.89	0.10	2.82	2.90	2.94
As-fed TMR >19 mm in length, %	0.13	0.08	0.07	0.12	0.16
Estimated DMI, kg/cow per day	25.1	1.6	24.2	25.1	26.3
Forage percent of ration DM	52.0	6.1	48.7	52.2	54.9
Corn silage percent of ration DM	30.1	6.3	25.2	31.0	34.6
Legume forage percent of ration DM	21.0	6.3	17.0	19.5	25.8
Ration CP content, %	16.9	0.6	16.6	16.8	17.4
Ration NE_L content, Mcal/kg DM	1.67	0.08	0.60	1.68	1.72
Ration NDF content, %	28.2	2.0	27.0	27.9	29.4
Milk yield, kg ECM/cow per day	40.8	4.6	37.6	41.5	43.5
Feed cost, $/cow per day	5.91	0.79	5.44	5.97	6.46
Feed cost, $/45.4 kg ECM	7.18	0.92	6.55	7.01	7.73

[1] FTE = Full time employee (50 h/wk.)

Table 9: Overall frequency of the qualitative herd-level variables for 67 freestall dairy farms in Minnesota

Variable	Overall Frequency
Feeding frequency, x/d	
One	89.6
Two or greater	10.4
Number of different lactating rations	
One	31.3
Two	20.9
Three or greater	47.8
Number of different non-lactating rations	
One	46.3
Two	53.7
Anionic salts in pre-fresh diet	
Yes	63.9
No	36.1
Corn silage hybrid variety	
Silage hybrid	65.7
Grain hybrid	26.9
Both silage and grain hybrids	7.4
Feed mixer type	
Horizontal	11.9
Vertical	88.1
Pre-processing of alfalfa hay	
Yes	28.4
No	71.6
Use of on-farm master mix	
Yes	26.9
No	73.1
Milking frequency	
2	32.8
3	67.2
Use of bST	
Yes	65.7
No	34.3
Dry cows separated by lactation[1]	
Yes	59.7
No	40.3
Close-up dry cows separated by lactation	
Yes	17.9
No	82.1
Post-fresh group separated by lactation[2]	
Yes	11.3
No	88.7

High-production group separated by lactation	
Yes	80.6
No	19.4
Separate pen for post-fresh cows	
Yes	77.6
No	22.4
Hoof trimming schedule	
When cows need it	19.4
Once annually plus when cows need it	40.3
Twice annually plus when cows need it	40.3
Heat abatement category	
Mechanical	17.9
Adequate	14.9
Moderate	25.4
Inadequate	41.8
High-production group feed barrier type	
Headlock	62.7
Post-and-rail	37.3
Freestall type	
Deep inorganic	52.2
Deep manure	13.4
Mattress	34.3

[1] Pregnant heifers separated from cows ≥ 1 lactation
[2] Primiparous cows separated from multiparous cows

Table 10: Univariate regression analysis probability values between energy corrected milk per cow per day and feed cost per 45.4 kg ECM and herd-level variables on 67 freestall dairy farms in Minnesota

	P-value	
Variable	ECM/cow	Feed cost/45.4 kg ECM
Herd size	<0.01	0.71
Number of cows per FTE equivalent[1]	0.14	0.53
Feedings per day	0.54	0.28
Number of different lactating rations	0.07	0.08
Number of different non-lactating rations	0.39	0.04
Anionic salts in pre-fresh diet	<0.01	0.44
Feed push-ups per day	<0.01	0.90
Target refusals, %	0.37	0.03
Corn silage hybrid variety	0.23	0.14
Haylage removal rate, cm/d	0.26	0.76
Feed mixer type	<0.01	0.06
Pre-processing of alfalfa hay	0.80	0.15
Milking frequency	<0.01	0.69
Time out of pen, min/milking	0.31	0.17
Use of bST	<0.01	0.65
Average dry period length	0.23	0.48
Transition period pen moves	0.10	0.62
Dry cows separated by lactation[2]	0.14	0.43
Close-up dry cows separated by lactation	0.03	0.40
Post-fresh group separated by lactation[3]	0.19	0.91
High-production group separated by lactation	0.18	0.02
Hoof trimming schedule	0.04	0.13
Footbath frequency, d/wk.	0.01	0.59
Heat abatement category	0.07	0.97
Stocking density, cows/freestall	<0.01	0.03

Feed barrier type	0.03	0.94
Linear feed bunk space, m/cow	0.12	0.49
Freestall type	<0.01	0.02
Freestall length	0.17	0.74
Freestall width	0.19	0.85
Brisket board height	0.20	0.03
Average body condition score	0.09	0.18
As-fed TMR >19 mm in length, %	0.05	0.88
Estimated DMI, kg/cow per day	<0.01	0.94
Forage percent of ration DM	0.07	0.36
Legume forage percent of ration DM	0.01	0.69
Ration CP content, %	0.18	0.21
Ration NE_L content, Mcal/kg DM	0.03	0.58
Ration NDF content, %	0.13	0.17
Feed cost, $/cow per day	<0.01	-

[1] FTE = Full time employee (50 h/wk.)

[2] Pregnant heifers separated from cows ≥ 1 lactation

[3] Primiparous cows separated from multiparous cows

Table 11: Herd level variables and their association with energy corrected milk yield per cow on 67 freestall dairy farms in Minnesota

Variable	Coefficient	SE	*P*-value
Feed mixer type			
Horizontal	-4.20	1.00	<0.01
Vertical	0	-	-
Milking frequency			
2	-3.25	0.76	<0.01
3	0	-	-
Use of bST			
No	-1.62	0.77	0.04
Yes	0	-	-
Stocking density, cows/freestall	9.36	2.02	<0.01
Feed cost, $/cow per day	1.79	0.46	<0.01

Table 12: Herd level variables and their association with feed cost per 45.4 kg of energy corrected milk on 67 freestall dairy farms in Minnesota

Variable	Coefficient	SE	*P*-value
Target refusals, %	-0.09	0.05	0.05
Corn silage hybrid variety			
Silage hybrid	-0.96	0.35	0.01
Grain hybrid	-0.78	0.39	0.05
Both silage and grain hybrids	0	-	-
Hoof trimming schedule			
When cows need it	-0.67	0.26	0.01
Once annually plus when cows need it	-0.29	0.21	0.18
Twice annually plus when cows need it	0	-	-
Stocking density, cows/freestall	-1.51	0.59	0.01
Freestall type			
Deep inorganic	-0.10	0.21	0.65
Deep manure	0.77	0.30	0.01
Mattress	0	-	-
Brisket board height, cm	0.08	0.02	<0.01