ABSTRACT

HEIZER, BRITTANY THOMPSON. Impact of Management Practices on Milk Quality on North Carolina Dairy Farms (Under the direction of Dr. Stephanie H. Ward).

Adoption of mastitis control programs over recent decades has improved milk quality across US dairies; however, the Southeast is still the poorest region for milk quality. Eroding milk prices creates an opportunity for interruption of proper management practices and producers to lose focus on low somatic cell counts (SCC). Because the Southeast is a milk deficit area, producers must find ways to remain sustainable and competitive. The objective(s) of this study are: 1) to assess NC milk quality and 2) to understand how management practices impact milk quality. Eighteen farms voluntarily participated in milk quality assessments, and 27 evaluations were conducted. Herds were categorized as high (SCC > 350,000 cells/mL), medium (200,000 < SCC ≤ 350,000 cells/mL), and low (SCC < 200,000 cells/mL) bulk tank SCC prior to the start of herd visits. Herd evaluations were conducted on 30% of the lactating cow herd for the following variables: teat end scores (TES), locomotion, udder cleanliness, and body condition score (BCS). Housing evaluations were performed on each herd, with assessment of the following factors: housing type, bedding type and quantity, bedding frequency, and use of bedding conditioners. Parlor evaluations were conducted at each visit to observe milking procedures. Herd managers completed an on-farm questionnaire interview evaluating management strategies and herd demographics. Herd data was categorized for analysis. A monthly average of temperature humidity index (THI) was calculated for each visit and classified as no heat stress (THI <68) or heat stress (THI ≥ 68). Data were analyzed using PROC GLM in SAS. Bulk tank SCC (BTSCC) and standard plate count (BTSPC) were dependent variables and all other variables were independent. Bulk tank SCC and SPC were significantly lower for large herds compared to small herds. Jersey herds had the highest average BTSCC and BTSPC. Herds milked 3X had lower

BTSCC and BTSPC compared to 2X. Bulk tank SCC was greatest during periods of heat stress compared to no heat stress while BTSPC was lowest during periods of heat stress. Bulk tank SCC was lower in herds with more clean udders compared to dirty and very dirty udders. Herds with more clean udders had lower BTSPC compared to dirty udders, and very dirty udders were intermediate. There was a tendency that as TES increased from low to high, BTSCC increased and TES significantly reduced BTSPC as TES decreased. Herds with more normal gaited cows had lower bulk tank SPC compared to herds with more moderately lame cows and severe lameness was intermediate. Bulk tank SPC was lowest in herds with more ideal BCS cows compared to thin cows, and fat cows were intermediate. Freestall housing and recycled sand bedding were found to be associated with the lowest BTSCC. Deep bedded stalls had lower BTSCC and BTSPC than non-deep bedded stalls. Bedding once a week demonstrated lower BTSCC and BTSPC compared to bedding more or less frequently. Prep lag time of 90 s or greater than 90 s had lower BTSCC than less than 90 s. Prep lag of less than 90 s had the lowest BTSPC. Pre-dip contact time of 30 s or greater had the lowest BTSCC and BTSPC. Peroxide pre-dip had the lowest BTSCC but the highest BTSPC. Chlorine dioxide and iodine had the lowest BTSPC. Forestripping resulted in lower BTSCC but higher BTSPC. Dry wiping prior to pre-dip reduced BTSCC but not BTSPC. Udder hair removal lowered BTSCC but increased BTSPC. Less cracked teat ends resulted in lower BTSCC but increased BTSPC. Use of teat sealant at dry off reduced BTSCC and BTSPC. Conducting milk quality evaluations to assess NC milk quality and better understand how management practices impact milk quality is pivotal for prioritizing and determining herd based solutions for improving on-farm milk quality and herd profitability.

Impact of Management Practices on Milk Quality on North Carolina Dairy Farms

by
Brittany Thompson Heizer

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Animal Science

Raleigh, North Carolina
2020

APPROVED BY:

Dr. Stephanie H. Ward Committee Chair	Dr. Mark Alley
Dr. Kevin Anderson	

DEDICATION

This work is dedicated to my son, Barrett York Heizer. You have quickly taught me to never say never because who would have imagined starting a master's program with a 6-month-old. Together our independent personalities have grown and learned and pushed through the long tiring days. Little buddy you have been my reason. As this one journey comes to an end you have reminded me that anything is possible, always work hard and never be afraid to chase your dreams.

BIOGRAPHY

The author, Brittany Thompson Heizer, was born June 11, 1989 to Tim and Karen Thompson and spent her childhood being raised in Snow Camp, NC. Brittany graduated from Southern Alamance High School in 2007, and proceeded to Virginia Tech for a Bachelor's degree in Dairy Science, which was received in May 2011. Following a summer internship in animal health, Brittany was hired by Pfizer Animal Health (now Zoetis) as a Cattle Territory Business Manager covering in July 2011. She then spent the next 7 years devoted to calling on strategic veterinarians and resellers as well as dairy and beef producers promoting an extensive animal health portfolio and relevant business solutions. In June 2015, Brittany married Derek Heizer, and upon his graduation from Virginia Maryland College of Veterinary Medicine in 2016, they moved back to her hometown of Snow Camp, NC where together they operate Brittco Farms. On March 7th, 2018, Brittany and Derek welcomed their first child, a son, Barrett York Heizer. Brittany loves spending time with family and it was this priority that led to her resignation from traveling with Zoetis in May 2018. Since her departure, Brittany has returned to school and is attending NC State University to pursue a master's degree in Animal Science. In her spare time, Brittany enjoys working on the farm, showing and fitting cattle, as well as creating entrepreneurial opportunities such as her newest business venture with H and H Farmstand LLC.

ACKNOWLEDGMENTS

This work would not have been possible without the NC Dairy Foundation, my committee, fellow graduate students and the North Carolina State University, Department of Animal Science.

First, I would like to give a special thank you to my advisor, Stephanie Ward, for offering me this opportunity and providing the flexibility and understanding for completing this program while learning to be a new mom. A big thank you to my fellow graduate students, Katie Kelly, and Sarah Allen for their friendship, helping the oldie in the office navigate graduate school, SAS and for all their time and effort in helping me complete on-farm assessments and data analysis. I also must thank the awesome undergraduates, Emily Freed, and Abby Jones for their go with the flow, up for anything attitudes and all their help in collecting and entering data. Also, this thesis would not have been possible without the guidance and knowledge of my committee members, Dr. Mark Alley and Dr. Kevin Anderson. I'd especially like to recognize and say thank you to all the NC Dairy Producers who volunteered to participate in the project and opened up their farms for us to visit as well as the NC Dairy Foundation for providing the funding to allow this project to happen.

A thank you is not enough for my husband, Derek Heizer. Thank you for being my rock and my support through this journey. Thank you for providing for our family and for stepping up with Barrett and filling my duties when I was unable. Most importantly, thank you for never letting me give up and for always encouraging me to pursue my dreams and better myself. And lastly a thank you to my parents, my village, and my friends who have always been my biggest fans and helped shape me into the woman and mother I am today.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: Introduction

"Milk is the most nearly perfect food" containing more vitamins, minerals, and other essential nutrients than any other single food (Patton, 2004). With this comes the heightened pressure from both consumers and processors on dairy operations to produce a higher-quality product. Processors mandate a high-quality product as poor-quality milk with elevated somatic cells leads to reduced shelf life of dairy products due to reduced processing properties and a product with decreased nutrient values. (Boor et al., 1998; Ma et al., 2000; Jayarao et al., 2004; Barbano et al., 2006). Shipping a higher quality product is more economical for a producer as it may be the difference between making a profit and breaking even (Dickrell, 2019).

In the United States, Somatic Cell Count (SCC) and total bacterial counts known specifically as, Standard Plate Count (SPC) are two recognized regulatory measurements used to determine the quality of raw milk under the Grade "A" Pasteurized Milk Ordinance (PMO; US Department of Health and Human Services, 2009). Bacterial concentrations in milk typically are measured as colony forming units (cfu/mL) and cannot exceed 100,000 cfu/mL to qualify as Grade "A" milk. Increased SPC concentrations are predominantly influenced by bacterial growth on unsanitary milking equipment, dirty udders, improper cooling of milk, and accidental milking of mastitic cows (Murphy and Boor, 2000; Hayes et al., 2001; Chambers, 2002; Costello et al., 2003). Currently the United States has the highest legal SCC limit with a Bulk Tank Somatic Cell Count (BTSCC) less than 750,000 cells/mL. Nationally, in 2019, the average BTSCC of herds enrolled in the Dairy Herd Improvement Association was 187,000 cells/mL. While 2019 marked the lowest average BTSCC ever recorded in DHI history, the BTSCC variation across the US remained large with the Southeastern states often being higher as seen in Figure 2.1. When looking specifically at North Carolina, the 2019 BTSCC average was 207,000

cells/mL, down 13,000 cells/mL from 2018, with 20.4% of herds having test day averages over 400,000 cells/mL (Norman et al., 2020). Typically, SCC are indicators of udder health with an intramammary infection (IMI) influencing SCC the most compared to age, stage of lactation, stress, season, and mastitis management practices. A SCC greater than 200,000 indicates inflammation in the udder and potentially, mastitis (Dohoo and Meek, 1982; Eberhart et al., 1997; Laevens et al., 1997; Harmon, 2001). Mastitis costs the dairy industry an average of $2 billion per year because it reduces milk quality, production, and overall cow comfort (Donovan et al., 2005). An accumulation of studies has researched numerous management practices implemented across dairy operations and their associations with BTSCC, BTSPC, and mastitis control. These results form the foundation of udder health recommendations for producers today.

While the industry has made tremendous strides through the adoption of mastitis control programs, opportunity persists for herds to set more ambitious goals as the Southeast still is noted as the poorest region for milk quality (Oliver, 2008). Recently, eroding milk prices have interrupted management practices and threatened operations sustainability, and it is critical that producers shift their mindset around milk quality. Therefore, the objective of this research project was to prioritize the management practices within NC Dairy operations that have the greatest impact on milk quality and overall herd profitability.

CHAPTER 2: Literature Review

2.1. Milk Quality

Producers easily recognize the necessary actions to help connect with consumers to build trust and encourage consumption but the market volatility over the last four years has amplified this challenge. With the ever-growing threat of sustainability for family businesses and their livelihoods, it is crucial that the dairy industry shift its mindset to address the heightened challenges surrounding milk quality by connecting with today's consumer and striving to put a higher quality product on the shelf. This mindset can be difficult for a producer when one is facing eroding milk prices that interrupt proper management practices and make producers question why they should bother with a low somatic cell count (SCC). Every reason is tied to their bottom line, simply having access to a market may be predicated on what the quality is of the product you produce (Dickrell, 2019). Processors mandate a high-quality product as poor-quality milk has a high number of somatic cells that leads to reduced shelf life of dairy products as a result of reduced processing properties and a product with decreased nutrient values. (Boor et al., 1998; Ma et al., 2000; Jayarao et al., 2004; Barbano et al., 2006). The shelf life of high-quality milk (SCC= 45,000) is 21 days, compared to 14 days for low quality milk (SCC=849,000; Ma Y et al., 2000). Shipping a higher quality product is more economical for a producer especially when milk prices are low as it is essential to capture premiums and avoid imposed poor quality deductions set by processors. The difference between making a profit and breaking even is a low BTSCC (Dickrell, 2019).

In the United States, Somatic Cell Count (SCC) and bacterial, Standard Plate Count (SPC) are two assigned measurements used to determine the quality of raw milk under the Grade "A" Pasteurized Milk Ordinance (PMO; US Department of Health and Human Services, 2009).

Currently in the United States, an individual dairy producer can legally ship milk if their milk has a Bulk Tank Somatic Cell Count (BTSCC) less than 750,000 cells/mL. This benchmark standard has been in place since implementation in 1993 when the standards were lowered from 1,000,000 cells/ml (FDA 1991). To date the United States has the highest upper limit for somatic cell count for milk sell when compared to other developed countries such as the European Union (**EU**), New Zealand, Australia, Switzerland, and Norway who have all accepted 400,000 cells/mL as the upper limit, and Canada at 500,000 cells/mL (Dong et al, 2012). Nationally, in 2019 the average BTSCC of herds enrolled in the Dairy Herd Information Association was 187,000 cells/mL. While 2019 marked the lowest average BTSCC ever recorded in DHI history the BTSCC variation across the US remained large with the Southeastern states often being higher (Figure 2.1). When looking specifically at North Carolina, the 2019 BTSCC average was 207,000 cells/mL, down 13,000 cells/mL from 2018, with 20.4% of herds having test day averages over 400,000 cells/mL (Norman et al., 2020).

Somatic cells are predominantly white blood cells (macrophages, lymphocytes, and polymorphonuclear neutrophils (PMN)) and milk-secreting epithelial cells that have entered the mammary gland in response to injury or infection (Dairyman's Digest, 2009). The SCC population shifts from majority lymphocytes and macrophages to PMN when an IMI is present (Harmon, 1994). Typically, SCC are general indicators of udder health with an IMI influencing SCC the most (Dohoo and Meek, 1982). While multiple factors influence SCC, parity, stage of lactation, and heat stress were documented to have no effect (Harmon, 1994). A SCC less than 100,000 cells/mL typically indicates an udder free of infection and an animal in better health. Multiple studies concluded that SCC elevations greater than 200,000 cells/mL indicated abnormal milk and inflammation in the udder (Eberhart et al., 1997; Laevens et al., 1997;

Harmon, 2001). Eberhart et al. (1979) found that 50% of uninfected cows had SCC <100,000 cells/mL and 80% were less than 200,000 cells/mL. In addition, Laevens et al. (1997) demonstrated a geometric mean SCC of 49,400 cells/mL across 44 uninfected cows within their first to third lactations while a 16-month University of Kentucky survey demonstrated a geometric mean SCC of 29,000 per ml for 4,213 bacteriologically negative quarters (Harmon, 2001). Harmon's previous research in 1994 concluded the SCC was not significantly influenced by parity, stage of lactation or heat stress. These studies demonstrated that a normal, healthy SCC for cows without mastitis is less than 200,000 cells/mL.

2.2. Milk Quality and Animal Health

2.2.1 Mastitis

Mastitis is the result of physical, chemical, and bacteriological changes in the milk as well as pathological changes in the glandular tissue of the udder (Sharma et al, 2011). The primary causative agent for mastitis is bacteria that entered the mammary gland thru the teat canal, initiated an inflammatory response and multiplied in the milk. These mastitis infections can be either clinical or subclinical, with subclinical infections remaining the most economically important due to long-term effects on total milk-yield from a chronic infection (Ruegg, 2005). Mastitis is difficult to control due to the diverse bacteriological pathogens that can infect the udder. These bacteriological pathogens are typically broken down into two broad categories, contagious pathogens, which are spread between cows during milking; and environmental pathogens, which are found throughout cattle housing facilities and equipment (Oliver, 2008). To assist producers with the threat of mastitis, the National Mastitis Council (NMC) developed a 10-step recommendation plan for controlling mastitis. The 10-steps to mastitis control included: 1) setting udder health goals, 2) housing cows in a clean and dry environment, 3) utilizing proper

milking procedures, 4) adequate function and maintenance of milking equipment, 5) detailed record keeping, 6) clinical mastitis management, 7) effective dry cow management, 8) implementation of biosecurity protocols, 9) monitoring SCC as indicator of udder health, and 10) regular evaluation of the mastitis control program. Moxley et al., (1978) demonstrated that herds on a mastitis control program organized by a professional (18%) and those on a self-organized program averaged 58,800 and 40,800 cells/ml lower counts than herds without a control program. Herds, in that study, on a mastitis control program tended to more frequently use recommended practices of hygiene and record keeping.

Recent studies have calculated that an average case of mastitis costs a producer $444 with labor, milk discard, treatment and veterinary care, and erosion of lactation curve driving this expense (Kirkpatrick, 2018). A report from Zoetis and Compeer Financial (2016) used production and financial data from 367 herds to determine key drivers of profitability, of which mastitis and SCC were identified as leading drivers. The study identified an average BTSCC difference of 152,000 cells/mL between the top performing herds and the worst one-third of herds, which correlated to 5 kg/d increase in milk produced, which netted a $0.63/cwt differential in net farm income (NFI). They also concluded that for every 100,000 cells/mL change in BTSCC, production of energy corrected milk (ECM) shifted 2.5 kg/cow/d. The data also indicated that average BTSCC was highly correlated with several other key performance indicators such as death loss, days open, and 21-day pregnancy risk. Based on reported results, (Lormore, 2018) deemed that opportunity persisted for herds to set more ambitious goals to drive SCC lower – to 150,000 or even 100,000 to capture marginal milk and production efficiencies left on the table.

2.2.2 Lameness

Lameness is a growing health and welfare concern for the dairy industry and was reported as the third most prevalent reason for dairy cattle culling, behind mastitis and poor reproductive performance (Kossaibati and Esslemont, 1997). Lameness is defined as any condition that alters a cow's gait due to hoof or limb injury (Olechnowic and Jaskowski, 2011) or simply any abnormality which causes a cow to change the way she walks (Ronk, 2016). These alterations in gait can exist based on a multitude of foot and leg conditions such as foot rot, digital dermatitis, laminitis, and claw disease (Ronk, 2016). In addition, lameness in dairy cattle is a multifactorial condition influenced by nutrition, infectious disease agents, genetics, housing environment, and management factors. Not only does lameness create pain and discomfort for the animal, it limits production and causes great economic loss on farms through reduced milk yield, lowered reproductive performance, increased culling risk, and increased labor and treatment cost (Ronk, 2016; Green et al., 2010; Sogstad 2006). Ronk (2016) indicated a single case of lameness can cost a producer anywhere from $90-$300 per cow. Lameness was estimated to be present in 20 to 30% of lactating dairy cows in herds located in North America (Cook, 2003; Espejo et al., 2006), with the greatest incidence of lameness recorded in confinement-housed freestall herds (Cook, 2003; Haskell et al., 2006; Cook and Nordlund, 2009).

Currently, two-thirds of US dairy herds practice conventional confinement-housed management strategies as intensive farming systems have become a common practice to meet the demand of milk production (USDA NASS, 2010; von Keyserlingk et al., 2012). The USDA NASS reported approximately 68% of the herds with <500 cows and 73% of herds with >500 cows were housed in free-stall environments. However, cows managed in this manner are at a

greater risk of injury and lameness and the industry may face animal welfare concerns from consumers who have expectations that cattle should be outdoors in a grazing system.

Preventing lameness is a critical management strategy for producers to reduce the negative welfare implications and the economic costs associated with the debilitating conditions of lameness. Locomotion scoring were developed to assist producers with determining the extent of lameness across their herd. The locomotion scoring systems help producers assess the severity, duration, and prevalence of lameness in their herd through quick, visual observation of cow movement. This assessment is guided by two key parameters; gait and back posture and is scored on a scale of 1 to 5 **(Appendix A)** with severity increasing, respectively. A score of 1 reflected a cow that walks normally, while scores of 2 or 3 are associated with subclinical lameness and anything greater implies a cow is clinically lame (Robinson and Juarez, 2013). Cows displaying clinical or subclinical signs are examined to determine source of discomfort, identify lesion type (infectious or non-infectious) and then follow corrective and preventative treatment recommendations (Socha et al., 2006). Continual locomotion monitoring is imperative to follow up on these treatment measures and make sure lameness is reduced in the herd.

High locomotion scores were shown to have numerous negative effects across the wellbeing and production of a dairy cow. It is well documented that fertility in dairy cattle is compromised by an onset of lameness. Studies have demonstrated delayed cyclicity, increased days open, greater risk of ovarian cyst, and decreased conception rates that lead to longer calving to conception intervals and increased services per pregnancy (Sprecher et al., 2007; Garbarino et al., 2004; Melendez et al, 2003). Non-lame cows are quicker to conceive as the median time to conception increases by 36-50 days for lame cows and even longer, 66 days, among lame cows

with high cumulative locomotion scores (Hernandez et al., 2005). More recently Bicalho, 2011 demonstrated a 25% decrease in likelihood of becoming pregnant in cows that were clinically lame during the first 70 days in milk (DIM) compared with non-lame cows.

In addition, it is well documented that cows with lameness have increased stall lying time (Singh et al., 1993; Walker et al., 2008; Chapinal et al., 2009), reduced dry matter intake (DMI) because they spend less time standing at the feed bunk, and have lower milk yields (Robinson and Juarez, 2003) . Cows effected by lameness produce 1.9 kg/d less for each increase of 1 locomotion score (Robinson and Juarez, 2003). An ideal BCS at calving is essential as cows that are too thin have an increased risk (3-9X) of developing lameness during the lactation compared to cows with a higher BCS (Hoedemaker, 2009). Räber et al. (2004) also concluded that incidence of lameness is positively associated with animal age as older cows tend to be thinner cows that suffer from hoof damage and lower overall digital cushion thickness. Van Straten (2011) illustrated the relationship between milk fat and subacute ruminal acidosis (SARA) and indicated that decreased test day milk fat percentage could indicate cows at risk for claw horn lesions. Olechnowicz and Jaskowski, 2010, while investigating the effect of clinical lameness on milk yield, observed that groups of clinically lame cows (both lame for one month and > one month) had significantly larger SCC when compared to groups that had no incidence of lameness or groups that were categorized mildly lame (5.47 v. 5.15 and 5.22 ± 0.60 log SCC; $P<0.01$). Researchers suspected the synergistic stressful effects of both subclinical mastitis and lameness to be the cause of the increased SCC in clinically lame cows but did not offer an underlying mechanism for the increase.

2.2.3. Body Condition

The body condition score (BCS) of a dairy cow is a visual, subjective assessment of the proportion of body fat that she possesses and has been used by animal scientists, veterinarians, and producers as a key monitoring tool in dairy cow management since its introduction in the 1970s (Roche et al., 2009). The scoring chart (Appendix B) used to measure BCS differs between countries (Bewley and Schutz, 2008), but lowest values always reflect emaciation (thin cow) and highest values equate to obesity (Roche et al., 2004). Utilizing the 1 to 5 scale, the BCS and change in body condition served as as an indirect indicator of energy balance. According to Ferguson (1996) a one-unit change in BCS represented about 56 kg (120 lb) of body weight change and about 16 742 MJ (400 Meal) of net energy. Generally, BCS decreased in early lactation as cows cannot consume enough energy yielding nutrients to meet the needs of production and maintenance therefore energy from body reserves are partitioned. Energy balance (EB) is the difference in net energy consumed minus the net energy required for maintenance and production (EB = NE1 (consumed) - NE1 (required)) (Butler and Smith, 1989). The goal of BCS is to reach an ideal level of body fat that maximizes milk production without increasing metabolic and reproductive disorders (Perkins et al., 1985b).

Bewley and Schutz (2008) performed a comprehensive review on BCS and concluded that milk yield, herd health, reproductive performance, and animal well-being are all impacted by BCS changes. Excessive loss of energy reserves during early lactation, generally associated with cows of higher BCS at calving, often results in impaired health and reproductive performance. Studies by Ferguson (1996) and Coffey et al. (2004) demonstrated ideal BCS was significantly influenced by stage of lactation and management of production system. Loker et al. (2012) demonstrated an effect of BCS on mastitis susceptibility, where cows with low BCS had an

increased predisposition to mastitis. Positive genetic correlations between energy reserve changes and SCC or clinical mastitis have been noted. Loker et al. (2012) indicated the genetic correlations between BCS and mastitis were moderate to strong throughout the lactation, becoming stronger as lactation progressed with an average daily genetic correlation of −0.730 (0.110 MAST posterior std deviation). Neuenschwander (2010) obtained a genetic correlation between BCS and mastitis occurrence of about −0.30 throughout the majority of the lactation while Koeck et al. (2011a) obtained a genetic correlation of −0.35 (SE = 0.10) and Lassen et al. (2003) reported a genetic correlation of −0.16 (SE = 0.09) between BCS and mastitis in the first 50 DIM. Cows with an average BCS ≤2.0 in the first 100 DIM had an incidence of mastitis of 8.53%, and those with BCS >2.0 had an incidence of mastitis of 10.40% (Loker et al., 2012). Although the difference in mastitis incidence between thin and not-thin cows was small, the thin cows were expected to have a greater incidence as authors hypothesized that cows that mobilized more tissue (and experienced a lower BCS during lactation) are more susceptible to health and fertility problems. To the authors knowledge, the direct relationship between BCS and mastitis is illustrated rarely. Berry et al. (2007c) reported reduced SCS in parity 1 and 2 cows and increased SCS in parity 3 cows with increasing BCS at calving. However, clinical mastitis rates were not significantly associated with BCS. Most studies have not demonstrated any relationship between mastitis and BCS (Gearhart et al, 1990; Dyk, 1995; Ruegg and Milton, 1995; Heuer et al., 1999). BCS is a practical indicator for health and fertility status. Garnsworthy (2007) claimed it to be the most valuable management tool for assessing nutritional status of dairy cattle.

2.3. Farm Management Practices, Milk Quality and Milk Harvesting

2.3.1 Milk Harvesting

The invention of the mechanical parlor shaped the modern-day dairy industry and over the last 100 years, many advances in designs led to improved efficiency of milk harvest and match the genetic potential of the modern cow for increased milk production and milking frequency. Reinemann et al. (2003) described milking as a compromise between milking the cow as quickly and completely as possible without compromising teat end health. To achieve this compromise, proper maintenance and system operation is essential as research documented that improper milking unit function can cause poor teat health ultimately leading to increased risk of mastitis (Neijenhuis, 2004; Ohnstad et al., 2007; Mein, 2012). According to Spencer (1989), in a recent review of Current Concepts in Bovine Mastitis, there are 4 common ways the milking unit influences new IMI rate: 1) passes pathogens between cows, 2) potential for cross-infection within cows, 3) improper function can predispose cow to mastitis through teat end damage, and 4) pathogens can be forced past streak canal defense if milking vacuum is abruptly stopped or lost. Additionally, O'Shea (1987) described five mechanisms by which the milking machine affects udder health: 1) harbor bacteria on teat skin, 2) teat end trauma, 3) carrier for bacteria to enter teat canal 4) bacterial circulation in quarter, and 5) incomplete milk removal.

The milk machine is a vector for bacteria, whether it be between the cows or from teat to teat (Neijenhuis, 2004). Tremendous strides were made within the industry as the majority of new infections are caused by factors unrelated to the milking machine thus indicated by statistics showing that only 10% of herds new infection rates are linked to the milking unit (Mein, 2012).

2.3.2 Milking Vacuum Pressure

During machine milking, the vacuum system has two essential functions: the removal of milk from the udder and "holding" the milking unit to the udder. The claw vacuum (the vacuum beneath the teat) is constantly changing during the course of the milking but a certain level and degree of stability is needed to ensure a rapid, complete milk removal with minimal tissue trauma (Jones, 1999). To achieve this the recommended ISO standard of an average claw vacuum is 32 to 40 kPa. This degree of stability is influenced by two control elements: 1) the vacuum regulator and 2) the design and configuration of system components (Reinemann, 2005). In relation to design, Reinemann noted that vacuum was more stabilized at the teat end with the incorporation of low-level pipeline systems in milking parlors. Most parlors have demonstrated that the most efficient and most complete milkout was achieved at a vacuum level of 10.5-12.5 inches Hg at the teat end during peak milk flow (Stewart et al., 1996). The industry standard for vacuum stability in bovine milking systems is that the vacuum level should never drop more than 0.6" Hg (2 kPA) with all units operating at the designed milk and airflow rates. Nyhan and Cowhig, (1967) were the first two researchers to validate that fluctuating vacuum increased new IMI ($P<0.05$). They also demonstrated the necessity for each system having an adequate vacuum pump to support the corresponding number of units in the parlor otherwise inadequate capacity led to higher bulk milk cell counts (Mein et al., 2004). Field observations demonstrated that milkline vacuum levels between 48 and 52 kPa support the best udder health rates in herds with known mastitis problems (Rasmussen and Madsen, 2000). However, Besier (2016) documented that vacuum levels, > 42 kPa, are too high and will cause damage to the teat end. Additional studies demonstrated that increased vacuum increased the number of infected quarters ($P < 0.0001$, Mahle et al., 1982), hyperkeratosis rates, and prevalence of intramammary infections

(Barkema et al, 1999). The tradeoff of setting vacuum levels low is the likelihood for increased unit attachment time, frequency of liner slips, and unit fall offs (Reinemann, 2005). On the other hand, milking at high vacuum levels decreased machine-on time but consequently caused a negative effect on teat congestion (Hamman et al., 1993), teat end closure, teat end hyperkeratosis (Rasmussen et al., 1993; Mein et al., 2003) and strip yield volumes (Reinemann et al., 2001a). Ultimately, vacuum influences udder health through bacteria penetration to the teat canal and change of teat end condition thus making it essential to find that delicate balance in an operations system.

Even with a high performing. well-maintained system, vacuum fluctuations will occur. Decreases or increases in airflow within the milking system occurred rapidly from either a blocked vent or air leaks that allow excessive flow (Jones, 1999). Vacuum fluctuations are broken down into two categories, cyclic and irregular vacuum fluctuations. Cyclic vacuum fluctuations (CVF) occur at regular intervals while milking with the greatest fluctuations occurring at peak milk flow (Rasmussen et al., 2006). Furthermore, CVF are influenced by milk flow from the liner opening (Thiel et al., 1974) as well as liner movement (Besier et al., 2016). Regardless, the occurrence of CVF with either a low or high milk flow rate was still proven to have no effect on new IMI in the udder (Thiel et al., 1974)

A substantial decrease in vacuum, consequently followed by a vacuum recovery is defined as irregular cyclic fluctuations (ICF; Thiel et al., 1974). These are most captured in the parlor as events that decrease milk flow rates such as liner slips, squawking, or unit fall off occur during milking. More than 5-10 slips or falloffs per 100 cows within a milking indicated a vacuum problem and require correction. Corrective measures would depend on timing of the fluctuations. For instance, low vacuum levels, blocked air vents, or restrictions in the short milk

tube are often causes of a unit slips or squawking within first half of milking (Jones, 1999). Slips in the latter part of milking are commonly related to unit alignment, age and condition of liner, or cluster weight that is unbalanced (Mein and Reid, 1996). Each of these conditions increased the number of liner slips and multiple studies have shown that infection rates increase as a result of poor udder and teat end health caused by irregular vacuum fluctuations (Wilson, 1958; Beckley and Smith, 1962; Stanley et al., 1962; Wilson, 1963; Nyhan and Cowhig., 1967; McDonald and Witzel., 1968; Nyhan, 1968).

2.3.3 Teat Cup Liner Design

Liners are a critical piece to the milking machine as they are in direct contact with the cow's teats. Worn liners damaged teat tissues, increased machine on time through slower milk out, and caused more liner slips during milking which are a known source for new intramammary infections (Jarrett, 1984; Spencer, 1989). There is not an "ideal" standard liner for the industry as there are several hundred types marketed all with varying design characteristics. Along those same lines, there are no formal guidelines for evaluating how efficiently a liner can remove fluid milk while simultaneously maintaining teat end condition. However, many producers assessed liner performance based upon milking speed, comfortability related to cow behavior, teat health, and mastitis incidence rate (Hillerton 2005). Schukken et al., 2006, demonstrated a difference in type of liners when comparing round verses square. Data showed that prevalence of cracked teat ends increased by 20% and average keratinization score was 0.43 higher in herds milking with round liners. The authors also compared over a three-month period the herd effect of switching from round to square liners. By switching to square liners both keratinization (0.18) and cracking (0.16) were reduced. Further research by O'Shea et al., 1979, concluded that liner slip was highly dependent on liner design. They noted that infection rates

increased in the order of two to three-fold with high slip liners when compared to low slip liners ($P < 0.05$). In a study by Baxter et al. (1992), he concluded that high slip liners had an increased association with (IMI) verses cows that were milked with low slip liners. The high slip liner averaged 6.1 slips and 7.6 major vacuum fluctuations per cow milking, while the low slip liner averaged 3.6 slips and 3.1 vacuum fluctuations per cow milking ($P < 0.01$). Lastly, Baxter et al. (1992) indicated that previously infected cows were more susceptible to new infections when milked with high slip liners.

2.3.4 Teat End Condition

Teat end health and skin condition play an integral part in any effective mastitis program. Hyperkeratosis means "excessive keratin growth" which is a thickening of the teat canal skin that results from forces applied during milking or a calf suckling. Over the years, multiple teat-end scoring systems have been developed to evaluate teat-end health and skin condition, with the most common methods utilized being visual assessment, photographic comparison, and scoring schematics (Britt and Farnsworth, 1996; Neijenhuis, 1998; Shearn and Hillerton, 1996; Sieber and Farnsworth, 1984; Timms et al., 1998; Mein et al., 2001). Dairy producers and veterinarians require an efficient and reliable way to evaluate teat end health across their herds and Mein et al., 2001 suggests the system below for simplified on farm evaluation:

No ring (N) – a typical status for many teats soon after the start of lactation. This category includes teat-ends scored as HK0 in the UK or N in NL, and some teats scored as 1 in US.

Smooth or Slightly rough ring (S) – a raised ring with no roughness or only mild roughness and no keratin fronds. This category includes teats classified as HK0 or 1 in UK, as 1A, 1B or 2A in NL, 1 in AU, and most teats scored as 2 in the US.

Rough (R) – a raised roughened ring with isolated fronds of old keratin extending 1-3 mm from the orifice. This category indicates some breakdown in epithelial integrity. It includes teat-ends classed as HK2 or 3 in UK, 2B or 2C in NL, 2 in AU, or 3 in the US.

Very Rough (VR) – a raised ring with rough fronds of old keratin extending >4 mm from the orifice. The rim of the ring is rough and cracked giving the teat-end a "flowered" appearance. This category includes teat-ends classified as HK4 or 5 in UK, 2D in NL, 3 in AU, or 4 in US.

A study in Brazil conducted by de Pinho Manzi et al. (2012) showed a 30% increase in intramammary infection for each 1-unit increase in teat-end HK score ($P < 0.001$). Teat-end hyperkeratosis is a dynamic condition influenced by a multitude of factors including climate, seasonal and environmental conditions, genetics, teat end shape, stage of lactation, milk production level, milking equipment function, and milking management (particularly slow milking and over-milking). Teat-end hyperkeratosis was reported most prevalent in high producing herds particularly during colder climate months (Mein et al., 2003). Teat-end scoring is an essential tool for producers to utilize to monitor teat-end health and risk of IMI across milking machines, milking management, and environmental conditions the teat tissue is subject to (Mein et al, 2001).

2.3.5 Overmilking

Overmilking occurred when teat cistern milk flow dropped below milk flow out of the teat canal. Past beliefs in the industry, "milk all cows out as completely as possible at every milking" contributed to prolonged machine on time as well as parlors not utilizing automatic take-offs. Veterinarians at Michigan State University stated that following milking completion a unit should be removed within 15 seconds and any unit attached for greater than 30 seconds is

overmilked (Erskine and Moore-Foster, 2018). This is also supported by Mein (2003) who states that teat-end health is significantly impacted when milk flow rate is less than about 1 kg/min. It has been proven that overmilking has a negative effect on udder health by causing a greater number of quarters to become infected (Natzke et al., 1982). Thiel, (1974) described the end of milking and the time around milking unit removal to be the highest risk of new infections. Thus, overmilking merely lengthens the time of potential risk of bacterial transfer and subsequent new infection (Natzke et al., 1982). Neijenhuis et al. (2000b and 2001), has also shown that teat-end lesions and mastitis occurrence are reduced as machine-on time it shortened. Lastly, Rasmussen (1993) demonstrated that hyperkeratosis can be reduced by shortening average milking times per cow through adjustment of automatic cluster remover threshold settings.

2.3.6 Automatic Cluster Removal

Automatic milking machine removal more commonly referred to as automatic cluster removal (ACR) was first introduced to the dairy industry approximately 50 years ago. O'shea et al. (1987) suggested that automatic detachers may have an association with decreased herd SCC, since the problem of overmilking is greatly reduced. Multiple studies have demonstrated the association of ACR use/nonuse with BTSCC (Fenlon et al., 1995; Hutton, 1990; Jayaro et al., 2004). Fenlon et al., 1995 showed herds with a high BTSCC were less likely to use ACR, while a Washington State study found that automatic milking unit detachers were used on more low SCC than high SCC herds ($P < 0.02$; Hutton, 1990). In addition, after evaluating Pennsylvania dairy herds in 2004, Jayaro found producers that utilized ACR had lower BTSCC and significantly less coagulase-negative staphylococci (CNS) counts in the bulk tank milk, as opposed to those who did not use ACR and had higher BTSCC.

The primary objective of an ACR is to detach the milking unit from the cow once milk flow had decreased below a predetermined level, or switch point (kg/min). Traditionally, a milk flow rate of 200g/min is the switch point to trigger unit removal and imply that a cow is sufficiently milked out. However, just because that threshold (200 g/min) is reached, it does not guarantee that the milk flow rate will not be less than threshold at the physical time of unit detachment (Rasmussen, 1999). This is dependent on the ACR delay time which is a set adjustment that tells the unit how long it will remain attached after the switch point is reached (Stewart, 2002; Magliaro, 2005). The selection of various ACR switch point and ACR delay time settings have been documented to influence milking duration with no effect on production and udder health (Rasmussen, 1993; Stewart et al., 2002). Rasmussen reported an experiment that tested two ACR switch points (200 g/min and 400 g/min) and two delay times (18 s and 12 s) respectively. Increasing the ACR threshold level from 0.2 to 0.4 kg/min demonstrated a reduction in machine-on time by 0.52 min ($P < 0.05$) without affecting milk yield, milk composition, or the incidence and prevalence of clinical and subclinical mastitis (Rasmussen, 1993). Additional reports cited field experience in commercial dairies indicating that time in parlor is decreased and volume and quality of milk is maintained when ACR settings are increased from 0.32 to 0.59 kg/min or to an even higher threshold of 0.82 kg/min (Reid and Stewart, 1997; Stewart et al., 1999 and 2002). The latest report demonstrated that the incidence of clinical mastitis was not altered by raising the ACR threshold setting nor by applying a maximum milking time; however, SCC was greater ($P < 0.05$) for cows in the higher threshold setting (ACR400; Jago, 2010.) All in all, producers who utilized ACR increased milking efficiency thru decreased machine-on time, increased average milk flow and improve teat

condition and BTSCC if all best practice pre-milking preparation routines were followed (Jago, 2010).

2.3.7 Milking Pulsation and Pulsation Ratios

Pulsation is another key element of milking machine function that has significant influence on milking and udder health. Pulsation is defined as cyclic opening and closing of the barrel of a teat cup liner. Its main purpose is to provide liner compression to the teat end, which assists the return of blood and lymph flow through the veins and lymph ducts during milking ultimately preventing congestion and edema of the teat during machine milking (Mein and Williams, 1984; Hamann and Mein, 1996). The 4 phases of each pulsation cycle are defined by the International Organization for Standardization (ISO) as a: liner opening; b: liner open, or milking; c: liner closing: and d: liner closed or rest. The duration of each phase is measured between the points at which the pulsation chamber vacuum is 4 kPa below nominal system vacuum (a-to-b and b-to-c transitions) and 4 kPa above atmospheric pressure (d-to-a and c-to-d transitions; Upton, 2016). The ISO specified that the d-phase should be at least 15% of the pulsation cycle and have a minimum d-phase duration of 150 ms. This recommendation was supported by Upton (2016) who conducted a 7 d-phase duration trial to measure the effect of duration on the teat canal cross-sectional area (CA). Upton (2016) concluded that d-phase durations of 50 and 100 ms significantly reduced CA of the teat canal unlike d-phase durations of 150, 175, 225, 250, and 300 ms ($P<.001$). An older challenge study by O'Shea et al. (1984) analyzed two levels of d-phase duration (72 and 187 ms) for their effect on new mastitis infections when the teats were dipped in a *Staphylococcus aureus* culture before and after milking. O'shea identified that the short d-phase duration triggered a new infection 5 times faster than the long d-phase; one new infection every 800 quarter milkings, verses one new

infection every 4,000 quarter milkings. Additionally, Reitsma et al. (1981) found that decreasing the duration of liner closure significantly increased the occurrence new quarter infections across all four durations of liner closure (0, 0.17, 0.34, and 0.51 s) per pulsation cycle.

Pulsation ratios (PR) refer to the amount of time the liner is in milk phase (open) or massage phase (closed). The most common ratio used across the industry is 60:40 with the range of 55:45 to 70:30. It is common knowledge that widening the PR increases the speed at which a cow is milked out but at what cost. Most literature supported the earliest work stating when effective pulsation is applied in the conventional teat cup, it is remarkably difficult to increase new mastitis infections even in association with high vacuum levels (Olney and Mitchell, 1983) or prolonged overmilking (Olney and Mitchell, 1983; Mein et al., 1986). For example, Thomas et al. (1993) found no differences in milk production when comparing 50:50 and 70:30 PR as well as no differences when evaluating BTSCC, clinical mastitis cases, or number of cows culled for mastitis. Mahle et al. (1982) compared three PR, 50:50, 60:40, and 70:30, and identified no changes in infection rates or number of new infections in cows despite a bacterial challenge, however the study revealed that the 70:30 PR was associated with SCC through increased Wisconsin mastitis test scores. Lastly, Hamann & Mein (1996) demonstrated an increased teat tissue thickness when PR increased from 50:50 to 80:20 with the most significant increase arising from 70:30 to 80:20. Zecconi et al. (1992) identified teat tissue thickness that arises from milking forces to be a risk factor for mastitis and a minimal 5% increase in teat end thickness during milking increased the risk for teat-end bacterial colonization. While research reports vary, the clear message is that pulsation is an important function to the milking machine system and cow because pulsation-less milking is detrimental. Capuco et al. (1994) demonstrated those impacts with 68% of quarters becoming infected with bacterial pathogens after 2 weeks,

compared to 2% new infections among quarters milked with pulsation, an 8% increase in teat end thickness, and a sevenfold mean SCC increase in pulsation-less quarters ($P < 0.05$).

2.3.8 Milk Wash System

The work is not over when the last cow leaves the parlor. Instead the next critical step to ensuring high quality milk has just begun. At the end of each milking, the milking pipeline must be washed promptly to remove the buildup of milk soils, organic and mineral solids, and prevent microbial growth. The dairy industry widely adopted the use of Clean-In-Place (CIP) systems starting in the 1960s (Fan et al., 2015). The CIP process consisted of up to 4 phases; pre-rinse, detergent wash, acid rinse, and sanitize cycle. Each step has its own requirements and the time, temperature, water volume, chemical balance, velocity, and drainage of each must be monitored to make sure no results are compromised (Engel, 2016). The pre-rinse wash is tasked to remove 90-95% of the soil load and to warm up the equipment for cleaning. The pre-rinse water should be lukewarm, between 100 to 110°F. If the pre-rinse is too hot (>120°F) then proteins will be denatured leaving protein film on surfaces where bacteria can grow. On the other hand, if the pre-rinse is too cold then milk fat crystallization will occur and form a greasy film on surfaces (Jones, 2009). In 2015, Fan studied the effectiveness of rinse water at three temperatures (22 °C, 45 °C, and 67 °C). Fan concluded that rinse water effectiveness was improved significantly ($P < 0.05$) when temperature was increased from 22 °C to 45 °C, but found no difference when increased to 67 °C. At the conclusion of the pre-rinse all water must be completely drained from the system in preparation for the detergent wash to follow. The detergent wash cycle typically contains a chlorinated alkaline detergent that should circulate through the system with a pH between 11 and 13, and a starting solution temperature between 160ºF and 170ºF, and maintained above 120ºF for roughly 7-10 minutes depending on parlor size and number of slugs

generated. While cleaning action can be achieved at a minimum velocity of 5 ft/sec it is strongly recommended that the system deliver 20 good slugs going 25 to 35 feet per second to ensure optimum effectiveness (Jones, 1999; Engel, 2016). The next cycle is the acid rinse cycle that circulates for 3-5 minutes at 95 to 110ºF, with a pH between 2.0 to 3.5 to neutralize any detergent residue, remove minerals and inhibit bacteria growth (Engel, 2016). The last cycle of the wash system is the sanitize cycle. This cycle is typically run just prior to milking or in conjunction with the acid cycle. Either way, the sanitize cycle is used to kill bacteria and to have the most impact the solution should circulate for three to five minutes at 95 to 110ºF and yield 100 to 200 ppm of chlorine when testing the drain of the cycle (Engel, 2016). To have the most success its essential to have regular system maintenance and monitor milk quality tests of Standard Plate Count, Laboratory Pasteurization Count, Coliform Count and Preliminary Incubation Count (SPC, LPC, CC and PI) to know when and where action needs to take place (Oliver, 2010).

2.4. Milking Management Practices

Milking parlor management is deciding upon a specific milking routine for a specific parlor design. Milking routine and milking procedures; while often misconstrued as the same thing, it is important to recognize their distinct differences. A milking routine is "the system by which milkers move through a milking parlor" while the milking procedures are defined "the steps that define the routine" also commonly observed as the cow side activities conducted by each milker (Fuhrmann, 2002). There is vast amount of literature that demonstrates the influence of these cow side hygienic activities (pre-milking disinfection, fore-stripping, teat drying method, post-milking disinfection, glove use, udder hygiene and hair management) on somatic cell count (Pankey, 1989). Herds with stricter attention on hygiene and these cow side activities

will have a lower BTSCC (Barkema et al, 1998). Smith and Armstrong, 1998 also demonstrated a production advantage to proper pre-milking hygiene with an additional 9 lbs. more milk per cow in herds using full preparation vs minimal.

2.4.1 Pre-Dip Active Ingredients, Application, and Timing

Good udder preparation alone is not enough to reduce IMI, instead more is needed to decrease teat end exposure to environmental pathogens. The main factor to bacterial control is the use of pre and post teat disinfectants (Philpot, 1979). The use of a pre-milking disinfectant is widely supported in literature with its effectiveness in decreasing bacteria counts and incidence of clinic mastitis (Galton et al., 1986; Rasmussen et al., 1992). Pankey et al. (1987) successfully proved that good udder preparation plus pre-dipping significantly reduced rate of IMI (51.5% ($P < 0.001$) for environmental pathogens; 48.2% ($P < 0.025$) for EPS (Esculin-positive streptococci); and 54.0% ($P < 0.005$) for CO (Coliform). These effective results were obtained using three formulations of iodine-based disinfectants across the herds. However, Galton, 1986 found other compounds (Iodophor, sodium hypochlorite, and dodecyl benzene sulfonic acid) to be just as effective at reducing total bacteria in milk with no significant differences among the disinfectants. More recently, Enger et al. (2015) evaluated mastitis pathogen strain sensitivities across four different commercially available teat disinfectants (dip A: 1% H2O2; dip B: 1% chlorine di-oxide; dip C: 1% iodophor; and dip D: 0.5% iodophor) and concluded that all four significantly reduced log bacteria versus the undipped control ($P < 0.0001$). When comparing the disinfectants, Enger found that dip A, the 1% H2O2 was the least efficacious and significantly different from the other three disinfectants ($P < 0.05$). In addition, dip C, the 1% iodophor, was the superior disinfectant with the greatest log bacteria reduction (95.1%), which was significantly different from dip D, 90.9% log reduction ($P < 0.05$) but not from dip B, 92.9%

(P > 0.05). In a second experiment, Enger also evaluated dip contact time for three different teat dips (dip A: T-Prox a 1% H2O1 dip; dip D: T-505 a 0.5% iodophor (Thatcher Company); and dip E: DellaCare Enhanced, a 0.25% iodophor (DeLaval). Once again Enger found significant differences between types of dip with log reductions of 40.3%, 34.3%, and 26.5% for dips D, E, and A respectively (P<0.05). When looking at herds in the Southeast, Blakely (2017) found that herds using dips with hydrogen peroxide had double the BTSCC than other ingredients. While there are discrepancies in literature about which active ingredient is most effective, it is important to remember that a pre-dip is still essential and that there are other factors associated with the pre-dip that are critical influencers of bacteria counts as well. These factors include contact time, application technique, and drying method.

The industry recommendation for pre-dip contact time with the teat skin is 30 seconds (s). Studies by (Reneau, 2001; Bray and Shearer, 2012) supported this recommendation while others demonstrated optimal time depending on active ingredient. When contact times of 15 s, 30 s, and 45 s were evaluated, Enger concluded that all resulted in mean log reductions of 30.0, 34.1, and 37.0% respectively, all significantly different (P < 0.05). The study also determined that different active ingredients had different optimal contact times with a 30 s contact time for iodophors but only 15 s contact needed for hydrogen peroxide dips. Additional research has shown significant germicidal efficacy against mastitis pathogens with disinfectant contact times of 15 to 20 s (Galton et al., 1988) and 60 s (Peters et al., 2000).

The most common application methods of pre-milking disinfectant have been evaluated (foam, dip-cup, and spray) with multiple results as well. Jayarao et al. (2004) concluded that herds applying pre-dip using a dip-cup verses spray had a significantly lower BTSCC, SPC, and PIC in their BTM (P < 0.05). When producers in Virginia and Tennessee were evaluated in the

Southeast Quality Milk Initiative (SQMI) in 2016, Blakely found that producers using foam (24%) had the lowest SCC (294,000 cells/ml, SE=13,147), those using dip cups (55%) had the second lowest at 300,000 cells/ml (SE=13,147), and those using spray (18%) had the greatest SCC at 342,000 cells/ml (SE=33,054) ($p<0.05$).

2.4.2 Cleaning and Drying Teats

Once adequate contact time is achieved the next essential step to reduced bacterial counts and decreased milk sediment is the removal of the pre-dip by thorough cleaning and manual drying of teats immediately before milking (Galton et al., 1984 and 1986; Pankey et al., 1989). Moxley et al. (1978) found BTSCC values to be 44,000 cell/ml lower for herds that dried teats compared to herds that left teats wet. Two common and accepted methods in the US for cleaning and drying teats are individual paper towels or cotton towels washed between milkings and literature disputed which is most effective. Galton et al. (1986) concluded that type of towel used in drying teats had no effect on bacterial accounts across the nine different preparations and that duration of drying was of no importance as well. On the other hand, more recent studies by Jayarao et al. (2004) and Bach et al. (2008), concluded that type of towel did impact SCC ($P < 0.011$ and $P < 0.001$, respectively). Bach noted that producers that used paper towels (68.1%) had lower SCC ($P < 0.001$) than those that used cloth towels (31.9%). What the literature doesn't dispute is that regardless of type of towel, the use of a single service towel per cow provided the lowest bacterial counts and greatly reduced the risk of bacterial transmission between cows (Galton et al.,1986; Elmoslemany et al., 2010). In addition, reusable cloth towels may function as a vehicle for mastitis causing pathogens, therefore it is critical that they be washed and disinfected between uses to stop the spread of mastitis pathogens. Data from Gradle and Dee (2003) showed an advantage to sanitizing detergents having greater killing power over

normal detergents and that complete drying of towels resulted in a significant reduction across all types of bacteria tested, verses leaving towels damp. Rowe et al., 2019 discovered that towels that were not dried were 8.2 times more likely to have a coliform count ≥ 5 CFU/in² (P = 0.003).

2.4.3 Forestripping

Pre-milking udder preparation that included forestripping, expressing 2-3 streams of milk prior to unit attachment, should be a standard practice across all operations to ensure adequate milk letdown and identification of all abnormal milk (Rasmussen et al., 2000). Goodger et al., (1993) stressed the importance of forestripping for the purpose of detecting mastitis early to allow cows to be properly treated and separated from healthy cows to decrease the risk of bacterial spread. The first streams of milk located in the teat cistern are known to have the greatest concentration of bacteria of any milk fraction, thus discarding this milk through forestripping resulted in lower somatic cell and organism prevalence (Harmon, 1994; Fahr, 2002). In addition, the bulk tank milk is 2.5 times less likely to become contaminated with L. monocytogenes if forestripping is practiced (Hassan et al., 2001). In addition, forestripping was associated with enhanced parlor performance thru increased milk yield per milking, greater peak milk flowrates, more cows per hour, and lesser bimodality (Ruegg, 2004; Sandrucci et al., 2007). However, Wagner and Ruegg (2002) found contrasting results as no effect of forestripping was observed on milk yield, unit attachment time, or average milk flow rates. Further studies discussed forestripping as an effective method of lowering SCC but simultaneously increased the frequency of IMI due to teat-contact with hands of milking personnel and increased exposure of pathogens to neighboring cows (Peeler et al., 2000; Rasmussen, 2000). Schukken et al. (1991b) supported this increased exposure to pathogens, specifically contagious pathogens, when suggesting that forestripping was a risk factor for *Staphylococcus aureus* mastitis. Jayarao et al.

2004, also discovered that herds that practiced forestripping had higher BTSCC than herds that did not ($P = 0.028$). When specifically looking at VA and TN dairies, forestripping was a common practice (71%) that resulted in herds having a higher SCC (337,000 cells/ml vs 332,000 cells/ml ± 25,474) than those that did not forestrip ($P < 0.05$; Blakely, 2016).

2.4.4 Post-Milking Teat Disinfection

Post-milking teat disinfection (PMTD) is an essential step of any mastitis control program and is widely adopted by producers (96.8%, USDA 2014) because it is simple, economic, and effective. PMTD immediately following the removal of the milking unit was noted as one of the most significant practices influencing herd SCC (Barkema et al., 1998; Dufour et al., 2011). Barkema et al., 1998 found herds that utilized PMTD were more likely to have a BTSCC <150,000 cells/mL versus those that did not. The goal of PMTD is to ensure full coverage of the teat barrel and teat end with an efficacious post-milking teat disinfectant. Adequate coverage aids bacterial kill of the teat surface and soft agile teat skin is maintained when an emollient is included in the dip to help withstand the rigors of milking (Ohnstad et al., 2018). Multiple studies have demonstrated reduced rates of new IMI through PMTD depending on pathogen specificity. For instance, post-milking teat dips have validated efficacy in reducing the incidence of both opportunistic (Hogan et al., 1995; and Quirk et al., 2012) and contagious (Neave et al., 1969; Bramley et al., 1984; Pankey at al., 1984; Pankey at al., 1985; Oliver et al.; 1991; Williamson and Lacy-Hulbert, 2013) IMI. There is discussion across the literature regarding PMTD effectiveness against environmental mastitis pathogens. A few studies proved that pre-milking teat dips were effective in reducing the incidence of environmental IMI across varying concentrations of iodine (Wesen and Schultz, 1970; Eberhart et al.,1983; Nickerson et al., 1986; Pankey et al., 1987). Eberhart et al. (1983) and Wesen and Schultz (1970) both

indicated that a 1% iodine post-milking teat disinfectant was 65% efficacious in reducing new IMI caused by environmental streptococci other than *S. agalactiae*. In contrast to these results, (Oliver et al., 1991) concluded that low concentration iodine post-milking teat disinfectant was ineffective against environmental pathogens (24.1% reduction) but highly effective against contagious mastitis pathogens. Additional active ingredients other than iodine, were studied as well to determine their efficacy against major mastitis pathogens. Oliver et al., (1990) found chlorhexidine teat dip to be 50% efficacious ($P<.01$) against major mastitis pathogens and Erskine and Eberhart, (1991) supported this in their study with chlorhexidine herds being associated with lower SCC. Pankey et al., (1985) also looked at two other formulations: 1) linear dodecyl benzene sulfonic acid - .55% iodophor and 2) barrier-type product consisting of milk protein solubilized with lauryl sulfate, a surface active detergent, and 4.8% glycerin to test their efficacy against *Streptococcus agalactiae* and *Staphylococcus aureus.* Pankey et al. (1985) concluded significant reductions in incidence of infection of 52.7% ($P<0.025$) and 70.7% ($P < 0.005$) for formula one and 60.3% ($P < 0.005$) and 67.9% ($P < 0.01$) for formula two across the two pathogens, respectively. When application methods for post-milking teat dip were evaluated, Blakely et al. (2016) discovered that 87% of producers applied PMTD with a cup and were associated with a lower SCC (322,000 cells/mL) than the 11% of producers who used spray (380,000 cells/mL; $P < 0.05$).

2.4.5 Hygienic Practices – Glove Use and Udder Cleanliness

The second parlor practice that Dufour et al. (2011) found to have a significant impact on influencing herd SCC was glove use ($P < 0.03$). Multiple studies demonstrated that BTSCC decreased with the use of gloves during milking (Hutton et al., 1990; Bach et al., 2008; Cicconi-Hogan et al., 2013). Additional literature from Rodrigues et al. (2005) in Wisconsin found

associations of glove use and lower SCC as well as facility type. The authors concluded that milkers wore gloves less often in herds with a high BMSCC ($P < 0.001$) and that milkers in stallbarn herds were less likely to wear gloves when compared to free-stall facilities ($P < 0.01$). Japanese dairies also reported an association between wearing gloves routinely and a lower BTSCC ($P < 0.01$; Kawai et al., 2015). However, research reports from Great Britain by Peeler et al. (2000) and O'Reilly et al. (2006) disputed these observations. Peeler and O'Reilly reported that wearing rubber gloves during milking resulted in an increased incidence rate of clinic mastitis (IRCM) compared to herds who never wore gloves ($P < 0.01$).

Across herds the ability to keep cows clean and reduce teat end exposure to pathogens is increasingly challenging with increased herd size, parlor throughput pressure, infrequent alley scraping and manure removal, and bedding material availability. Ward et al. (2002) described the lowest incidences of mastitis occurring in the herds with the cleanest cows and the most satisfactory beds. Assessing proper udder hygiene (UH) is a critical component as quantity and bacterial species present on teat ends is influenced by udder cleanliness. Several different scoring methods have been developed to assess cow hygiene (Cook, 2002 ; Schreiner and Ruegg, 2003; Reneau et al., 2005) and demonstrated that poor hygiene results in udder health problems.

Through utilization of these scoring assessments, researchers have discovered positive associations between excessive dirt and manure particularly on udders and legs with level of mastitis (Schreiner and Ruegg, 2003; Reneau et al., 2005). For instance, Schreiner and Ruegg, (2003) concluded that clean cows (udder scores 1 and 2) were 1.5 times less likely to be infected with a major mastitis pathogen than dirty cows using their scoring method. Utilizing a more complex scoring system, Reneau et al. (2003) found somatic cell score (SCS) to be significantly affected by udder and lower rear leg hygiene scores with SCS increases of 0.13, 0.17 and 0.17

for each 1 standard deviation increase in Udder, Rear legs, or Udder-Rear Legs Composition, respectively ($P = 0.03$, $P < 0.01$, $P < 0.01$). This equated to a 40-50,000 cells/ml difference in herd SCC for each 1-unit increase or decrease in cow hygiene scores. In a more recent study, Sant'Anna and Paranhos da Costa (2011) compared the effect of hygiene on SCLS and found all body areas evaluated (leg, flank, abdomen, udder) to be significant ($P < 0.0001$; $P = 0.0008$; $P = 0.0008$; and $P = 0.0003$) respectively. UH score is also associated with bulk tank milk bacterial counts (Elmoslemany et al., 2010). Furthermore, a study in the Netherlands found 4 times more dry cows in herds with >30% of their udders covered in manure in high SCC herds compared to herds with BTSCC <150,000 cells/mL ($P < 0.05$; Barkema et al., 198). Udder hair management was documented as an influential component of UH as hair removal reduced the bacterial content around the udder and teat ends. A few studies have advocated clipping udder hair for the control of IMI and decreased SCC (Barkema et al., 1998; Elmoslemany et al., 2010; Dufour et al., 2011). Yet, a 10-month study by Silk et al. (2003) disputed that singeing udder hair had no effect on new IMI or bacterial counts in the milk or on the teat skin. Rodrigues et al. (2005) also demonstrated that frequency of hair removal is essential as low and medium BMSCC herds removed udder hair more frequently than high BMSCC herds ($P < 0.01$). Despite the dispute, the PMO dictated that milk should be harvested from clean udders, more specifically udders clipped or trimmed to facilitate ease of cleaning and prevent bacterial harboring that could interfere with providing a safe wholesome product.

2.4.6 Dry Cow Management Practices

Dry cow therapy (DCT) also commonly referred to has blanket dry cow treatment is defined as a prophylactic antibiotic treatment at the end of a cow's lactation. The goal of DCT is to reduce the prevalence of intramammary infections (IMI) by curing existing IMI at dry off and

reducing the new infection rate during the dry period (Eberhart, 1986) Barkema et al. (1998) demonstrated that DCT was practiced most frequently among herds with low BMSCC and the low BMSCC herds paid stricter attention to DCT. Scherpenzeel et al., (2014) evaluated the use of DCT across low SCC cows (<150,000 cells/mL for primiparous and <250,000 cells/mL for multiparous cows) and its effect on CM and SCC. Data concluded that quarters dried off without antibiotics were 3.7 times more likely to acquire CM than quarters dried off with antibiotics and that SCC and QSCC200 at calving and D14 were significantly higher in quarters dried off without antibiotics ($P < 0.01$). When IRCM was evaluated, quarters dried off without antibiotics were 1.7 times higher than in quarters dried off with antibiotics and this increased IRCM was significantly higher from dry-off through the first 100 d of lactation when compared to quarters treated with dry cow antibiotics (Scherpenzeel et al., 2014). Prior studies observed comparable findings. Hassan et al., (1999) showed that quarters dried off with antibiotics were 1.4 times less likely to have CM than quarters dried off without antibiotics. Schukken et al. (1993) illustrated a 2-fold increase in new IMI across major and minor pathogens in quarters dried off without antibiotics in herds with low BTSCC. If DCT was utilized, teat disinfection prior to (Hutton et al., 1990; Barnouin et al., 2004) and after (Barnouin et al., 2004) intramammary infusion was proven to be significant as well and characterized low SCC herds. Recently, with the heightened concern regarding antibiotic use and resistance, the use of selective dry cow therapy (SDCT) was considered. SDCT means not administering antibiotic to cows that had a low SCC at the last milk test day before drying off (Scherpenzeel et al., 2014). SDCT substantially reduced the amount of antibiotic use (85%) but Scherpenzeel et al., (2014) observed increased number of cases of CM and higher SCC in low-SCC cows when SDCT is implemented. This correlated with SCDT inadequacy of fulfilling the second objective of DCT, preventing new IMI. Dufour

et al. (2011) reported that SDCT is not consistently associated with lower SCC and administration of an approved intramammary antibiotic treatment to all cows at dry-off is still the best-supported recommendation to dairy producers. With that said, producers must weigh the decision of mastitis or antibiotic use when deciding on which method of DCT to adopt.

Considering the concern of antibiotic use, products such as teat sealants were developed to help producers minimize the impact of the dry period. Teat sealants supported DCT objectives and were proven to lower mastitis rates by forming an artificial barrier that blocks pathogens from entering the teat canal. Teat sealants are essential as all teat ends do not close as documented by Dingwell et al. (2003) who reported 50% and 23% of teat ends still open after 1 and 6wk of the dry period, respectively. Godden et al. (2003) observed a 30% reduction of new IMI and a 33% reduction in clinical mastitis cases between dry off and 60 days in milk (DIM) in quarters treated with DCT and an internal teat sealant at dry-off. Schewe et al. (2015) also demonstrated a reduction in BTSCC with use of internal teat sealants in a study evaluating 628 herds ($P < 0.016$). Additional studies also suggested the incorporation of coliform mastitis vaccinations at dry-off as their use were associated with a lower BTSCC ($P = 0.017$; Wenz et al., 2007).

2.4.7. Milking Consistency and Ejection

Consistent milking routines are a key aspect to milking parlor management as timing of the milking procedure must be monitored to achieve optimum stimulation and milk removal. When milking routines remained consistent, 305 d milk yield increased by 5.5% compared to herds who implemented a careless and inconsistent milking routine. Many are familiar with the role of oxytocin in milk letdown however, few realize that the process of milk letdown is more complex. Studies demonstrated that there are multiple factors that control the effectiveness of

oxytocin response and milk ejection (Mayer et al., 1984; Svennersten and Claesson, 1990). For instance, Lefcourt, (1982) identified a second milk letdown mechanism when measuring the effect of teat stimulation on sympathetic tone in the mammary gland. Bruckmaier and Blum, (1996) also demonstrated that the nervous systems had an active role in the rate of milk flow through the teat canal and proper nerve stimulation, a minimum of 12-15 seconds of teat contact time, is required to prompt ample oxytocin release and milk ejection response (Mein and Reid, 1996). With milk ejection two primary factors to monitor are Prep time (PT) and Prep-lag time (PLT). PT is defined as the time taken to manually clean and dry teat surfaces, particularly teat-ends while PLT is measured from the start of teat preparation to the attachment of the milking unit. Consistent milk let down and effective teat sanitation is normally achieved with a quality stimulus PT of 10 to 20 seconds. Reneau and Chastain (1995) determined that at least 20 s of stimulus and a total PLT of 60 s increased average flow rate and reduced unit on time when compared with no stimulation.

A proper pre-stimulation is essential to obtain continuous and rapid milk removal because without it milk let-down is delayed, and milk flow reduced. This phenomenon is known as bimodality. Both milking efficiency and udder health are negatively influenced by this gap between the flow of the milk stored in the cistern (at the beginning of the milking) and the flow of the milk from the alveolus (Bruckmaier et al., 1995; Bruckmaier and Blum, 1996; Dodenhoff et al., 1999). A recent analysis of greater than 2,400 milk-flow curves from 82 Italian Holstein-Friesian herds found that 35.1% of curves were bimodal which suggested improper milking routines (Sandrucci et al., 2007). Bimodality more commonly occurred in cows with greater peak milk flow rates (fast emptying of the udder cistern) and cows with bimodal milk curves were more susceptible to mastitis (Grindal and Hillerton, 1991) and tended to have increased SCS

(Dodenhoff et al., 1999; Sandrucci et al., 2007). Sandrucci et al., (2007) also discovered that the percentage of bimodal curves decreased with increasing attachment delay (PLT; $P < 0.05$) but as number of clusters per milker increased ($P < 0.01$) bimodality increased in all parlor types. To avoid the consequences of bimodality and achieve a continuous milk flow, an udder pre-stimulation of 20 to 90 s, depending on the degree of udder filling is necessary (Weiss and Bruckmaier, 2005). In addition, Rasmussen et al. (1992) reported an ideal prep-lag time of 1.3 (one minute and 18 s) following 20 to 30 s of pre-stimulation across both Holstein and Jersey cows for optimum milk yield. Turki and Winnicki (2001) concluded that PT did not influence milk yield, however it was affected significantly ($P \leq 0.05$) by PLT. Furthermore, a prep-lag time interval that is prolonged (>3 min) was shown to have detrimental effects on milk yield. To maximize milk harvested in the first two minutes (50-55% EML and 53-61% LL of milk), Watters et al. (2012) discovered that a PLT ≥60 s and <240 s for early to mid-lactation (EML) and ≥60 s for late lactation (LL) was significant ($P < 0.001$).

As the dairy industry consolidates and herd size increases, extra pressure is applied to maximizing cow throughput to get the most profitability out of the parlor. There is a fine line of too fast that compromises milking prep procedures, especially in the udder preparation phase creating a negative effect on milk quality. It's essential that owners and employees find that combination where cows are milked fast, gently and completely without affecting milk production, udder health and milk quality. Once that routine is established, proper training of employees and continuous monitoring and feedback is necessary to excel in successful parlor management and performance.

2.5. Employee Management and Training Practices

The structure change to the US dairy industry, with increased herd sizes generated a greater reliance on nonfamily labor and an increased responsibility of immigrant labor to perform critical tasks across the operations. This variability in employment practices and organization created a greater need for understanding dairy producer attitudes and beliefs regarding management and training practices, communication efforts and employee performance to continue to advance milk quality.

Reports from a national survey of 5,005 dairy farms concluded that 50% of the farms hired immigrant labor and 62% of the US milk supply came from dairy farms employing immigrant labor (Rosson et al., 2009). With the rise of immigrant labor, comes the cultural and communication barriers that complicated management on top of dairy owners who more than likely have limited human resource knowledge and management experience to professionally train employees (Stup et al., 2006). These barriers raised perceived conceptions that employees are not motivated to engage in success of meeting milk quality goals and poor protocol compliance. According to Wenz (2007) management often failed to provide the necessary resources to properly perform a task or failed to provide immediate feedback to workers which inadvertently enabled protocol drift. Across 12 Michigan dairies, Erskine (2015) discovered that 36% of employees did not know SCC goals for the farm and Spanish-speaking employees (41%) were less aware of herd SCC goals that English-speaking workers (87%, $P < 0.001$). Further data showed that employees primarily received milking protocol training from other employees or on their own (71%), versus being trained by an owner or manager. Milker training should be a top priority for a herd to have effective parlor management which was not noted by the survey results as only 14% of Latino workers were taught milking protocols by an owner or manager which was significantly less than English-speaking workers (42%, $P < 0.01$). In addition, 49%

of employees stated they received no mastitis control and management education, and only 16% received education on a regular basis. Obviously, this demonstrated a gap in education and training and more is needed to address employee turnover rates and the fact that many hired workers do not have previous dairy experience and they are being tasked with larger roles including milking, cow health, housing maintenance, and so on (Erskine et al., 2015). Therefore, the case was made that communication and training between owners and employees is essential to the prevention and control of mastitis in a herd.

A study by Barkema et al. (1998) is one of a few studies which correlated attitude and behavior with milk quality. Barkema categorized management styles as either "clean and accurate" (BMSCC <150,000 cells/mL) or "quick and dirty" (BMSCC 250-400,000 cells/mL) and found a significant association between BMSCC and management style. The herds classified as "clean and accurate" were characterized by a younger generation of owners with a higher level of education, who know their cows better and were more hygienically meticulous. The most prominent difference between the 74% of "clean and accurate" herds verses the 73% of "quick and dirty" herds was the fact that the former preferred to work precisely while the latter preferred to work quickly (Barkema et al., 1998). This was previously supported by Hutton et al., (1990) and Tarabla and Dodd, (1990) and more recently by Barnouin et al., (2004) and De Vliegher et al., (2004) who demonstrated the effect of herd manager attitudes on herd SCC. Tarabla and Dodd, (1990) showed that the management practices that impacted milk quality would be applied correctly if a positive attitude regarding animal and milking is present.

Milk quality is a multifactorial, continuous improvement process. Deming noted that in the quest for "continuous improvement," attitude is the key component as it is the greatest barrier to quality management. Within a herd the commitment to producing quality milk must be firm

and the consistent application of quality milk management practices must be enforced through the attitude reflected in management behavior to reduce variation, lower BMSCC and develop a "milk quality mind-set" (Reneau et al., 2002).

2.6 Housing Management and Cow Comfort

Cow comfort is a top priority for dairy producers. When cows are cool and comfortable, they spend more time lying down and chewing their cud, ultimately making more milk. However, this time spent lying increases a cow's chance of intramammary infection if housing is dirty. Teat ends are the primary target for potential mastitis pathogens as they become exposed to environmental bacteria through manure splatter with rapid cow movement, bedding material contaminants while lying and other environmental risk factors (Rendos et al., 1975; Schreiner and Ruegg, 2003; Zdanowicz et al., 2004; Ruegg, 2006; DeVries et al., 2012). Multiple studies demonstrated that bedding resources are the primary host for environmental pathogens and when cows are comfortable, they may lay for 12 to 14 h per day, substantially increasing their exposure to harmful mastitis pathogens (Tucker and Weary, 2004; Cook et al., 2005; Hogan and Smith, 2012). Therefore, it is essential that tasks involving selection of bedding material, manure removal and cleanliness of cow beds are performed consistently as they all have major influence on hygiene and control of environmental mastitis.

2.6.1 Bedding Management

Successful bedding management is a major contributing factor to reducing bacterial numbers on teat-ends (Bey, et al., 2002; Hogan et al., 1989, Zdanowicz, et al., 2004). There is ample evidence in the literature to show that multiple aspects of bedding management reduce mastitis rates. In general, organic bedding sources will host more bacterial growth as compared to inorganic sources (Fairchild et al., 1982; Janzen et al., 1982; Zdanowicz et al., 2004).

However, it is important to remember that pathogen growth can be supported by either type, once bedding material becomes soiled with urine and feces. Additional studies (Wenz et al., 2007; Dufour et al., 2011) demonstrated that mattresses and sand bedding for lactating cows and heifers were associated with lower BTSCC but sand bedding will worsen the exposure rates to Streptococci spp. and Klebsiella spp. Rowbotham and Ruegg, (2015) found that solids over foam-core mattress (SBMS) bedding carried the greatest bacteria load and that new sand (NS) had the lowest gram-negative bacterial population. In another study, it was proven that recycled manure bedding had the greatest bacterial counts and rates of new coliform IMI during the summer (Smith et al., 1985). Even with these results authors have stated that the relationship between bedding bacterial populations and IMI needs to be investigated further and under direct comparison as two other studies disputed these conclusions and found no effect between coliform bacterial numbers in bedding and coliform IMI (Natzke and LeClair, 1976; Fairchild et al., 1982). Dry cow housing facilities that were loose or free-stall were also associated with a lower BTSCC when compared to tie-stalls, stanchions, or outside housing facilities. Barkema, (1999) also showed that the installation of free-stall dividers reduced the risk of clinical E.coli mastitis by 1.3 times. Frequency of bedding application and removal of manure also significantly reduced IMI rates (Rowbotham and Ruegg, 2015). Rowbotham and Ruegg, (2015) herds reduced their bulk milk somatic cell score (BMSCS) by removing the organic bedding from the back one-third of the stall at least once a week and by increasing the number of times per week that new bedding was added to the stall. However, in the same study herds that utilized inorganic bedding it was found that the increased frequency of replacement bedding was associated with an increased BMSCS. This was associated with his findings that farms that utilized inorganic bedding were 1.8 times more likely to deep bed their stalls verses operations

using organic bedding or manure products. Recycled manure products may provide some economic opportunity to producers, but they do come at potential cost as they harbor greater bacteria counts than new inorganic bedding like sand (Rowbotham and Ruegg, 2015). Utilizing deep bedding increased cow comfort but added to the necessity of raking manure out of stalls. When manure is raked out of stalls, Schukken et al. (1991) demonstrated a 74% reduction in clinical coliform mastitis cases and bedding was dryer (76% versus 68% dry matter) in herds with BTSCC <283,000 cells/ml (Hutton et al., 1990). Another study demonstrated poor hygiene across herds with SCC > 250,000 cells/ml as these herds were associated with a greater percentage of stalls containing >10% manure (19% versus 12%), stalls were raked clean less often throughout the day (1.6 versus 2.2 times/day) and less bedding was applied in stalls (Ruegg, 2006).

2.6.2. Heat Stress Abatement

Across the United States, but particularly in the Southeastern United States, dairy producers must combat heat stress on their operations. Heat stress occurred when an animal's body temperature elevated above the thermoneutral zone (TNZ) and the body exceeded its the ability to abate heat (Dahl, 2018). A cow's ideal body temperature is around 38ºC and this is markedly influenced by the two primary heat stress parameters of elevated temperatures and relative humidity along with additional factors such as air and radiant temperature, and wind speed. The Temperature–Humidity index (THI) is the primary indicator used in the USA to assess heat stress and when this reading exceeds 68, the animal is heat stressed. Heat stress is a pivotal concern as it ultimately impacts a cow's production potential and it targets high producing cows the hardest because of their high feed intake levels. Cows that are cooled properly will produce 9 lb. more milk per day than non-cooled cows (Jones, 1999). Research

illustrated that temperature and humidity are related to mastitis infection, occurrence of clinical mastitis (CM), and increased milk SCC (Morse, 1988). Two additional studies indicated that cows housed in hot environments suffering from heat stress had increased risk of udder health implications such as higher rates of CM or increased SCC (Cook et al., 2002; Bertocchi et al., 2014). The economic implications of heat stress were documented to cost the US dairy industry between 0.8 to 1.5 million dollars annually (St-Pierre et al., 2003) Multiple side effects are associated with heat stress such as reduced dry matter intake, difficult births and underweight calves, increased metabolic disease, lower production, and higher incidence of laminitis (Jones, 1999). It is critical that dairy facilities utilize cooling systems (fans, sprinklers, misters, etc.), provide shade and water to keep cows cool because otherwise milk production and components are reduced due to elevated body core temperature. In addition, producers run the risk of elevated udder temperatures when lactating cattle are under heat stress which is associated with higher incidence rates of mastitis (Igono et al., 1988) and disease occurrence due to immunosuppression that occurs after rumination is inhibited (Temple et al., 2015). Regardless of location it is essential that producers maximize heat stress abatement across all areas of their operation to improve production, animal welfare, and milk quality.

2.7 Research Objective

An accumulation of studies has researched numerous management practices implemented across dairy operations and their associations with BTSCC and mastitis control. These results form the foundation of udder health recommendations by producers today. It is common knowledge that the SE United States is known to be the poorest region for milk quality with SCC continuing to be greater than national average. While other states in the SE have evaluated the effects of management practices on SCC, North Carolina has not. Therefore, the objective of

this project is to prioritize the management practices within a NC Dairy operation that have the greatest impact on milk quality and overall herd profitability.

2.8 References

Bach, A., N. Valls, A. Solans, and T. Torrent. "Associations between nondietary factors and dairy herd performance." *Journal of dairy science* 91, no. 8 (2008): 3259-3267.

Barbano, D. M., Y. Ma, and Marcos Veiga dos Santos. "Influence of raw milk quality on fluid milk shelf life." *Journal of dairy science* 89 (2006): E15-E19.

Barkema, H. W., Y. H. Schukken, T. J. G. M. Lam, M. L. Beiboer, G. Benedictus, and A. Brand. "Management practices associated with low, medium, and high somatic cell counts in bulk milk." *Journal of dairy science* 81, no. 7 (1998): 1917-1927.

Barkema, H. W., Y. H. Schukken, T. J. G. M. Lam, M. L. Beiboer, G. Benedictus, and A. Brand. "Management practices associated with the incidence rate of clinical mastitis." *Journal of dairy science* 82, no. 8 (1999): 1643-1654.

Barnouin, J., M. Chassagne, S. Bazin, and D. Boichard. "Management practices from questionnaire surveys in herds with very low somatic cell score through a national mastitis program in France." *Journal of dairy science* 87, no. 11 (2004): 3989-3999.

Baxter, James D., G. W. Rogers, S. B. Spencer, and R. J. Eberhart. "The effect of milking machine liner slip on new intramammary infections." *Journal of dairy science* 75, no. 4 (1992): 1015-1018

Beckley, M. S., and F. F. Smith. "Vacuum Stability in Pipeline Milker." In *Journal of Dairy* Science, vol. 45, no. 5, p. 700. 1111 N Dunlap Ave, Savoy, IL 61874: Amer Dairy Science Assoc., 1962.

Berry, D. P., J. M. Lee, K. A. Macdonald, K. Stafford, L. Matthews, and J. R. Roche. 2007c. Associations among body condition score, body weight, somatic cell count, and clinical mastitis in seasonally calving dairy cattle. J. Dairy Sci. 90:637.

Bertocchi, L., A. Vitali, N. Lacetera, A. Nardone, G. Varisco, and U. Bernabucci. "Seasonal variations in the composition of Holstein cow's milk and temperature–humidity index relationship." *Animal* 8, no. 4 (2014): 667-674.

Besier, J., O. Lind, and R. M. Bruckmaier. "Dynamics of teat-end vacuum during machine milking: types, causes and impacts on teat condition and udder health–a literature review." *Journal of applied animal research* 44, no. 1 (2016): 263-272.

Bewley, Jeffrey & Schutz, Michael. (2008). Review: An interdisciplinary review of body condition scoring for dairy cattle. The Professional Animal Scientist. 24. 507-529. 10.15232/S1080-7446(15)30901-3.

Bey, R., Jeffrey K. Reneau, and Ralph J. Farnsworth. "The role of bedding management in udder health." In *Annual Meeting-National Mastitis Council Incorporated*, vol. 41, pp. 45-55. National Mastitis Council; 1999, 2002.

Bicalho, Rodrigo C. "Lameness in dairy cattle: a debilitating disease or a disease of debilitated cattle." In *Western Dairy Management Conference*. 2011.

Blakely, C., G.M. Pighetti, P.D. Krawczell, R.A. Almeida, C.S. Petersson-Wolfe, K. Enger, J.M. Bewley, S. H. Ward, A. Stone, and S. P. Oliver. “Practices Surveyed in the Southeast USA that Impact Milk Quality.” *NMC Annual Meeting Proceedings*, (2016)

Blakely, Chandler Lauren Moats. "Relationship of observed parlor practices and producer attitudes with bulk tank somatic cell counts in the Southeast USA." (2017).

Boor, K. J., D. Brown, S. Murphy, S.M. Kozlowski, and D.K. Bandler. 1998. Microbiological and chemical quality of raw milk in New York State. *J. Dairy Sci.* 81:1743-1748.

Bramley, A. John, and Frank H. Dodd. "Reviews of the progress of dairy science: mastitis control–progress and prospects." *Journal of Dairy Research* 51, no. 3 (1984): 481-512.

Bray, D.R., and J.K. Shearer. 2012. Proper milking procedures. 1–2. Accessed March 24, 2020. https://edis.ifas.ufl.edu/pdffiles/DS/DS12900.pdf

Britt J.S. and R. Farnsworth. 1996. Here's a system for evaluating teat condition. Hoard's Dairyman, August 25: 570-571

Bruckmaier, R. M., E. Rothenanger, and J. W. Blum. "Milking characteristics in dairy cows of different breeds from different farms and during the course of lactation." *Journal of animal breeding and genetics* 112, no. 1-6 (1995): 293-302.

Bruckmaier, Rupert M., and Jürg W. Blum. "Simultaneous recording of oxytocin release, milk ejection and milk flow during milking of dairy cows with and without prestimulation." *Journal of Dairy Research* 63, no. 2 (1996): 201-208.

Butler, W. Ro, and R. Do Smith. "Interrelationships between energy balance and postpartum reproductive function in dairy cattle." *Journal of dairy science* 72, no. 3 (1989): 767-783.

Capuco, A. V., G. A. Mein, S. C. Nickerson, L. J. W. Jack, D. L. Wood, S. A. Bright, R. A. Aschenbrenner, R. H. Miller, and J. Bitman. "Influence of pulsationless milking on teat canal keratin and mastitis." *Journal of dairy science* 77, no. 1 (1994): 64-74.

Chambers, J. V. 2002. The microbiology of raw milk. Pages 39–90 in Dairy Microbiology Handbook. 3rd ed. R. K. Robinson, ed. John Wiley and Sons, New York, NY.

Chapinal, N., A. M. De Passille, D. M. Weary, M. A. G. Von Keyserlingk, and J. Rushen. "Using gait score, walking speed, and lying behavior to detect hoof lesions in dairy cows." *Journal of dairy science* 92, no. 9 (2009): 4365-4374.

Cicconi-Hogan, K. M., M. Gamroth, R. Richert, P. L. Ruegg, K. E. Stiglbauer, and Y. H. Schukken. "Associations of risk factors with somatic cell count in bulk tank milk on organic and conventional dairy farms in the United States." *Journal of Dairy Science* 96, no. 6 (2013): 3689-3702.

Coffey, M. P., G. Simm, J. D. Oldham, W. G. Hill, and S. Brotherstone. 2004. Genotype and diet effects on energy balance in the first three lactations of dairy cows. J. Dairy Sci. 87:4318.

Cook, N. B., T. B. Bennett, K. M. Emery, and K. V. Nordlund. "Monitoring nonlactating cow intramammary infection dynamics using DHI somatic cell count data." *Journal of dairy science* 85, no. 5 (2002): 1119-1126.

Cook, N. B., T. B. Bennett, and K. V. Nordlund. "Monitoring indices of cow comfort in free-stall-housed dairy herds." *Journal of dairy science* 88, no. 11 (2005): 3876-3885.

Cook, Nigel B., and Kenneth V. Nordlund. "The influence of the environment on dairy cow behavior, claw health and herd lameness dynamics." *The Veterinary Journal* 179, no. 3 (2009): 360-369.

Costello, M., M. S. Rhee, M. P. Bates, S. Clark, L. O. Luedecke, and D. H. Kang. 2003. Eleven-year trends of microbiological quality in bulk tank milk. Food Prot. Trends. 23:393–400

Dahl, Geoffrey E. "Impact and Mitigation of Heat Stress for Mastitis Control." *Veterinary Clinics: Food Animal Practice* 34, no. 3 (2018): 473-478.

Dairyman's Digest 2009. What you should know about somatic cells. Winter issue.

De Pinho Manzi, Marcela, Diego Borin Nóbrega, Patrícia Yoshida Faccioli, Marcella Zampolli Troncarelli, Benedito Donizete Menozzi, and Hélio Langoni. "Relationship between teat-end condition, udder cleanliness and bovine subclinical mastitis." *Research in veterinary science* 93, no. 1 (2012): 430-434.

De Vliegher, Sarne, Hans Laevens, H. W. Barkema, Ian R. Dohoo, H. Stryhn, Geert Opsomer, and Aart de Kruif. "Management practices and heifer characteristics associated with early lactation somatic cell count of Belgian dairy heifers." *Journal of Dairy Science* 87, no. 4 (2004): 937-947.

DeVries, T. J., M. G. Aarnoudse, H. W. Barkema, K. E. Leslie, and M. A. G. Von Keyserlingk. "Associations of dairy cow behavior, barn hygiene, cow hygiene, and risk of elevated somatic cell count." *Journal of dairy science* 95, no. 10 (2012): 5730-5739.

Dickrell, Jim. Milk Quality Pays, Dairy Herd Management. March 12, 2019 https://www.dairyherd.com/article/dickrells-diary-even-lower-premiums-milk-quality-pays

Dingwell, R. T., L. L. Timms, J. M. Sargeant, D. F. Kelton, Y. H. Schukken, and K. E. Leslie. "The association of teat canal closure and other risk factors for new dry period intramammary infections." In Annual Meeting-National Mastitis Council Incorporated, vol. 42, pp. 298-299. National Mastitis Council; 1999, 2003.

Dodenhoff, Jörg, Dorette Sprengel, Jürgen Duda, and Leo Dempfle. "Potential use of parameters of the milk flow curve for genetic evaluation of milkability." *Interbull Bulletin* 23 (1999): 131-131.

Dohoo, Ian R., and A. H. Meek. "Somatic cell counts in bovine milk." *The Canadian Veterinary Journal* 23, no. 4 (1982): 119.

Dong, Fengxia, David A. Hennessy, and Helen H. Jensen. "Factors determining milk quality and implications for production structure under somatic cell count standard modification." *Journal of dairy science* 95, no. 11 (2012): 6421-6435.

Donovan, David M., David E. Kerr, and Robert J. Wall. "Engineering disease resistant cattle." *Transgenic research* 14, no. 5 (2005): 563-567.

Dufour, S., A. Fréchette, H. W. Barkema, A. Mussell, and D. T. Scholl. "Invited review: Effect of udder health management practices on herd somatic cell count." *Journal of dairy science* 94, no. 2 (2011): 563-579.

Dyk, Paul Brian. "The association of prepartum non-esterified fatty acids and body condition with peripartum health problems on 95 Michigan dairy farms." (1995): 1469-1469.

Eberhart, R.J., H.C. Gilmore, L.J. Hutchinson, and S.B. Spencer. 1979. Somatic cell counts in DHI samples. Proc. Ann. Mtg. Natl. Mastitis Council., p. 32.

Eberhart, R. J., P. L. LeVan, Lester C. Griel Jr, and E. M. Kesler. "Germicidal teat dip in a herd with low prevalence of Streptococcus agalactiae and Staphylococcus aureus mastitis." *Journal of dairy science* 66, no. 6 (1983): 1390-1395.

Eberhart, R. J. "Management of dry cows to reduce mastitis." *Journal of Dairy Science* 69, no. 6 (1986): 1721-1732.

Elmoslemany, Ahmed Morsy, G. P. Keefe, I. R. Dohoo, J. J. Wichtel, H. Stryhn, and R. T. Dingwell. "The association between bulk tank milk analysis for raw milk quality and on-farm management practices." *Preventive veterinary medicine* 95, no. 1-2 (2010): 32-40.

Engel, K. L., 2016. Six requirements for clean milking equipment. *Progressive Dairymen*. GEA Farm Technologies.

Enger, B. D., L. K. Fox, J. M. Gay, and K. A. Johnson. "Reduction of teat skin mastitis pathogen loads: differences between strains, dips, and contact times." *Journal of dairy science* 98, no. 2 (2015): 1354-1361.

Erskine, R. J., and R. J. Eberhart. "Post-milking teat dip use in dairy herds with high or low somatic cell counts." *Journal of the American Veterinary Medical Association* 199, no. 12 (1991): 1734-1736.

Erskine, R. J., R. O. Martinez, and G. A. Contreras. "Cultural lag: a new challenge for mastitis control on dairy farms in the United States." *Journal of dairy science* 98, no. 11 (2015): 8240-8244.

Erskine, R.J., and R. Moore-Foster. “How is your Milking Efficiency? Part 2.” *Current, Quality Milk Tips*, November 13, 2018.

Espejo, L. A., Marcia I. Endres, and James A. Salfer. "Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota." *Journal of dairy science* 89, no. 8 (2006): 3052-3058.

Fabian, J., R. A. Laven, and H. R. Whay. "The prevalence of lameness on New Zealand dairy farms: A comparison of farmer estimate and locomotion scoring." *The Veterinary Journal* 201, no. 1 (2014): 31-38.

Fahr, R. D. "Influencing milk quality and composition: options and limits." *Arch Tierz* 45 (2002): 51-9.

Fairchild, T. P., B. J. McArthur, J. H. Moore, and W. E. Hylton. "Coliform counts in various bedding materials." *Journal of dairy science* 65, no. 6 (1982): 1029-1035.

Fan, Mengyuan, David M. Phinney, and Dennis R. Heldman. "Effectiveness of Rinse Water during In-Place Cleaning of Stainless Steel Pipe Lines." *Journal of food science* 80, no. 7 (2015): E1490-E1497.

Fenlon, D. R., D. N. Logue, J. Gunn, and J. Wilson. "A study of mastitis bacteria and herd management practices to identify their relationship to high somatic cell counts in bulk tank milk." *British Veterinary Journal* 151, no. 1 (1995): 17-25.

Ferguson, James D. "Implementation of a body condition scoring program in dairy herds." In *The Penn Annual Conference. Center for Animal Health and Productivity. University of Pennsylvania*. 1996.

FDA, Food and Drug Administration. 1991. Actions of the 1991 National Conference on Interstate Milk Shipments, August 22 memorandum from Milk Safety Branch. http://www.fda.gov/Food/FoodSafety/ProductSpecificInformation/MilkSafety/CodedMemoranda/MemorandaofConferenceActions/ucm07372 3.htm.

Fuhrmann, T. "Quality milk starts with quality management." In In Annual Meeting-National Mastitis Council Incorporated, vol. 41, pp. 131-139. National Mastitis Council; 1999, 2002.

Galton, D. M., L. G. Petersson, W. G. Merrill, D. K. Bandler, and D. E. Shuster. "Effects of premilking udder preparation on bacterial population, sediment, and iodine residue in milk." *Journal of dairy science* 67, no. 11 (1984): 2580-2589.

Galton, D. M., L. G. Petersson, and W. G. Merrill. "Effects of premilking udder preparation practices on bacterial counts in milk and on teats." *Journal of dairy science* 69, no. 1 (1986): 260-266.

Galton, D. M., L. G. Peterson, and W. G. Merrill. "Evaluation of udder preparations on intramammary infections." *Journal of Dairy Science* 71, no. 5 (1988): 1417-1421.

Garbarino, Eduardo Jose, J. A. Hernandez, J. K. Shearer, C. A. Risco, and W. W. Thatcher. "Effect of lameness on ovarian activity in postpartum Holstein cows." *Journal of dairy science* 87, no. 12 (2004): 4123-4131.

Garnsworthy, P. C. 2007. Body condition score in dairy cows: Targets for production and fertility, p. 61 in Recent Advances in Animal Nutrition 2006. P. C. Garnsworthy and J. Wiseman, ed. Univ. of Nottingham Press, Nottingham, UK.

Gearhart, M. A., C. R. Curtis, H. N. Erb, R. D. Smith, C. J. Sniffen, L. E. Chase, and M. D. Cooper. "Relationship of changes in condition score to cow health in Holsteins." *Journal of dairy science* 73, no. 11 (1990): 3132-3140.

Godden, S., P. Rapnicki, S. Stewart, J. Fetrow, A. Johnson, R. Bey, and R. Farnsworth. "Effectiveness of an internal teat seal in the prevention of new intramammary infections during the dry and early-lactation periods in dairy cows when used with a dry cow intramammary antibiotic." *Journal of Dairy Science* 86, no. 12 (2003): 3899-3911.

Goodger, W. J., T. Farver, J. Pelletier, P. Johnson, G. DeSnayer, and J. Galland. "The association of milking management practices with bulk tank somatic cell counts." *Preventive Veterinary Medicine* 15, no. 4 (1993): 235-251.

Gradle, C., and A. Dee. "A Comparison of Different Products for Sanitizing Dairy Cloths." In In Annual Meeting-National Mastitis Council Incorporated,, vol. 42, pp. 308-309. National Mastitis Council; 1999, 2003.

Green L.E., Borkert J., Monti G., Tadich N. Associations between lesion-specific lameness and the milk yield of 1635 dairy cows from seven herds in the Xth region of Chile and implications for management of lame dairy cows worldwide. Anim. Welf. 2010;19:419–427.

Grindal, Robert J., and J. Eric Hillerton. "Influence of milk flow rate on new intramammary infection in dairy cows." *Journal of Dairy Research* 58, no. 3 (1991): 263-268.

Hamann, J., G. A. Mein, and S. Wetzel. "Teat tissue reactions to milking: effects of vacuum level." *Journal of Dairy Science* 76, no. 4 (1993): 1040-1046.

Hamann, Jörn, and Graeme A. Mein. "Teat thickness changes may provide biological test for effective pulsation." *Journal of Dairy Research* 63, no. 2 (1996): 179-189.

Harmon, B. "Somatic cell counts: A primer." In *Annual Meeting-National Mastitis Council Incorporated*, vol. 40, pp. 3-9. National Mastitis Council; 1999, 2001.

Harmon, R. J. "Physiology of mastitis and factors affecting somatic cell counts." *Journal of dairy science* 77, no. 7 (1994): 2103-2112.

Haskell, M. J., L. J. Rennie, V. A. Bowell, M. J. Bell, and A. B. Lawrence. "Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows." *Journal of dairy science* 89, no. 11 (2006): 4259-4266.

Hassan, Latiffah, Hussni O. Mohammed, and Patrick L. McDonough. "Farm-management and milking practices associated with the presence of Listeria monocytogenes in New York state dairy herds." *Preventive veterinary medicine* 51, no. 1-2 (2001): 63-73.

Hassan, Z., R. C. W. Daniel, D. O'Boyle, and A. J. Frost. "Effects of dry cow intramammary therapy on quarter infections in the dry period." *Veterinary Record* 145, no. 22 (1999): 635-639.

Hayes, M. C., R. D. Ralyea, S. C. Murphy, N. R. Carey, J. M. Scarlett, and K. J. Boor. 2001. Identification and characterization of elevated microbial counts in bulk tank raw milk. J. Dairy Sci. 84:292–298

Hernandez, Jorge A., Eduardo J. Garbarino, Jan K. Shearer, Carlos A. Risco, and William W. Thatcher. "Comparison of the calving-to-conception interval in dairy cows with different degrees of lameness during the prebreeding postpartum period." *Journal of the American Veterinary Medical Association* 227, no. 8 (2005): 1284-1291.

Heuer, C., Y. H. Schukken, and P. Dobbelaar. "Postpartum body condition score and results from the first test day milk as predictors of disease, fertility, yield, and culling in commercial dairy herds." *Journal of dairy science* 82, no. 2 (1999): 295-304.

Hillerton, J.E. 2005. Do liners differ? Proc. 44th Annual Meeting of the National Mastitis Council, pp 133-138.

Hoedemaker, M., D. Prange, and Y. Gundelach. "Body condition change ante-and postpartum, health and reproductive performance in German Holstein cows." *Reproduction in domestic animals* 44, no. 2 (2009): 167-173.

Hogan, J. S., K. L. Smith, K. H. Hoblet, D. A. Todhunter, P. S. Schoenberger, W. D. Hueston, D. E. Pritchard et al. "Bacterial counts in bedding materials used on nine commercial dairies." *Journal of dairy science* 72, no. 1 (1989): 250-258.

Hogan, J. S., K. L. Smith, D. A. Todhunter, and P. S. Schoenberger. "Efficacy of a Barrier Teat Dip Containing. 55% Chlorhexidine for Prevention of Bovine Mastitis1." *Journal of dairy science* 78, no. 11 (1995): 2502-2506.

Hogan, Joe, and K. Larry Smith. "Managing environmental mastitis." *Veterinary Clinics: Food Animal Practice* 28, no. 2 (2012): 217-224.

Hutton, C. T., L. K. Fox, and D. D. Hancock. "Mastitis control practices: differences between herds with high and low milk somatic cell counts." *Journal of Dairy Science* 73, no. 4 (1990): 1135-1143.

Igono, M.O., H.D. Johnson, B.J. Steevens, W.A. Hainen and M.D. Shanklin, 1988. Effect of season on milk temperature, milk growth hormone, prolactin and somatic cell counts of lactating cattle. Int. J. Biometeorol., 32: 194-200.

Jago, J. G., J. L. Burke, and J. H. Williamson. "Effect of automatic cluster remover settings on production, udder health, and milking duration." *Journal of dairy science* 93, no. 6 (2010): 2541-2549.

Janzen, J. J., J. R. Bishop, A. B. Bodine, C. A. Caldwell, and D. W. Johnson. "Composted dairy waste solids and crushed limestone as bedding in free stalls." *Journal of Dairy Science* 65, no. 6 (1982): 1025-1028.

Jarrett, James A. "Environmental effects on mastitis and milk quality." *The Veterinary clinics of North America. Large animal practice* 6, no. 2 (1984): 371-375.

Jayarao, B.M., S.R. Pillai, A.A. Sawant, D.R. Wolfgang, and N.V. Hegde. 2004. Guidelines for monitoring bulk tank milk somatic cell and bacterial counts. *J. Dairy Sci.* 87:3561-73.

Jones, Gerald Murray. "The role of milking equipment in mastitis." (1999).

Kawai, K., S. Kurosawa, and H. Nagahata. " Evaluation of Dairy Management Practices on Japanese Dairy Farms; Relationships to Bulk Tank SCC and Individual Linear Scores." SCORES." *NMC Annual Meeting Proceedings pp 285-286* (2005).

Kirkpatrick, Mark. "A Numbers Game: Impact of Mastitis and High SCC"", *Zoetis Dairy Wellness;* December 21, 2018. https://www.dairywellness.com/authors/mark-kirkpatrick/2018/a-numbers-game-impact-of-mastitis-and-high-scc.aspx#.XqMpWshKhPY

Koeck, Astrid, Filippo Miglior, David F. Kelton, and Flavio S. Schenkel. "Genetic association of body condition score with disease resistance in first lactation Canadian Holsteins." *Canadian Journal of Animal Science* 92, no. 3 (2011a): 285-289.

Kossaibati M.A., Esslemont R.J. The costs of production diseases in dairy herds in England. Vet. J. 1997;154:41–51. doi: 10.1016/S1090-0233(05)80007-3.

Laevens, H., H. Deluyker, Y.H. Schukken, L. de Meulemeester, R. Vandermeersch, E. de Muelenaere, and A. de Kruif. 1997. Influence of parity and stage of lactation on somatic cell count in bacteriologically negative dairy cows. J. Dairy Sci. 80:3219.

Lassen, J., M. Hansen, M. K. Sorensen, G. P. Aamand, L. G. Christensen, and P. Madsen. 2003b. Genetic relationship between body condition score, dairy character, mastitis, and diseases other than mastitis in first-parity Danish Holstein cows. J. Dairy Sci. 86:3730.

Lefcourt, Alan. "Effect of teat stimulation on sympathetic tone in bovine mammary gland." *Journal of dairy science* 65, no. 12 (1982): 2317-2322.

Loker, S., F. Miglior, A. Koeck, TF-O. Neuenschwander, Catherine Bastin, J. Jamrozik, L. R. Schaeffer, and D. Kelton. "Relationship between body condition score and health traits in first-lactation Canadian Holsteins." *Journal of dairy science* 95, no. 11 (2012): 6770-6780.

Lormore M. 2018. *What Drives Financial Success on a Dairy?* Parsippany, NJ: Zoetis

Lormore, Michael. "Somatic Cell Count Impacts Everything." Zoetis Dairy Wellness. September 16, 2018. https://www.dairywellness.com/authors/mike-lormore/2018/somatic-cell-count-impacts-everything.aspx#.XKc0zShKhPY

Ma, Yinqing, C. Ryan, D. M. Barbano, D. M. Galton, M. A. Rudan, and K. J. Boor. "Effects of Somatic Cell Count on Quality and Shelf-Life of Pasteurized Fluid Milk1." *Journal of dairy science* 83, no. 2 (2000): 264-274.

Magliaro, A. L., and R. S. Kensinger. "Automatic cluster remover setting affects milk yield and machine-on time in dairy cows." *Journal of dairy science* 88, no. 1 (2005): 148-153.

Mahle, D. E., D. M. Galton, and R. W. Adkinson. "Effects of vacuum and pulsation ratio on udder health." *Journal of Dairy Science* 65, no. 7 (1982): 1252-1257.

Mayer, H., D. Schams, H. Worstorff, and A. Prokopp. "Secretion of oxytocin and milk removal as affected by milking cows with and without manual stimulation." *Journal of Endocrinology* 103, no. 3 (1984): 355-361.

McDonald, J. S., and D. A. Witzel. "Vacuum fluctuation at the teat end during mechanical milking." *Journal of Dairy Science* 51, no. 4 (1968): 543-548.

Mein, Graeme A. "The role of the milking machine in mastitis control." *Veterinary Clinics: Food Animal Practice* 28, no. 2 (2012): 307-320.

Mein, G. A., and D. A. Reid. "Milking-time tests and guidelines for milking units." In *National Mastitis Council (US). Meeting (USA)*. 1996.

Mein, G. A., F. Neijenhuis, W. F. Morgan, D. J. Reinemann, J. E. Hillerton, J. R. Baines, I. Ohnstad et al. "Evaluation of bovine teat condition in commercial dairy herds: 1. Non-infectious factors." In *Proceedings of the 2nd International symposium on mastitis and milk quality*, pp. 347-351. 2001.

Mein, G. A., and D. M. Williams. "Liner massage and teat condition." In *Annual meeting-National Mastitis Council, Inc (USA)*. 1984.

Mein, G., David MD Williams, and Douglas J. Reinemann. "Effects of milking on teat-end hyperkeratosis: 1. Mechanical forces applied by the teatcup liner and responses of the teat." In *Annual Meeting-National Mastitis Council Incorporated*, vol. 42, pp. 114-123. National Mastitis Council; 1999, 2003.

Mein, G., D. Reinemann, N. Schuring, and I. Ohnstad. "R-MM-1: Milking machines and mastitis risk–A storm in a teatcup." In *Proceedings of the National Mastitis Council Annual Meeting*, pp. 176-188. 2004.

Mein, Graeme A., Murray R. Brown, and David M. Williams. "Effects on mastitis of overmilking in conjunction with pulsation failure." *Journal of Dairy Research* 53, no. 1 (1986): 17-22.

Melendez, P., J. Bartolome, L. F. Archbald, and A. Donovan. "The association between lameness, ovarian cysts and fertility in lactating dairy cows." *Theriogenology* 59, no. 3-4 (2003): 927-937.

Morse, D., M. A. DeLorenzo, C. J. Wilcox, Robert J. Collier, R. P. Natzke, and D. R. Bray. "Climatic effects on occurrence of clinical mastitis." *Journal of dairy science* 71, no. 3 (1988): 848-853.

Moxley, J. E., B. W. Kennedy, B. R. Downey, and J. S. T. Bowman. "Survey of milking hygiene practices and their relationships to somatic cell counts and milk production." *Journal of Dairy Science* 61, no. 11 (1978): 1637-1644.

Murphy, S. C., and K. J. Boor. 2000. Trouble-shooting sources and causes of high bacteria counts in raw milk. Dairy Food Environ. Sanitation 20:606–611

Natzke, R. P., and Barbara J. LeClair. "Coliform contaminated bedding and new infections." *Journal of dairy science* 59, no. 12 (1976): 2152-2154.

Natzke, R. P., R. W. Everett, and D. R. Bray. "Effect of overmilking on udder health." *Journal of Dairy Science* 65, no. 1 (1982): 117-125.

Neave, F. K., F. H. Dodd, R. G. Kingwill, and D. R. Westgarth. "Control of mastitis in the dairy herd by hygiene and management." *Journal of dairy science* 52, no. 5 (1969): 696-707.

Neijenhuis, F. 1998. Teat end callosity classification system. Proc. 4th Intl. Dairy Housing Conference, American Society of Agricultural Engineers, St Louis, MO, USA. pp117-123.

Neijenhuis, Francesca. *Teat condition in dairy cows*. Utrecht University, 2004.

Neijenhuis, F., K.C. de Koning, G. Klungel, H.W. Barkema, and H. Hogeveen. 2000b. The effects of machine milking on teat condition. 51th Meeting European Association Animal Production (EAAP), The Hague, The Netherlands.

Neijenhuis, F., H.W. Barkema, H. Hogeveen, and J.P.T.M. Noordhuizen. 2001. Relationship between teat end callosity and incidence of clinical mastitis. in prep.

Neuenschwander, T. F. O. "Studies on disease resistance based on producer-recorded data in Canadian Holsteins." PhD diss., PhD Thesis. University of Guelph, Guelph, ON, Canada, 2010.

Nickerson, S. C., J. L. Watts, R. L. Boddie, and J. W. Pankey. "Evaluation of. 5% and 1% iodophor teat dips on commercial dairies." *Journal of dairy science* 69, no. 6 (1986): 1693-1698

Norman, H., Guinan, F., Walton, L. and Durr, J., 2020. *Somatic Cell Counts Of Milk From DHI Herds*. [online] Queries.uscdcb.com. Available at: <https://queries.uscdcb.com/publish/dhi/current/sccx.html> [Accessed 24 March 2020].

Nyhan, J. F. "The effect of vacuum fluctuation on udder disease." In *Proceedings of the Symposium on Machine Milking*, pp. 71-82. NIRD Reading, 1968.

Nyhan, J. F., and M. J. Cowhig. "Inadequate milking machine vacuum reserve and mastitis." *The Veterinary record* 81, no. 5 (1967): 122-124.

Ohnstad, I., G. A. Mein, J. R. Baines, Morten Dam Rasmussen, R. Farnsworth, B. Pocknee, T. C. Hemling, and J. E. Hillerton. "Addressing teat condition problems." In *Proceedings of the National Mastitis Council 46th Annual Meeting, San Antonio, Texas, USA*, pp. 188-189. 2007.

Ohnstad, Ian C., David Donaldson, Colin Kingston, Richard Hiley, and Brian R. Pocknee. "Effectiveness of teat coverage with post milking teat disinfectant applied with a dip cup." In *Proceedings of the British Mastitis Conference, Worcester*. 2018.

Olechnowicz, J., and J. M. Jaskowski. "Behaviour of lame cows: a review." *Veterinarni Medicina* 56, no. 12 (2011): 581-588.

Olechnowicz, Jan, and Jedrzej M. Jaskowski. "Impact of clinical lameness, calving season, parity, and month of lactation on milk, fat, protein, and lactose yields during early lactation of dairy cows." *Bull Vet Inst Pulawy* 54, no. 4 (2010): 605-10.

O'Reilly, K. M., M. J. Green, E. J. Peeler, J. L. Fitzpatrick, and L. E. Green. "Investigation of risk factors for clinical mastitis in British dairy herds with bulk milk somatic cell counts less than 150,000 cells/ml." *Veterinary Record* 158, no. 19 (2006): 649-653.

O'Shea, J., E. O'Callaghan, and W. J. Meaney. "Relationship between machine milking and the incidence of mastitis in dairy cows." *Irish Journal of Agricultural Research* (1979): 225-235.

O'Shea, J., E. O'Callaghan, and W. J. Meaney. "Effect of machine milking on new mastitis infections." *Irish Journal of Agricultural Research* (1984): 155-171.

O'shea, J. "Machine milking factors affecting mastitis. A literature review." *International Dairy Federation* (1987).

Oliver, S. P. "Best Management Practices to Improve Milk Quality." In *Southeast Dairy Herd Management Conference*, p. 46. 2008.

Oliver, S. P. "How milk quality is assessed." *URL: www. extension. org/pages/21197/how-milk-quality-is-assessed#. VeQ51_lzS2F* (2010).

Oliver, S. P., S. H. King, M. J. Lewis, P. M. Torre, K. R. Matthews, and H. H. Dowlen. "Efficacy of chlorhexidine as a postmilking teat disinfectant for the prevention of bovine mastitis during lactation." *Journal of dairy science* 73, no. 8 (1990): 2230-2235.

Oliver, S. P., M. J. Lewis, S. H. King, B. E. Gillespie, T. Ingle, K. R. Matthews, H. H. Dowlen, P. A. Drechsler, E. E. Wildman, and J. W. Pankey. "Efficacy of a low concentration iodine postmilking teat disinfectant against contagious and environmental mastitis pathogens in two dairy herds." *Journal of food protection* 54, no. 9 (1991): 737-742.

Olney, George R., and Robert K. Mitchell. "Effect of milking machine factors on the somatic cell count of milk from cows free of intramammary infection: II. Vacuum level and overmilking." *Journal of Dairy Research* 50, no. 2 (1983): 141-148.

Pankey, J. W. "Postmilking teat antisepsis [Dairy cows, mastitis-causing organisms]." *The veterinary clinics of North America* (1984).

Pankey, J. W., R. L. Boddie, and S. C. Nickerson. "Efficacy evaluation of two new teat dip formulations under experimental challenge." *Journal of dairy science* 68, no. 2 (1985): 462-465.

Pankey, J. W. "Premilking udder hygiene." *Journal of dairy science* 72, no. 5 (1989): 1308-1312.

Pankey, J. W., E. E. Wildman, P. A. Drechsler, and J. S. Hogan. "Field trial evaluation of premilking teat disinfection." *Journal of Dairy Science* 70, no. 4 (1987): 867-872.

Patton, Stuart. "Milk : its remarkable contribution to human health and well-being." *Transaction Publishers, NJ, 2004*

Peeler, E. J., M. J. Green, J. L. Fitzpatrick, K. L. Morgan, and L. E. Green. "Risk factors associated with clinical mastitis in low somatic cell count British dairy herds." *Journal of dairy science* 83, no. 11 (2000): 2464-2472.

Perkins, B. L., R. D. Smith, and C. J. Sniffen. "Troubleshooting your herd with the body condition scoring system." *Cornell Coop. Ext. Dairy Manage. Fact Sheet 151. Cornell Univ., Ithaca, NY* (1985).

Peters, R. R., S. Komaragiri, M. J. Paape, and L. W. Douglass. "Evaluation of 1.6% phenol as a premilking and postmilking teat dip in preventing new bovine intramammary infections." *Journal of dairy science* 83, no. 8 (2000): 1750-1757.

Philpot, W. N. 1979. Control of mastitis by hygiene and therapy. J Dairy Sci 62:168-176.

PMO, Grade. "A" pasteurized milk ordinance." *US Department of Health and Human Services, Public Health Service* (2009).

Quirk, T., L. K. Fox, D. D. Hancock, J. Capper, J. Wenz, and J. Park. "Intramammary infections and teat canal colonization with coagulase-negative staphylococci after postmilking teat disinfection: Species-specific responses." *Journal of dairy science* 95, no. 4 (2012): 1906-1912.

Räber, Marta, Ch J. Lischer, Hans Geyer, and Pete Ossent. "The bovine digital cushion–a descriptive anatomical study." *The veterinary journal* 167, no. 3 (2004): 258-264.

Rasmussen, M.D., Influence of Switch Level of Automatic Cluster Removers on Milking Performance and Udder Health. J. Dairy Res. 60:287-297; 1993

Rasmussen, Morten Dam, Erik Skovsted Frimer, D. M. Galton, and L. G. Petersson. "The influence of premilking teat preparation and attachment delay on milk yield and milking performance." *Journal of dairy science* 75, no. 8 (1992): 2131-2141.

Rasmussen, Morten Dam, and Niels Peder Madsen. "Effects of milkline vacuum, pulsator airline vacuum, and cluster weight on milk yield, teat condition, and udder health." *Journal of Dairy Science* 83, no. 1 (2000): 77-84.

Rasmussen, Morten Dam. "Benefits from early removal of the milking unit." In *Proc. Brit. Conf. on Mastitis, Stoneleigh, UK*, pp. 55-61. 1999.

Rasmussen, Morten Dam. "A review of milking preparation: the science." In *Annual Meeting of the National Mastitis Council*, pp. 104-110. 2000.

Rasmussen, Morten Dam, Lars Wiking, Martin Bjerring, and H. C. Larsen. "Influence of air intake on the concentration of free fatty acids and vacuum fluctuations during automatic milking." *Journal of Dairy Science* 89, no. 12 (2006): 4596-4605.

Reid, D. A., and S. Stewart. "effects on parlor performance by variations of detacher settings." In *Annual meeting*. 1997.

Reinemann, Douglas J. "The history of vacuum regulation technology." In *Proceedings of the 44th Annual meeting of the National Mastitis Council*, pp. 17-27. 2005.

Reinemann, D., Graeme A. Mein, and M. Johnson. "Milking Machine Research: Past, Present, and Future." In *Annual Meeting-National Mastitis Council Incorporated,*, vol. 42, pp. 110-113. National Mastitis Council; 1999, 2003.

Reinemann, Douglas J., Misty A. Davis, Debora Costa, and Ana Carolina Rodriguez. "Effects of milking vacuum on milking performance and teat condition." In *Proceedings of the AABP-National Mastitis Council Symposium, International Symposium on Mastitis and Milk Quality, Vancouver, BC, Canada*, pp. 13-15. 2001a.

Reitsma, S. Y., E. J. Cant, R. J. Grindal, D. R. Westgarth, and A. J. Bramley. "Effect of duration of teat cup liner closure per pulsation cycle on bovine mastitis." *Journal of Dairy Science* 64, no. 11 (1981): 2240-2245.

Rendos, J. J., R. J. Eberhart, and E. M. Kesler. "Microbial populations of teat ends of dairy cows, and bedding materials." *Journal of Dairy Science* 58, no. 10 (1975): 1492-1500.

Reneau, J. K. "Prepping cows: who needs it." In *Proceedings NMC 40th annual meeting*, vol. 40, pp. 33-42. 2001.

Reneau, Jeffrey K., Anthony J. Seykora, Bradley J. Heins, Russell F. Bey, and Ralph J. Farnsworth. "Relationship of cow hygiene scores and SCC." In *Annual Meeting-National Mastitis Council Incorporated,* vol. 42, pp. 362-363. National Mastitis Council; 1999, 2003.

Reneau, J.K., A.J. Seykora, B.J. Heins, M.I. Endres, R.J. Farnsworth and R.F. Bey. 2005. Association between hygiene scores and somatic cell scores in dairy cattle. JAVMA 227: 1297-1301.

Reneau, J. K., and J. P. Chastain. "Premilking cow prep: adapting to your system." In *Proc. Regional Meeting of the Natl. Mastitis Council*, p. 46. 1995.

Reneau, J. K., Y. H. Schukken, D. J. Wilson, and H. W. Barkema. "Best management practices to lower herd scc." National mastitis council annual meeting proceedings, 2002.

Robinson, P. H., and S. T. Juarez. "Locomotion scoring your cows: use and interpretation." *Abgerufen am* 5, no. 09 (2003): 2013.

Roche, J. R., P. G. Dillon, C. R. Stockdale, L. H. Baumgard, and M. J. VanBaale. "Relationships among international body condition scoring systems." *Journal of dairy science* 87, no. 9 (2004): 3076-3079.

Roche, John R., Nicolas Charles Friggens, Jane K. Kay, Mark W. Fisher, Kevin J. Stafford, and Donagh P. Berry. "Invited review: Body condition score and its association with dairy cow productivity, health, and welfare." *Journal of dairy science* 92, no. 12 (2009): 5769-5801.

Rodrigues, A. C. O., D. Z. Caraviello, and P. L. Ruegg. "Management of Wisconsin dairy herds enrolled in milk quality teams." *Journal of Dairy Science* 88, no. 7 (2005): 2660-2671.

Ronk, Eric. “Economics of Dairy Cattle Hoof Health.” UW-Extension Dairy Team *Walking Strong, Spring 2016*

Rosson, Parr, F. Adcock, D. Susanto, and D. Anderson. "The economic impacts of immigration on US dairy farms." *AgriLife Research, Texas A&M System. Prepared Under Contract for National Milk Producers Federation. Arlington, VA* (2009).

Rowbotham, R. F., and P. L. Ruegg. "Association of bedding types with management practices and indicators of milk quality on larger Wisconsin dairy farms." *Journal of dairy science* 98, no. 11 (2015): 7865-7885.

Rowe, S. M., S. M. Godden, E. Royster, J. Timmerman, and M. Boyle. " Investigation of the Relationship Between Udder Towel Hygiene, Udder Towel Management and Intramammary Infection in Late-lactation Dairy Cows." In *Annual Meeting- National Mastitis Council Incorporated,* vol. 58, pp.153-154. (2019).

Ruegg, P. "Premiums, production and pails of discarded milk how much money does mastitis cost you." *Resources Milk Money* 3 (2005): 50-56.

Ruegg, Pamela L. "The role of hygiene in efficient milking." In *Western Canadian Dairy Seminar (WCDS): Adv. Dairy Tech.*, vol. 18, pp. 285-293. 2006.

Ruegg, P. L., and R. L. Milton. "Body Condition Scores of Holstein Cows on Prince Edward Island, Canada: Relationships with Yield, Reproductive Performance, and Disease1." *Journal of dairy science* 78, no. 3 (1995): 552-564.

Sandrucci, A., A. Tamburini, L. Bava, and M. Zucali. "Factors affecting milk flow traits in dairy cows: results of a field study." *Journal of dairy science* 90, no. 3 (2007): 1159-1167.

Sant'Anna, A. C., and MJR Paranhos da Costa. "The relationship between dairy cow hygiene and somatic cell count in milk." *Journal of dairy science* 94, no. 8 (2011): 3835-3844

Scherpenzeel, C. G. M., I. E. M. Den Uijl, Gerdien van Schaik, RGM Olde Riekerink, J. M. Keurentjes, and T. J. G. M. Lam. "Evaluation of the use of dry cow antibiotics in low somatic cell count cows." *Journal of Dairy Science* 97, no. 6 (2014): 3606-3614.

Schewe, R. L., J. Kayitsinga, G. A. Contreras, C. Odom, W. A. Coats, P. Durst, Ernest Peter Hovingh et al. "Herd management and social variables associated with bulk tank somatic cell count in dairy herds in the eastern United States." *Journal of dairy science* 98, no. 11 (2015): 7650-7665.

Schreiner, D. A., and P. L. Ruegg. "Relationship between udder and leg hygiene scores and subclinical mastitis." *Journal of dairy science* 86, no. 11 (2003): 3460-3465.

Schukken, Y. H., F. J. Grommers, D. Van de Geer, H. N. Erb, and A. Brand. "Risk factors for clinical mastitis in herds with a low bulk milk somatic cell count. 2. Risk factors for Escherichia coli and Staphylococcus aureus." *Journal of Dairy Science* 74, no. 3 (1991): 826-832.

Schukken, Y. H., J. Vanvliet, D. Vandegeer, and F. J. Grommers. "A randomized blind trial on dry cow antibiotic infusion in a low somatic cell count herd." *Journal of Dairy Science* 76, no. 10 (1993): 2925-2930.

Schukken, Ynte H., Lennart G. Petersson, and Bradley J. Rauch. "Liners and teat end health." In *National Mastitis Council Annual Meeting Proceedings*, vol. 45, pp. 183-196. 2006.

Sharma, Neelesh, N. K. Singh, and M. S. Bhadwal. "Relationship of somatic cell count and mastitis: An overview." *Asian-Australasian Journal of Animal Sciences* 24, no. 3 (2011): 429-438.

Shearn, M.F.H. and J.E. Hillerton. 1996. Hyperkeratosis of the teat duct orifice in the dairy cow. J Dairy Res. 63:525-532

Sieber, R. L., and Ralph J. Farnsworth. "Differential diagnosis of bovine teat lesions." *The Veterinary clinics of North America. Large animal practice* 6, no. 2 (1984): 313-321.

Silk, A. S., L. K. Fox, and D. D. Hancock. "Removal of hair surrounding the teat and associated bacterial counts on teat skin surface, in milk, and intramammary infections." *Journal of Veterinary Medicine, Series B* 50, no. 9 (2003): 447-450

Singh, S. S., W. R. Ward, and R. D. Murray. "Aetiology and pathogenesis of sole lesions causing lameness in cattle: a review." *Vet. Bull* 63, no. 4 (1993): 7-9.

Smith, K. L., D. A. Todhunter, and P. S. Schoenberger. "Symposium: Environmental effects on cow health and performance." *J. Dairy Sci* 68 (1985): 1531-1553.

Smith, J. F., D. V. Armstrong, M. J. Gamroth, and J. Harner III. "Factors affecting milking parlor efficiency and operator walking distance." *Applied Engineering in Agriculture* 14, no. 6 (1998): 643-647.

Socha, Michael T., Dana J. Tomlinson, and T. L. Ward. "Using Locomotion Scoring to put Together a Program to Reduce Lameness on the Dairy." In *Proceedings*, p. 45. Utah State University, 2006.

Sogstad A.M., Osteras O., Fjeldaas T. Bovine claw and limb disorders related to reproductive performance and production diseases. J. Dairy Sci. 2006;89:2519–2528.

Spencer, Stephen B. "Recent research and developments in machine milking—a review." *Journal of Dairy Science* 72, no. 7 (1989): 1907-1917.

Sprecher, D. J., D. E. Hostetler, and J. B. Kaneene. "A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance." *Theriogenology* 47, no. 6 (1997): 1179-1187.

Stanley, D. E., E. M. Kesler, and A. L. Bortree. "Effect of a fluctuating milking vacuum on certain measures of udder health." *Journal of Dairy Science* 45, no. 11 (1962): 1343-1347.

Stewart, S., R. Farnsworth, G. Mein, D. A. Reid, A. P. Johnson, G. Beehler, and J. Paasch. "Field measurement of vacuum levels using a portable liquid flow simulator." In *National Mastitis Council (US). Meeting (USA)*. 1996.

Stewart, S., S. Godden, P. Rapnicki, D. Reid, A. Johnson, and S. Eicker. "Effects of automatic cluster remover settings on average milking duration, milk flow, and milk yield." *Journal of Dairy Science* 85, no. 4 (2002): 818-823.

Stewart, S., Steven W. Eicker, David A. Reid, and G. A. Mein. "Using computerized data to find time for milk quality." In *Annual Meeting-National Mastitis Council Incorporated,* vol. 38, pp. 116-122. National Mastitis Council., 1999.

St-Pierre, N.R., B. Cobanov and G. Schnitkey, 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci., 86: E52-E77.

Stup, R. E., Jeffrey Hyde, and L. A. Holden. "Relationships between selected human resource management practices and dairy farm performance." *Journal of dairy science* 89, no. 3 (2006): 1116-1120.

Svennersten, Kerstin, Carl Olof Claesson, and Lennart Nelson. "Effect of local stimulation of one quarter on milk production and milk components." *Journal of dairy science* 73, no. 4 (1990): 970-974.

Tarabla, H. D., and K. Dodd. "Associations between farmers' personal characteristics, management practices and farm performance." *British Veterinary Journal* 146, no. 2 (1990): 157-164.

Temple, D., F. Bargo, E. Mainau, I. Ipharraguerre and X. Manteca, 2015. Heat stress and efficiency in dairy milk production: A practical approach. The Farm Animal Welfare Fact Sheet No. 12, Farm Animal Welfare Education Centre. http://www.fawec.org/media/com_lazypdf/pdf/fs12-en.pdf.

Thiel, C. C. "Mechanics of the action of the milking machine cluster." *Bienn Rev Natl Inst Res Dairy* (1974).

Thomas, C. V., D. R. Bray, and M. A. DeLorenzo. "Evaluation of 50: 50 and 70: 30 pulsation ratios in a large commercial dairy herd." *Journal of dairy science* 76, no. 5 (1993): 1298-1304.

Timms, L. L., M. J. der Maaten Van, Jr ME Kehrli, and M. R. Ackermann. "Histologic features and results of virus isolation tests of tissues obtained from teat lesions that developed in dairy cattle during winter." *Journal of the American Veterinary Medical Association* 213, no. 6 (1998): 862-865.

Tucker, C. B., and D. M. Weary. "Bedding on geotextile mattresses: How much is needed to improve cow comfort?." *Journal of dairy science* 87, no. 9 (2004): 2889-2895.

Turki, H., and S. Winnicki. "Milking variables in relation to teats preparation and unit attachment delay in cows." *ICAR Technical Series* 7 (2001): 89-95.

Upton, John, J. F. Penry, Morten Dam Rasmussen, P. D. Thompson, and D. J. Reinemann. "Effect of pulsation rest phase duration on teat end congestion." *Journal of dairy science* 99, no. 5 (2016): 3958-3965.

USDA, National Agricultural Statistics Service (NASS). 2010. Wisconsin Dairy Producer Survey 2010. Accessed May 7, 2013. http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/Dairy_OP_Release_10.pdf

USDA (United States Department of Agriculture). September 2016, Report II. National Animal Health Monitoring System: Dairy 2014 Milk Quality, Milking Procedures, and Mastitis on U.S. Dairies, 2014. USDA Animal Plant and Health Inspection Service, Washington, DC

Van Straten, M., I. Siani, and D. Bar. "Reduced test-day milk fat percentage in cows diagnosed with claw horn lesions during routine claw trimming." *Journal of dairy science* 94, no. 4 (2011): 1858-1863.

Von Keyserlingk, Marina AG, A. Barrientos, K. Ito, E. Galo, and Daniel M. Weary. "Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows." *Journal of Dairy Science* 95, no. 12 (2012): 7399-7408.

Wagner, A. M., and P. L. Ruegg. "The effect of manual forestripping on milking performance of Holstein dairy cows." *Journal of dairy science* 85, no. 4 (2002): 804-809.

Walker, S. L., R. F. Smith, J. E. Routly, D. N. Jones, M. J. Morris, and H. Dobson. "Lameness, activity time-budgets, and estrus expression in dairy cattle." *Journal of dairy science* 91, no. 12 (2008): 4552-4559.

Ward, W. R., J. W. Hughes, W. B. Faull, P. J. Cripps, J. P. Sutherland, and J. E. Sutherst. "Observational study of temperature, moisture, pH and bacteria in straw bedding, and faecal consistency, cleanliness and mastitis in cows in four dairy herds." *Veterinary Record* 151, no. 7 (2002): 199-206.

Watters, R. D., N. Schuring, H. N. Erb, Y. H. Schukken, and D. M. Galton. "The effect of premilking udder preparation on Holstein cows milked 3 times daily." *Journal of dairy science* 95, no. 3 (2012): 1170-1176.

Weiss, D., and R. M. Bruckmaier. "Optimization of individual prestimulation in dairy cows." *Journal of dairy science* 88, no. 1 (2005): 137-147.

Wenz, J. R., S. M. Jensen, J. E. Lombard, B. A. Wagner, and R. P. Dinsmore. "Herd management practices and their association with bulk tank somatic cell count on United States dairy operations." *Journal of dairy science* 90, no. 8 (2007): 3652-3659.

Wesen, D. P., and L. H. Schultz. "Effectiveness of a post-milking teat dip in preventing new udder infections." *Journal of dairy science* 53, no. 10 (1970): 1391-1403.

Williamson, J. H., and S. J. Lacy-Hulbert. "Effect of disinfecting teats post-milking or pre-and post-milking on intramammary infection and somatic cell count." *New Zealand veterinary journal* 61, no. 5 (2013): 262-268.

Wilson, C. D. "Factors that predispose to mastitis with special reference to milking technique." *Vet. Record* 70 (1958): 159.

Wilson, C. D. "Man, Machines and mastitis." *Vet. Record* 75 (1963): 1311.

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

Zecconi, Alfonso, Jörn Hamann, Valerio Bronzo, and Gianfranco Ruffo. "Machine-induced teat tissue reactions and infection risk in a dairy herd free from contagious mastitis pathogens." *Journal of Dairy Research* 59, no. 3 (1992): 265-271.

Zoetis. *Identifying Drivers of Profitability on Commercial Dairies.* GDR-00171- Dairy Scorecard Project no.14CARGOTH01. Zoetis Services LLC. June 2016

CHAPTER 3: Materials and Methods

3.1. Herd Selection and Farm Demographics

North Carolina State University conducted on-farm milk quality evaluations across 18 herds that spanned across 10 different counties in North Carolina. Milk quality data was obtained from the NC Department of Agriculture and Consumer Services and herds were initially identified and stratified by average BTSCC (low (<200,000 cells/mL), moderate (200,000 to 350,000 cells/mL) and high (>350,000 cells/mL) and herd size (small (<600 cows) and large (>600 cows). Herds were also classified by housing type (freestall, bedded pack, pasture/grazing). Herds were then contacted via phone and invited to participate in the research project. At the initial visit, producers were asked to sign forms indicating their willingness to participate in an evaluation and their release of data to the NCMQ team.

On-farm data was collected from September 2018 through October 2019, with 27 total farm visits at 18 farms. Nine farms were visited during a 'cool' season and again during a 'warm' season to determine the impact of increased heat stress on quality measures. A cool season visit was defined as periods of no heat stress as indicated by the Average THI reading of < 68 while a warm season visit was indicative of heat stress with an Average THI reading ≥ 68. Average herd size was 587 cows with 10 small herds and 8 large herds, as well as 10 low, 9 medium, and 8 high BTSCC herds represented.

3.2. Cow Evaluations

Herd size was used to determine sample size on the farm. If herd size was greater than 1000 cows, 300 cows were evaluated. In herds smaller than 1000 cows, at least thirty percent of the milking herd was evaluated for teat end health, udder cleanliness, locomotion, and body condition scoring with equal representation across all milking groups. Measures were collected

from cows across lactations and days in milk (DIM). All evaluators had previous experience with these scoring systems but were trained prior to study start at the Lake Wheeler Dairy facility by project directors and graduate students. .

3.2.1. Teat End Scoring

Teat end health was visually scored and then recorded utilizing the *Teat End Scorer* app developed by the University of Wisconsin School of Veterinary Medicine (Food Animal Production Medicine, 2015) immediately after milking unit removal, but prior to application of post-milking teat disinfectant. This application assessed hyperkeratosis of teat ends through graphical interface utilizing a simplified 4-point visual scoring scale from Mein et al., (2001), which can be viewed in **(Appendix C)**. Teat end scores ranged from 1 (Normal)= normal teat end with no ring around the teat canal; 2 (Smooth)= smooth raised ring or slightly rough ring with no keratin fronds; 3 (Rough) = rough ring with a raised, roughened ring with fronds or keratin extending 1–3 mm from the orifice; and 4 (Very Rough) = a raised roughened ring with a "flowered" appearance from keratin extending more than 4 mm from the orifice. A half point was assigned to the whole score if teat end "cracking" was observed on the teat orifice as well. Teat end scores on 30% of the milking herd were collected and averaged by cow, and percentage of total cracked teat ends was recorded. Average teat end score was categorized as low (<2), medium (2 to 3), or high (>3).

3.2.2. Udder Hygiene Scoring

Udder hygiene scores were also collected to determine the relationship between cow cleanliness and monthly average BTSCC. Cows were scored utilizing a multi-zone hygiene scoring system developed by Cook, (2002; Appendix D) which documents the degree of manure contamination on a 1-4 scale for each of three zones, the udder, the lower leg and the upper leg

and flank **(Appendix D)**. Udder cleanliness score was categorized as clean (<2), dirty (2 to 3), or very dirty (>3).

3.2.3. Locomotion Scoring

Locomotion scores were collected to determine effect of lameness on BTSCC and BTSPC. Lameness was assessed utilizing a 5-point scoring system from Sprecher et al., (1997) that assessed gait and placed a novel emphasis on back posture **(Appendix A)**. Lameness scores ranged from 1 (Normal)= cow stands and walks with a level-back posture and makes long confident strides with normal gait, to 5 (Severely Lame)= the arched back posture is always evident and the cow additionally demonstrates an inability or extreme reluctance to bear weight on one or more of her limbs/feet. Lameness scores were collected as cows were walking on a level surface as they returned to housing at the end of milking. Lameness score was categorized as normal (<2), moderate (2 to 3), or severe (>3).

3.2.4. Body Condition Scoring

Body condition scores (BCS) were also observed. The assessment of a cow's condition was collected using a numerical 5-point scale with 0.25-point increments. A score of 1 reflected an emaciated (very thin cow), while a 5 denoted an excessively fat cow, with an ideal average BCS represented at a score of 3 see (Ferguson et al., 1994; **Appendix B**). Body condition was categorized as thin (<3), ideal (3), or fat (>3).

3.3. Questionnaire and Milk Quality Data Collection

A modified version of the Southeast Quality Milk Initiative (SQMI; http://sequalitymilk.com) questionnaire was created and administered through interview with farm owner or manager during the initial farm evaluation visit. The purpose of the questionnaire was to obtain information pertaining to herd demographics and to assess management practices

related to milking, housing, cow management, nutrition, labor, replacements, and animal health. All answers were based upon management practice occurrence within the previous year. Questionnaire questions utilized in the data analysis included milking frequency, type of housing for lactating cows, type of bedding material, frequency of bedding application, etc. The full version of the survey evaluation can be viewed in **(Appendix E)**.

Data for 2018 and 2019 BTSCC and BTSPC were obtained from the NC Department of Ag and Consumer Sciences as well as milk cooperatives for each of the farms participating in the study. A monthly BTSCC and BTSPC was determined from the data provided for each farm based on the month of visit to the farm.

3.4. Parlor Evaluation

Parlor evaluations were conducted at each farm visit. One milking shift was observed to document type of milking parlor, number of milking units, milking protocol, and number of milking personnel. The Milking Prep Lag Timer application (Food Animal Production Medicine University of Wisconsin-School of Veterinary Medicine, 2015) was utilized to track the timing of the various stages of the milking procedure. Predefined steps of the farms milking protocol (Dry wipe, Dip 1, Foremilk, Dip 2, Wipe, Attach, Detach) were selected in the app after observing the farm's milking procedures, and the application timed the procedures accordingly for each turn of 8 cows. The application calculated averages for the following parameters:

$$Prep\ Lag\ Time\ (s) = Attachment - Preparation\ start\ (Step\ 1)$$

$$Dip\ Contact\ Time\ (s) = Wipe - Dip\ 1$$

$$Attached\ Time\ (s) = Detach - Attach$$

Timing began as the first cow entered the parlor on a side and ended when the last cow exited from that side. The number of timings recorded were based on parlor size with a minimum total

of three parlor turns recorded to represent a typical parlor routine for that herd. Parlor turn was defined as the number of cows per side. Because the app only recorded up to 8 cows, multiple recordings were performed to equal one turn if parlors were larger than 8 milking units per side. If multiple employees were milking, recordings were split evenly among employees. Average prep lag time was classified as < 90 s, 90 s, or > 90s. Pre-dip contact time was classified as < 30 s or ≥ 30 s.

3.5. Housing Assessments

A housing evaluation was also conducted to assess cow comfort across an operation. Type of housing and housing design was drawn. Housing type was defined as freestall, bedded pack, or mixed. Mixed housing included herds with access to more than one type of housing or herds with access to pasture. Bedding quantity, bedding material, use of bedding conditioners, and new bedding frequency were evaluated. Bedding quantity was defined as deep bedded or not deep bedded. Use of bedding conditioners was defined as yes or no. New bedding frequency was categorized as less than once a week, once a week, or greater than once a week. Bedding material was defined as recycled sand, fresh sand, shavings, or other. Other included herds with access to bedding materials such as mattresses, manure solids, or pasture.

3.6. Climatic Data Collection

Climatic data was collected using the National Oceanic and Atmospheric Administration Local Climatological Data (NOAA, 2020). Data were collected using the weather station closest to the farm location. Average, Maximum, and Minimum dry bulb temperature (T°C) and relative humidity (RH) hourly were obtained for the study period and used to calculate daily average, maximum, and minimum THI using the following equation (Kelly and Bond, 1971):

$$THI = (1.8 * T℃ + 32) - (0.55 - 0.0055 * RH) * (1.8 * T℃ - 26)$$

Then, daily values were combined into a monthly average for the month of the herd visit. Monthly averages were then classified as no heat stress (THI < 68) or heat stress (THI ≥ 68).

3.7. Statistical Analysis

All analyses were performed in SAS 9.4 using the GLM procedure of SAS (SAS Institute Inc., Cary, NC) to identify the practices most strongly associated with BTSCC and BTSPC. The categories for herd size, average teat end score, average udder cleanliness, average locomotion, and body condition (as described in the sections above) were used as independent variables. BTSPC and BTSCC for month of farm visit were dependent variables. Herd size, cow variables, parlor evaluation variables, housing variables, average monthly THI, and questionnaire responses were considered independent variables. Interactions between average monthly THI and herd evaluation variables were assessed.

Means were separated using Fisher's Least Significant Difference, and significance was declared when $P < 0.05$ (Fisher's Least Significant Difference). Trends were discussed when $P \leq 0.10$. All data were presented as mean ± the largest standard error of the mean (SEM).

CHAPTER 4: Results and Discussion

4.1.1. Farm Demographics

Observations from 18 herds spanning across 10 counties throughout 3 regions of North Carolina were included in this study. North Carolina herds enrolled in DHIA in 2019 had a BTSCC average of 207,000 cells/mL (Norman et al., 2020). Of the herds evaluated, 37, 33, and 30% of the herds were categorized as low, medium, and high BTSCC, respectively. Bulk tank SCC averaged 132,110, 250,467, and 449,381 ± 1428.9 cells/mL for low, medium, and high BTSCC herds, respectively (Table 4.1). Within the herds evaluated, 56% had a monthly average BTSPC < 5000 cfu/mL (Low) 33% had a BTSPC greater than 5,000 but less than the industry standard of 10,000 cfu/mL (Medium), and 11% had a BTSPC > 10,000 cfu/mL (High). Bulk tank SPC averaged 2,651, 7,951, and 13,425 ± 146.5 cfu/mL for low, medium, and high BTSCC herds, respectively (Table 4.2).

Of the operations evaluated, 28% milked Holstein cattle, 17% milked Jersey cattle, and 55% milked more than one breed. Significant differences were detected among breeds of cattle for BTSCC and BTSPC ($P<0.0001$; Table 4.3) with herds milking only Jerseys having the greatest BTSCC and BTSPC (323,456 and 10434 ± 7262.3 cells/mL and 304.5 cfu/mL, respectively), followed by Multiple Breeds (246,479 and 5481 ± 2960.7 cells/mL and 124.2 cfu/mL, respectively), and Holstein herds having the lowest BTSCC and SPC (206,893 and 4947 ± 2539.2 cells/mL and 106.5 cfu/mL, respectively). Bulk tank SCC and SPC were significantly lower ($P<0.002$ and $P<0.0012$) for herds milked 3X compared to herds milked 2X during the study (Table 4.3). Decreased BTSCC with 3X milking compared to 2X is consistent with previous research observations (Smith et al., 2002; Allen et al., 1986; Klei et al., 1997; Hogeveen et al., 2001). Smith et al. (2002) observed significantly lower SCC score and weighted SCC for

herds milked 3X compared to 2X during all three years of the study. Additionally, Hogeveen et al. (2001) demonstrated that changing from 2X to 3X across 57 herds, resulted in decreased BTSCC from 193,000 to 162,000 cells/mL. This decrease was reversed once herds resumed 2X milking. The study also found that there were fewer cows with cell counts greater than 250,000 cells/mL. when milked 3X a day.

Herd size ranged from 76 to 1568 lactating cows per herd with 55% of the herds milking fewer than 600 cows (small) and 45% of the herds housing ≥ 600 cows (large). The average herd size was 239 and 1016 ± 9.7 for small and large herds, respectively. Herd size was associated with BTSCC and BTSPC, and large herds were associated with a 139,496 cells/mL and 1619 cfu/mL lower BTSCC and BTSPC than small herds, respectively ($P<0.0001$; Table 4.3). Enger (2017) reported a negative relationship between bulk tank somatic cell score and herd size. As herd size increased, bulk tank somatic cell score decreased. However, the opposite was true when evaluating BTSPC. The relationship between herd size and BTSCC was supported by previous work showing reduced BTSCC in herds greater than 200 cows (Cicconi-Hogan et al., 2013). Additionally, herds smaller than 200 cows were shown to have increased concentration of spore-forming bacteria in pasteurized bulk tank milk (Masiello et al., 2014).

Average THI affected BTSCC and BTSPC differently (Table 4.3). Bulk tank SCC was greatest during periods of heat stress (291,262 vs. 244,144 ± 3628.8) when compared to periods of no heat stress. Periods of no heat stress resulted in a 19% reduction in BTSCC ($P < 0.0001$; Figure 4.1). This confirmed previous research that SCC increased during heat stress. For example, Smith et al. (2013) reported increased SCC for both Jersey and Holstein cows when THI was greater than 68. In contrast, BTSPC was greatest during periods of no heat stress (8,293 vs. 5,046 ± 166.4) and decreased by 64% during periods of heat stress ($P < 0.0001$; Figure 4.2).

When the impact of THI and heat abatement practices (fans only, fans and water system, or no heat abatement practices) utilized was analyzed, the use of heat abatement practices reduced somatic cell count, during times of heat stress and no heat stress (Figure 4.8). The addition of water to cool cows increased SCC, which we could expect as a wetter environment would result in a greater bacterial load. The use of heat abatement practices of both fans and a combination of fans and misters had the lowest SPC compare to no heat abatement practices utilized as well as heat abatement practices during periods of no heat stress (Figure 4.9).

A significant effect ($P<0.0001$) was also present between average THI and herd size. Large herds were consistently lower in BTSCC, 177,345 and 218,713 ± 3477.9 when compared to small herds in both times of no heat stress and heat stress, respectively. However, among small herds, BTSCC was greater during heat stress than periods of no heat stress (310,942, 363,811 ± 6370.1; Figure 4.3). It was expected that large herds would be less affected by THI because of their confinement housing system and access to heat abatement strategies observed in this study. Bulk tank SPC was lowest during heat stress (both large and small herds) and was greatest during no heat stress among small herds ($P < 0.0001$; Figure 4.4).

4.1.2. Cow Variables

Table 4.4 shows the effect of cow variables: teat end score (TES), udder cleanliness (UClean), locomotion scoring (LOCO), and body condition score (BCS). Of the teats evaluated, 69.4% were low, 27.5% were medium, and 3.1% were high. There was a tendency ($P<0.0750$) toward BTSCC to increase with increasing TES. The relationship between TES and SCC has conflicting results across research (de Pinho Manzi et al., 2012; Neijenhuis et al., 2000; Shearn and Hillerton, 1996). A study in Brazil conducted by de Pinho Manzi et al. (2012) showed a 30% increase in intramammary infection for each 1-unit increase in teat-end HK score ($P<.001$)

while Isaksson and Lind, (1992) and Shearn and Hillerton, (1996) found no association between TES and BTSCC. There was a positive effect between TES and BTSPC ($P<0.0001$) but further research needs to be carried out to understand the relationship between TES and BTSPC as there is little research conducted to date. Surprisingly, one paper by Paduch et al., 2012 reported that teat end condition influenced bacterial colonization differently depending on the mastitis pathogen present.

When the interaction between TES and monthly average THI was considered, there was not a significant interaction with BTSCC but there was with BTSPC. During periods of heat stress, as TES increased, BTSPC increased with high TES during no heat stress having the largest BTSPC (Figure 4.5). Teat-end hyperkeratosis is a dynamic condition influenced by a multitude of factors including climate, seasonal and environmental conditions, genetics, teat end shape, stage of lactation, milk production level, milking equipment function, and milking management (particularly slow milking and over-milking). Reports of teat-end hyperkeratosis are most prevalent in high producing herds particularly during colder climate months (Mein et al., 2003).

Across herds the ability to keep cows clean and reduce teat end exposure to pathogens has become increasingly challenging with increased herd size, parlor throughput pressure, infrequent alley scraping and manure removal, and bedding material availability. Of the udders evaluated, 82.3% were clean, 17.3% were dirty, and 0.4% were very dirty (Table 4.4). Clean udders had a significantly lower BTSCC ($P<0.0001$) than dirty and very dirty udders. This is consistent with previous research (Ward et al., 2002; Schreiner and Ruegg, 2003; Reneau et al., 2003; Sant'Anna and Paranhos da Costa, 2011). Reneau et al. (2003) reported increases in somatic cell score of 0.13, 0.17 and 0.17 for each 1 standard deviation increase in udder, rear

legs, or udder-rear legs composition, respectively. Clean udders also had a significantly lower BTSPC (P<0.0001) than dirty and very dirty udders. This is supported by research from Elmoslemany et al. (2010) that found a positive association between udder hygiene score and bulk tank milk bacterial counts. A significant association for both BTSCC and BTSPC was determined when the interaction between udder cleanliness and average THI was conducted. Bulk tank SCC was lowest for clean udders during no heat stress followed by clean udders during heat stress. As degree of manure contamination increased on udders during heat stress BTSCC increased (P < 0.0001; Figure 4.6). Clean udders during heat stress had the lowest BTSPC followed by clean udders during no heat stress and dirty udders in times of heat stress. Very dirty udders in both periods of heat stress and no heat stress had the greatest BTSPC (P < 0.0001; Figure 4.7).

In the current study, neither BCS nor LOCO affected BTSCC (Table 4.4), but both did have a significant effect on BTSPC (P<0.0001). Herds with more ideal and fat cows had a significantly lower BTSPC than herds with more thin cows. Herds with more normal LOCO cows had a lower BTSPC than herds with more moderate LOCO, and severe LOCO was intermediate. While comprehensive research has been conducted to conclude the effect of BCS on milk yield, herd health, reproductive performance, and animal well-being, there is little regarding BCS effect on BTSCC. However, Loker et al. (2012) reported that cows with a low BCS have an increased predisposition to mastitis. This would be expected as BCS is a practical indicator for health status, but further research would need to be carried out to determine direct relationship. In contrast to the results of the current study, research by Olechnowicz and Jaskowski (2010) observed greater SCC ingroups with clinically lame cows compared to groups with no incidence of lameness or groups categorized as mildly lame.

4.1.3. Housing Evaluation

Housing facility type was associated with BTSCC (P<0.0001; Table 4.5). Across this study 61% of operations were free stall barns, 11% were bedded packs and 28% offered mixed housing for the lactating herd. Free stall housing had the lowest BTSCC followed by bedded packs, and mixed housing had the greatest BTSCC (238,794; 364,334; and 410,408 ± 15,742.6 cells/mL, respectively). Research has shown no difference in SCC between confinement and pasture-based operations (Stiglbauer et al., 2013; Cicconi-Hogan et al., 2013). Hogan and Smith (2012) reported that clean and dry bedding with minimal organic matter had more impact on risk of environmental mastitis than whether the operation used confinement or pasture-based housing.

Successful bedding management is a contributing factor to reducing bacterial numbers on teat-ends (Bey, et al., 2002; Hogan et al., 1989, Zdanowicz, et al., 2004). Significant differences were observed between type of bedding used in lactating cow housing and BTSCC (P<0.0001; Table 4.5). Twenty-eight percent of operations utilized recycled sand and shavings while 22% used fresh sand and other bedding materials such as manure solids, pasture, etc. Recycled sand contributed to the lowest BTSCC (182,986 ± 5061.5 cells/mL) with an average BTSCC of 69,834; 96,099; and 192,740 ± 22,273.4 cells/mL less than other bedding, fresh sand, and shavings, respectively (Figure 4.9). In general, organic bedding sources have been shown to support more bacterial growth as compared to inorganic sources (Fairchild et al., 1982; Janzen et al., 1982; Zdanowicz et al., 2004). This is supported by Wenz et al., (2007) and Dufour et al., (2011) who demonstrated that mattresses and sand bedding for lactating cows and heifers were associated with lower BTSCC but sand bedding will worsen the exposure rates to Streptococcus spp. and Klebsiella spp. Rowbotham and Ruegg (2015) found that solids over foam-core mattress (SBMS) bedding carried the greatest bacteria load and that new sand (NS) had the

lowest gram-negative bacterial population. While the current study did not investigate bacterial populations, fresh sand had a higher BTSCC than expected. Interestingly, the current study did not find any difference between fresh sand and other bedding. It was expected that herds bedding with fresh sand would have the lowest BTSCC. This led to the investigation of the relationship between bedding type and bedding frequency (Figure 4.11). The interaction between bedding type and bedding frequency showed that those herds predominantly using shavings and adding more than once a week had a higher SCC compared to other bedding. Looking across all the different types of bedding the recycled sand was still the best option for having the lowest SCC. These differences iterated the importance of culturing our bedding before it goes in regardless of type as we do not know what is in it or necessarily where it has come from and in what condition.

Utilizing deep bedding increases cow comfort but adds to the necessity of raking manure out of stalls. Amount of bedding material available had a significant impact as seen in Table 4.5, with deep bedded stalls having a 20% reduction on BTSCC when compared to those stalls not deep bedded (234,640 v. 292,995 ± 21850.9 cell/mL, respectively; $P < 0.0309$). When manure is raked out of stalls, Schukken et al., (1991) demonstrated a 74% reduction in clinical coliform mastitis cases and bedding was dryer (76% versus 68% dry matter) in herds with BTSCC <283,000 cells/ml (Hutton et al., 1990).

There have been numerous attempts to add chemicals to bedding materials to control bacterial growth and reduce stall maintenance. The current study identified associations between use of bedding conditioners and BTSCC ($P < 0.002$). Surprisingly, herds that did not use a bedding conditioner had on average a 30,000 lower BTSCC than herds that did use a bedding conditioner (Table 4.5). Hogan et.al, (1999) found that effectiveness of bedding treatments on

bacterial concentrations differed between bedding types. Hydrated lime and alkaline conditioners were most effective in recycled manure while sawdust bacterial counts were reduced the most by an acidic conditioner. The antibacterial effects of each treatment had diminished between d 2 and 6 after use in bedding based on the bedding pH. The results in this study may be due to farms only implementing bedding conditioners when necessary. Herds already struggling with milk quality may have used these to combat increased BTSCC. This study was conducted during periods of low milk prices, potentially reducing the use of bedding conditioners in herds that do not struggle with SCC to save on expenses.

Frequency of bedding application and removal of manure also have been shown to significantly reduce IMI rates. Frequency of bedding application was significant ($P < 0.0001$) with adding bedding only once a week having the lowest BTSCC average (242273 ± 12614.5) and bedding more than once a week had the highest BTSCC (392,829 ± 37731.2). Of the operations evaluated, 53% were currently adding new bedding once a week, 29% added bedding multiple times a week, and 18% of operations bedded less than once a week. Previous research Rowbotham and Ruegg, (2015) demonstrated that herds reduced their bulk milk somatic cell score by removing the organic bedding from the back one-third of the stall at least once a week and by increasing the number of times per week that new bedding was added to the stall. However, in the same study herds that utilized inorganic bedding found the increased frequency of replacement bedding to be associated with an increased bulk milk somatic cell score. Although the current study did not distinguish between inorganic/organic bedding, it did observe increased BTSSC when bedding was added more than once weekly**.**

Regarding BTSPC, no significant effects were found when looking at type of lactating cow housing facility or type of bedding material used ($P < 0.4415$ and $P < 0.7403$, respectively;

Table 4.5). However, significant differences with BTSPC were found when reviewing bedding depth, use of bedding conditioners, and frequency of bedding application ($P < 0.0001$, $P = 0.0214$, $P < 0.0001$, respectively; Table 4.5). Deep bedded herds had lower BTSPC than non-deep bedded herds (6558 v. 14,220 ± 875.5 cfu,/mL respectively). Similarly, to BTSCC, herds that did not use bedding conditioners had significantly lower BTSPC than herds that did use bedding conditioners (7186 v. 6288 ± 328.6 cfu/mL, respectively). Herds that added bedding weekly had lower BTSPC (5740 cfu/mL) than herds that applied bedding less than once weekly (7656 cfu/mL), and herds that bedded more than once weekly were intermediate (7035 ± 1639.7 cfu/mL).

4.1.4. Parlor Assessment

Forestripping was reported by 44% of operations and was associated with an average 80,000 lower BTSCC compared to herds that did not include this in their parlor procedure (203,710 v. 283,948 ± 6669.0 cells/mL; $P < 0.0001$; Table 4.6). The first streams of milk located in the teat cistern are known to have the greatest concentration of bacteria and somatic cells, thus discarding this milk through forestripping will result in lower somatic cell and organism prevalence (Harmon, 1994; Fahr, 2002). Reverse effects were observed between forestripping and BTSPC. Parlor routines that reported forestripping in this data set had an increased BTSPC when compared to herds that were not forestripping. This is consistent with other studies reported increased BTSPC when forestripping was a part of the milking routine (Schukken et al., 1991; Peeler et al., 2000; Rasmussen, 2000; Jayarao et al., 2004; Blakely, 2016). This increase has been thought to be associated with increased teat-contact with hands of milking personnel and increased exposure of pathogens to neighboring cows (Schukken et al., 1991b; Peeler et al., 2000; Rasmussen, 2000). Inclusion of dry wipe prior to pre-dip application was recorded for

67% of the operations. Herds that dry wiped had a BTSCC 24% lower than herds that did not dry wipe (264,109 v. 346,089 ± 17928.4 cells/mL, respectively; P = 0.002).

Pre-milking teat disinfection was employed by 100% of the operations but type of pre-dip utilized varied. Peroxide was the most common active ingredient (44%, n=8) used by producers, followed by chlorine dioxide and iodine (28%, n=5). Use of peroxide-based pre-dips was associated with a significant reduction in BTSCC (P < 0.0001; Table 4.6) with the lowest BTSCC compared to iodine and chlorine dioxide (256,687 v. 336,401 and 338,214 ± 8976.8 cells/mL, respectively). Enger et al. (2015) reported reduced SCC when pre-dip was used (peroxide, chlorine dioxide, 1% iodophor, and0.5% iodophor), however in contrast to the current study, the previous authors reported that peroxide was the worst performing disinfectant while the 1% iodophor was the superior disinfectant. When looking at herds in the Southeast, Blakely, 2017 found that herds using dips with hydrogen peroxide had double the BTSCC than other ingredients as well. Active ingredient was also associated with significantly reduced BTSPC (P < 0.0001). Unlike BTSCC, herds using peroxide had the highest BTSPC while those using chlorine dioxide and iodine had lower BTSPC (11,203 v. 4703 and 5601 ± 641.4 cfu/mL). No preparation of udder and teats had higher standard plate count attributed to soiled teats at machine attachment, however the effect of active ingredient in teat dip on BTSPC has not been widely investigated (Galton et al., 1982).

Large farms using peroxide pre-dip had the lowest BTSCC followed by large farms using chlorine dioxide and small farms using iodine. Small farms using peroxide had lower BTSCC than small farms using chlorine dioxide and large farms using iodine (P < 0.0001; Figure 4.10). Active ingredient had significant but reverse effects on BTSPC in small and large herds (P < 0.0001). Large farms using chlorine dioxide and small farms using iodine had the lowest

BTSPC followed by small farms using chlorine dioxide and large farms using peroxide. Iodine use had the largest BTSPC for large herds and peroxide had the largest BTSPC across small farms (Figure 4.13).

The amount of time pre-dip was in contact with the teat was also important ($P < 0.0273$; Table 4.6). Pre-dips that were applied for 30 s or longer had a lower BTSCC compared to pre-dip that was removed faster than 30 s (289,243 v. 334,766 ± 19807.9 cells/mL, respectively). The industry recommendation for pre-dip contact time with the teat skin is 30 s (Bushnell, 1985). Studies by Reneau, (2001) and Bray and Shearer (2012) support this recommendation while others demonstrate optimal time depending on active ingredient. When evaluating contact time of 15 s, 30 s, and 45 s, Enger concluded that all resulted in mean log reductions of 30.0, 34.1, and 37.0%, respectively ($P < 0.05$). The study also determined that different active ingredients had different optimal contact times with a 30 s contact time for iodophors but only 15 s contact needed for hydrogen peroxide dips. Additional research has shown significant germicidal efficacy against mastitis pathogens with disinfectant contact times of 15 to 20 s (Galton et al., 1988) and 60 s (Peters et al., 2000).

Prep lag time (PLT) also influenced BTSCC. Bulk tank SCC was lower with a reported PLT of 90 s or longer, with the highest BTSCC associated with a short PLT less than 90 s (243,841 v. 311,010 ± 7611.9 cells/mL, respectively; Table 4.6). Reneau and Chastain (1995) determined that at least 20 s of stimulus and a total PLT of 60 s increases average flow rate and reduces unit on time when compared with no stimulation. Kaskous and Bruckmaier (2011) recommended a preparation lag time of 90 to 120 s to optimize oxytocin release and milk let down prior to unit attachment. This is consistent with the current study that reported the greatest BTSCC when PLT was lower than 90 s. Bulk tank SPC was also affected by PLT ($P < 0.0001$)

with a 90 s or longer PLT being associated with a 55% reduction in BTSPC when compared to a PLT shorter than 90 s (4017 v. 8851 ± 445.2 cfu/mL, respectively). Results from Enger (2017) supported the current study as longer prep-times were associated with lower BTSPC as well. This association is expected because if adequate time is spent to prep the cow then there is an increased likelihood that teat ends were getting properly cleaned leading to a lower prevalence of bacteria entering the milking system during milking.

Teat end cracking (TEC) observed in the parlor also affected BTSCC ($P< 0.0335$). Less than 20% TEC reported the lowest BTSCC compared to TEC greater than 20% (252,975 v. 273,441 ± 8711.9 cells/mL, respectively: Table 4.6). No significant effect was observed between TEC and BTSPC ($P < 0.888$). This association is opposite of Enger (2017) who reported a negative relationship between percent of cracked teat ends and BTSPC; as percent of cracked teat ends increased, BTSPC decreased. However, cracking is commonly known to increase susceptibility of pathogen so the lower BTSCC for less than 20% TEC observed in the current study was expected.

The removal of udder hair reduced BTSCC on average by 27% ($P < 0.0001$; Table 4.6). Operators who choose to not remove udder hair (44%, n=8) regularly in the last year reported a higher BTSCC (329857 ± 12027.2) when compared to herds that did remove udder hair (240880 ± 19672.0). This is consistent with previous work (Barkema et al., 1998; Rodrigues et al., 2005; Elmoslemany et al., 2010; Dufour et al., 2011). However, Silk et al. (2003) reported that singeing of udder hair had no effect on new IMI or bacterial counts in the milk or on the teat skin. Bulk tank SPC was negatively affected by udder hair removal ($P < 0.0304$), with removing udder hair contributing to a higher BTSPC when compared to no hair removal (7274 v. 5118 ± 849.8 cfu/mL, respectively). In contrast to the current study, clipping udder hair has previously

been associated with reduced bacterial counts (Dufour et al., 2011) and a decrease in risk of new mastitis infection (Elmoslemany et al., 2010). Despite the dispute, the PMO dictates that milk should be harvested from clean udders, more specifically udders clipped or trimmed to facilitate ease of cleaning and prevent bacterial harboring that could interfere with providing a safe wholesome product.

As seen in Table 4.6, two thirds of operations used teat sealants at dry off which demonstrated on average a 26% reduction in BTSCC compared to herds who did not use a teat sealant (209,023 v. 284,531 ± 3491.8 cells/mL, respectively; $P < 0.0001$). Teat sealants also significantly affected BTSPC ($P < 0.0001$) as non-use had a higher BTSPC compared to herds that did use a teat sealant (6241 v. 5238 ± 151.9 cfu/mL, respectively). These results were expected and are consistent with previous work (Godden et al., 2003; Bradley et al, 2010; Schewe et al., 2015). Godden et al. (2003) observed a 30% reduction of new IMI and a 33% reduction in clinical mastitis cases between dry off and 60 days in milk (DIM) in quarters treated with DCT and an internal teat sealant at dry-off.

4.2 Conclusion

North Carolina is nestled in the Southeast; the region noted for the poorest milk quality. The ability to reduce somatic cell counts (SCC) and improve milk quality depends on the effective and consistent application of established mastitis control practices. Eroding milk prices threaten the potential interruption of these mastitis control practices. The objectives of this study were to assess NC milk quality and prioritize management practices that influence on-farm milk quality. A total of 21 variables were evaluated in the current study and results revealed some important herd-management practices associated with BTSCC and BTSPC. Probably the most useful practice is the implementation of udder cleanliness scoring to monitor udder hygiene.

Keeping cow's cleaner will reduce herd BTSCC and BTSPC. This can be accomplished through stricter attention to housing elements such as bedding material type, bedding availability, and bedding frequency. Housing type also has a significant impact on BTSCC but changing housing type is unrealistic and uneconomical in our current industry state. Adoption of tools such as the Milking Prep Lag Timer app developed at the University of Wisconsin School of Veterinary Medicine provides producers opportunity to focus more on managing consistency through monitoring parlor procedures and essential measurements such as prep lag time and pre-dip contact time. Considering implementation of forestripping and dry wipe into milking procedures was shown to significantly reduce BTSCC. In addition, type of pre-dip used on farm should be evaluated as Peroxide based pre-dips had the lowest BTSCC. Lastly farm demographics such as milking Holsteins, large herd size >600 cows, and 3X milking will provide ample opportunity to have the lowest BTSCC and SPC in North Carolina based on the results of this study. There is not one silver bullet for improving milk quality. Therefore, it is important that producers assess what is their current milk quality situation and what are their milk quality goals. Determining this will allow producers to evaluate which of these management practices stand to benefit their operation the most through consistent and effective application. From these findings, relevant tools and resources will be developed for NC dairy producers to combat poor milk quality and work to achieve more ambitious milk quality goals through the implementation of these significant management practices.

4.3 Tables

Table 4.1. Distribution of monthly average herd BTSCC (cells/mL) during month of visit of study herds evaluated in North Carolina

BTSCC[1]	Number of Farms	Percent	Average BTSCC	SEM	*P* =
Low	10	37	132,110	942.3	<.0001
Medium	9	33	250,467	1,203.2	<.0001
High	8	30	449381	1,428.9	<.0001

[1]BTSCC = Bulk Tank Somatic Cell Count; Low = <200,000 cells/mL, Medium = 200,000-350,000 cells/mL, High =>350,000 cells/mL

Table 4.2. Distribution of monthly average herd BTSPC during month of visit of study herds evaluated in North Carolina

BTSPC[1]	Number of Farms	Percent	Average BTSPC	SEM	*P* =
Low	15	56	2,651	78.6	<.0001
Medium	9	33	7,951	111.3	<.0001
High	3	11	13,425	146.5	<.0001

[1]BTSPC=Bulk Tank Standard Plate Count; Low=<5,000, Medium=5,000-10,000, High=>10,000

Table 4.3. Herd demographics for NC dairies evaluated in study.

Farm Demographics	BTSCC[1]			BTSPC[2]		
	LSMEAN	SEM	*P* =	LSMEAN	SEM	*P* =
Herd Size[3]						
Small (n=10)	404,712	10,658.7	<.0001	8,395	506.5	<.0001
Large (n=8)	265,216	10,192.9	<.0001	6,776	484.4	<.0001
Breed						
Holstein (n=5)	206,893[a]	2,539.2	<.0001	4,947[a]	106.5	<.0001
Jersey (n=3)	323,456[c]	7,262.3	<.0001	10,434[c]	304.5	<.0001
Multiple Breeds[4] (n=10)	246,479[b]	2,960.7	<.0001	5,481[b]	124.2	<.0001
Milking Frequency[5]						
2X (n=6)	282,708	15,013.0	0.002	8,766	618.1	0.0012
3X (n=12)	234,235	4,441.3	0.002	6,677	182.9	0.0012
Average THI[6]						
No Heat Stress (n=10)	244,144	3,628.8	<0.0001	8,293	166.4	<0.0001
Heat Stress (n=17)	291,262	2,832.7	<0.0001	5,046	129.9	<0.0001

[1]BTSCC=Bulk Tank Somatic Cell Count
[2]BTSPC=Bulk Tank Standard Plate Count
[3]Herd Size=Small (<600 cows), Big (>600 cows)
[4]Multiple Breeds=Herds milking more than one breed
[5]Milking Frequency= 2X (Cows milked twice a day), 3X (Cows milked three times a day)
[6]Average THI=Regional monthly average temperature humidity index= no heat stress (THI < 68), or heat stress (THI ≥ 68)
n=Number of each herd demographic variable represented
[a-c] Superscript represents the differences between the means within each herd demographic variable

Table 4.4. Evaluation of effect of cow variables on BTSCC and BTSPC

Cow Variables[1]	BTSCC[2]			BTSPC[3]		
	LSMEAN	SEM	*P* =	LSMEAN	SEM	*P* =
Teat End Score						
Low (n=2561)	326,006	9,800.4	0.0750	6,077[a]	465.8	<.0001
Medium (n=1016)	330,059	10,161.1	0.0750	7,371[b]	483.0	<.0001
High (n=115)	348,826	13,977.4	0.0750	9,308[c]	664.3	<.0001
Udder Cleanliness						
Clean (n=3364)	266,760[a]	4,104.7	<.0001	7,181[a]	195.1	<.0001
Dirty (n=707)	341,229[b]	5,460.2	<.0001	8,199[b]	259.5	<.0001
Very Dirty (n=15)	396,902[b]	28,749.9	<.0001	7,377[ab]	1,366.3	<.0001
Locomotion						
Normal (n=3270)	228,790	2,132.0	0.2062	5,379[a]	90.5	<.0001
Moderate (n=820)	232,996	4,257.4	0.2062	6,223[b]	180.7	<.0001
Severe (n=24)	268,125	24,885.7	0.2062	6,725[ab]	1,056.4	<.0001
Body Condition Score						
Thin (n=945)	227,525	4,026.1	0.5685	6,066[b]	167.8	<.0001
Ideal (n=1914)	232,697	2,829.0	0.5685	5,148[a]	117.9	<.0001
Fat (n=1181)	231,665	3,601.5	0.5685	5,415[a]	150.1	<.0001

[1]Cow Variables-Teat End Score: Low=<2, Medium=2-3, High=>3; Udder Cleanliness: Clean=<2, Dirty=2-3, Very Dirty=>3; Locomotion: Normal=<2, Moderate=2-3, Severe=>3; Body Condition Score: Thin=<3, Ideal=3, Fat=>3
n=Represents the number of observed responses for each cow variable
[2]BTSCC=Bulk Tank Somatic Cell Count
[3]BTSPC=Bulk Tank Standard Plate Count
[ab] Superscript represents the differences between the means within each cow variable category

Table 4.5. Housing Evaluation Factors affecting BTSCC and BTSPC

Housing Assessment	BTSCC[1]			BTSPC[2]		
	LSMEAN	SEM	*P* =	LSMEAN	SEM	*P* =
Housing Type						
Freestall (n=11)	238,794[a]	12,330.8	<.0001	6,075	574.5	0.4415
Bedded Pack (n=2)	364,334[b]	9,587.6	<.0001	6,879	446.7	0.4415
Mixed[3] (n=5)	410,408[c]	15,742.6	<.0001	6,051	733.4	0.4415
Bedding Material						
Recycled Sand (n=5)	182,986[a]	5,061.5	<.0001	7,194	234.2	0.7403
Fresh Sand (n=4)	279,085[b]	6,618.6	<.0001	5,850	306.2	0.7403
Shavings (n=5)	375,726[c]	13,195.1	<.0001	5,938	610.4	0.7403
Other[4] (n=4)	252,820[b]	22,273.4	<.0001	14,189	1,030.4	0.7403
Deep Bedded						
YES (n=12)	234,640	4,395.0	0.0309	6,558	176.1	<.0001
NO (n=5)	292,995	21,850.9	0.0309	14,220	875.5	<.0001
Bedding Conditioners						
YES (n=8)	246,890	5,113.4	0.002	7,186	210.1	0.0214
NO (n=10)	217,559	7,995.6	0.002	6,288	328.6	0.0214
New Bedding Frequency						
Less than once a Week (n=3)	346,969[b]	17,409.3	<.0001	7,656[b]	756.6	<.0001
Once a Week (n=9)	242,273[a]	12,614.5	<.0001	5,740[a]	548.2	<.0001
More than once a Week (n=5)	392,829[b]	37,731.2	<.0001	7,035[ab]	1,639.7	<.0001

[1]BTSCC=Bulk Tank Somatic Cell
[2]BTSPC=Bulk Tank Standard Plate Count
[3]Mixed=Lactating cows have access to more than one type of housing
[4]Other=Herds had access to other bedding materials such as mattress, manure solids, or pasture
[abc] Superscript represents the differences between the means within each housing assessment variable
n=Represents the number of observed responses for each housing assessment variable

Table 4.6. Parlor Variables measured for effect on BTSCC and BTSPC

Parlor Evaluation	BTSCC[1]			BTSPC[2]		
	LSMEAN	SEM	*P* =	LSMEAN	SEM	*P* =
Prep Lag Time						
Less than 90 s (n=302)	311,010	7,611.9	<.0001	8,851	445.2	<.0001
≥ 90 s (n=726)	243,841	4,690.2	<.0001	4,017	274.3	<.0001
Pre-Dip Contact Time						
Less than 30 s (n=73)	334,766	19,807.9	0.0273	3,905	1,247.0	0.3753
30 s or greater (n=955)	289,243	5,658.1	0.0273	2,755	356.2	0.3753
Pre-Dip Active Ingredient						
Chlorine Dioxide (n=5)	338,214[b]	8,976.8	<.0001	4,703[a]	641.4	<.0001
Peroxide (n=8)	256,687[a]	3,214.0	<.0001	11,203[b]	229.6	<.0001
Iodine (n=5)	336,401[b]	4,199.3	<.0001	5,601[a]	300.0	<.0001
Parlor Procedure - Forestrip						
YES (n=8)	203,710	5,534.0	<.0001	7,447	229.3	0.0036
NO (n=10)	283,948	6,669.0	<.0001	6,400	276.3	0.0036
Parlor Procedure – Dry Wipe						
YES (n=12)	264,109	12,550.9	0.0002	6,084	554.7	0.8999
NO (n=6)	346,089	17,928.4	0.0002	5,962	792.3	0.8999
Udder Hair Management						
YES (n=10)	240,880	19,672.0	0.0001	7,274	849.8	0.0304
NO (n=8)	329,857	12,027.2	0.0001	5,118	519.6	0.0304
Teat End Cracking						
Less than 20% (n=7)	252,975	8,711.9	0.0335	6,140	433.2	0.8888
Greater than 20% (n=19)	273,441	4,086.6	0.0335	6,073	203.2	0.8888
Teat Sealant Use						
Yes (n=12)	209,023	2,182.4	<.0001	5,238	94.9	<.0001
No (n=6)	284,531	3,491.8	<.0001	6,241	151.9	<.0001

[ab] Superscript represents the differences between the means within each parlor evaluation variable
n=Represents the number of observed responses for each parlor variable

4.4 Figures

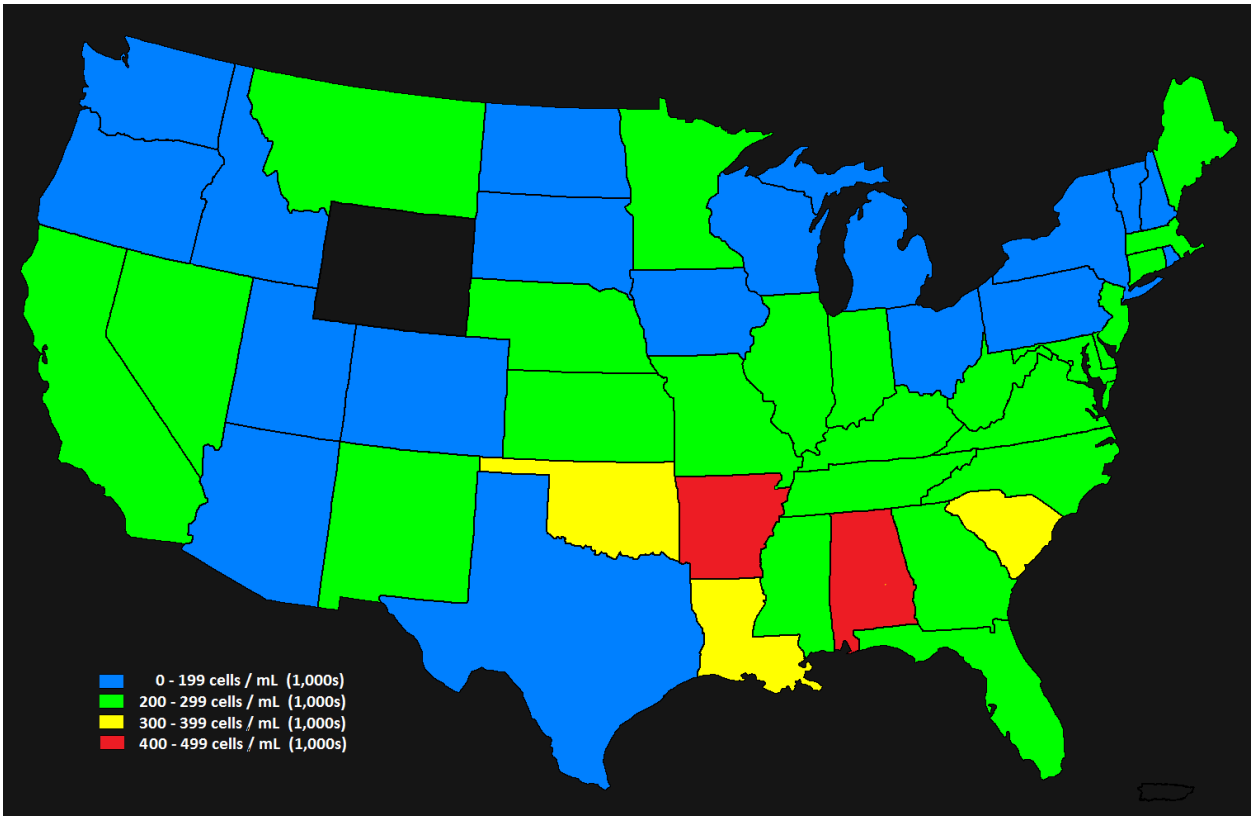


Figure 2.1: Average test-day somatic cell count from Dairy Herd Improvement herds during 2019 by state. (Norman, 2020; https://queries.uscdcb.com/publish/dhi/current/sccx.html)

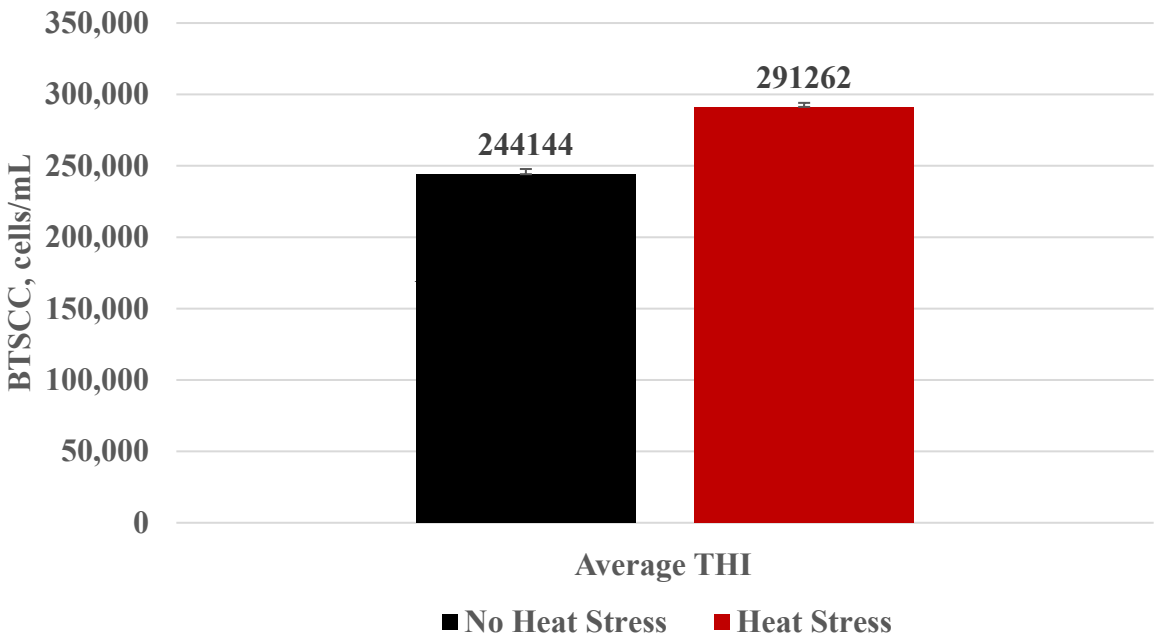


Figure 4.1: Monthly average Bulk Tank Somatic Cell Count (BTSCC) by regional average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)). Monthly average THI was classified as No heat stress (THI < 68) or Heat stress (THI ≥ 68).

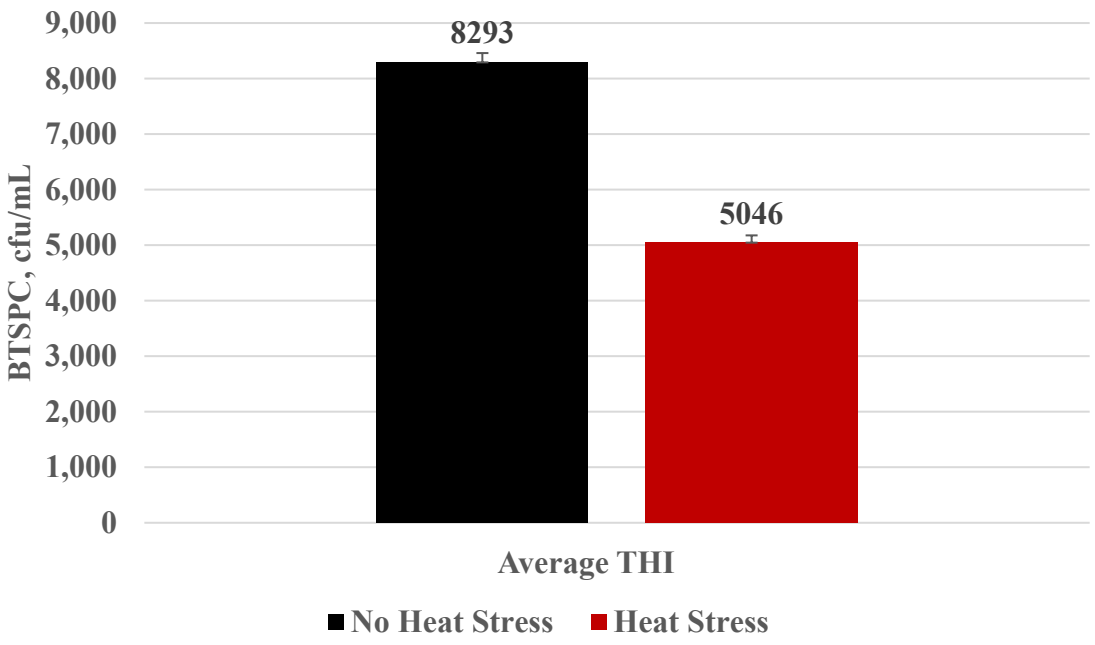


Figure 4.2: Monthly average Bulk Tank Standard Plate Count (BTSPC) by regional average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)). Monthly average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68).

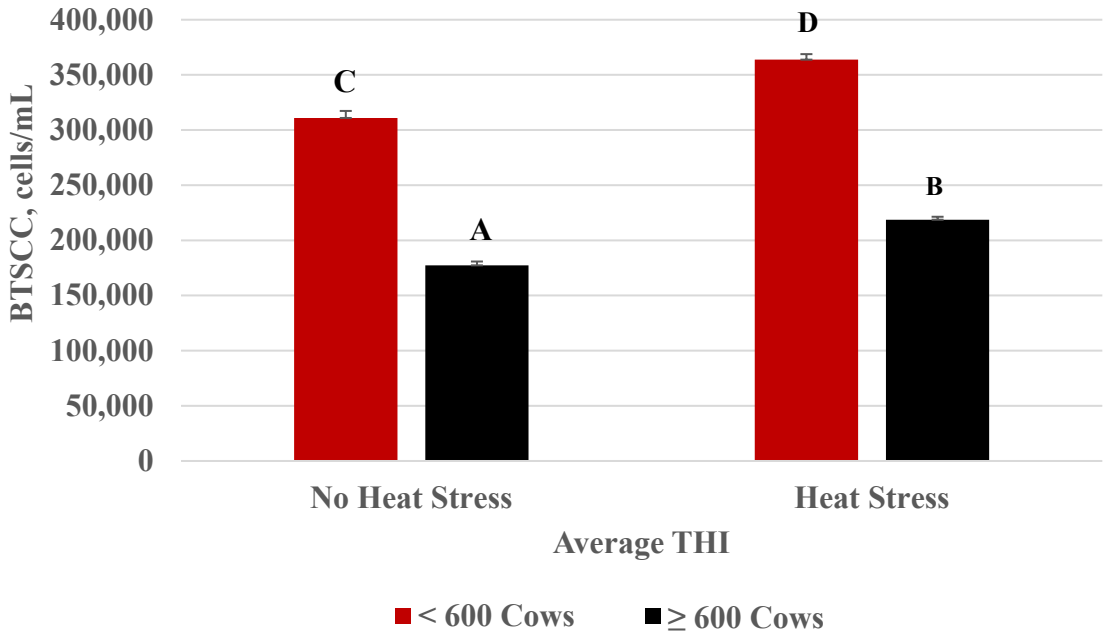


Figure 4.3: Monthly average Bulk Tank Somatic Cell Count (BTSCC) by Herd Size and regional average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Herd size was classified as Small (<600 lactating cows) or Large (≥ 600 Cows lactating cows).

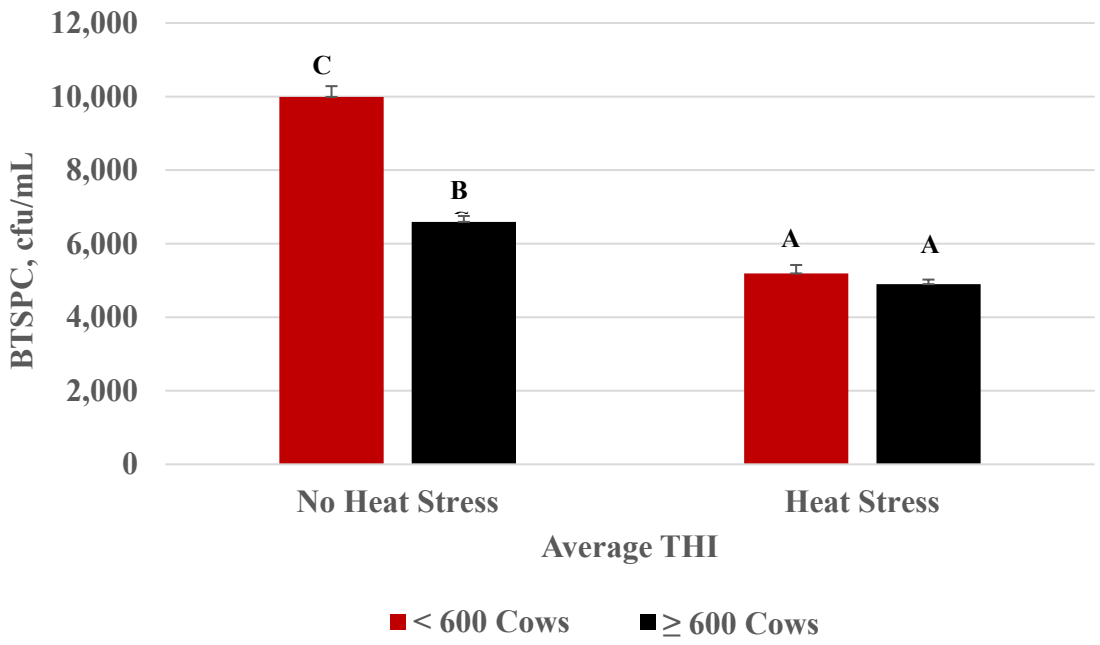


Figure 4.4: Monthly average Bulk Tank Standard Plate Count (BTSPC) by Herd Size and regional monthly average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Monthly average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Herd size was classified as Small (<600 lactating cows) or Large (≥ 600 Cows lactating cows).

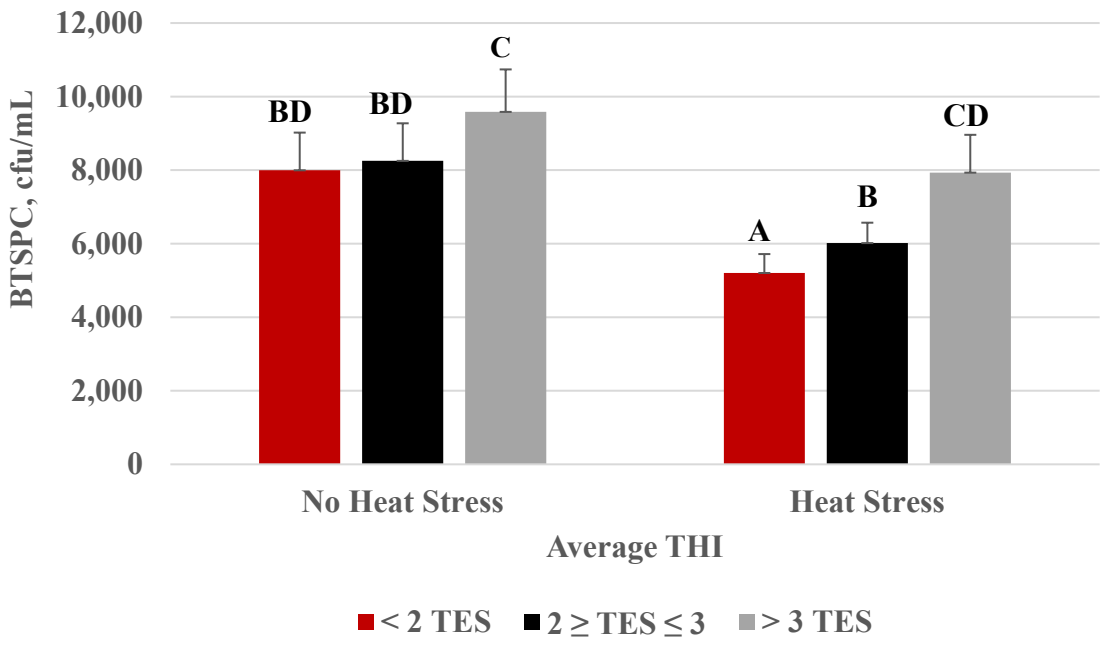


Figure 4.5: Monthly average Bulk Tank Standard Plate Count (BTSPC) by Teat End Score (TES) and regional average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Average THI was classified as No heat stress (THI < 68),), or Heat stress (THI ≥ 68). Teat End Scores were categorized as Low (TES < 2), Medium (2 ≥ TES ≤ 3), or High (TES > 3).

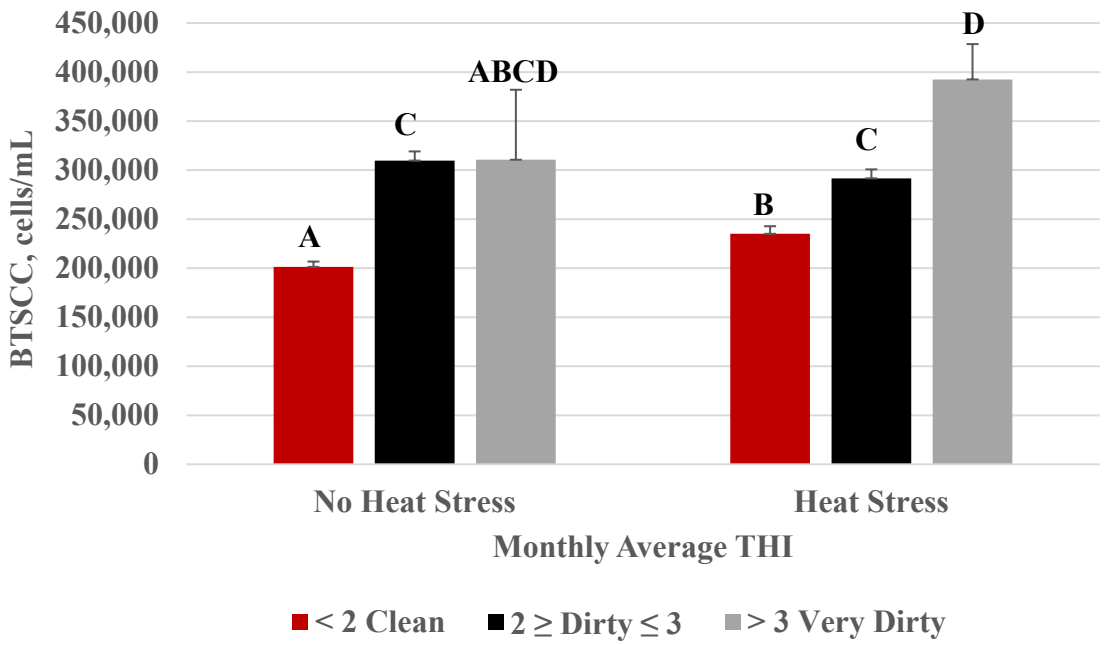


Figure 4.6: Monthly average Bulk Tank Somatic Cell Count (BTSCC) by Udder Cleanliness Score (UClean) and regional monthly average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Udder Cleanliness Scores were categorized as Clean (Cleanliness Score < 2), Dirty (2 ≥ Cleanliness Score ≤ 3), or Very Dirty (Cleanliness Score > 3).

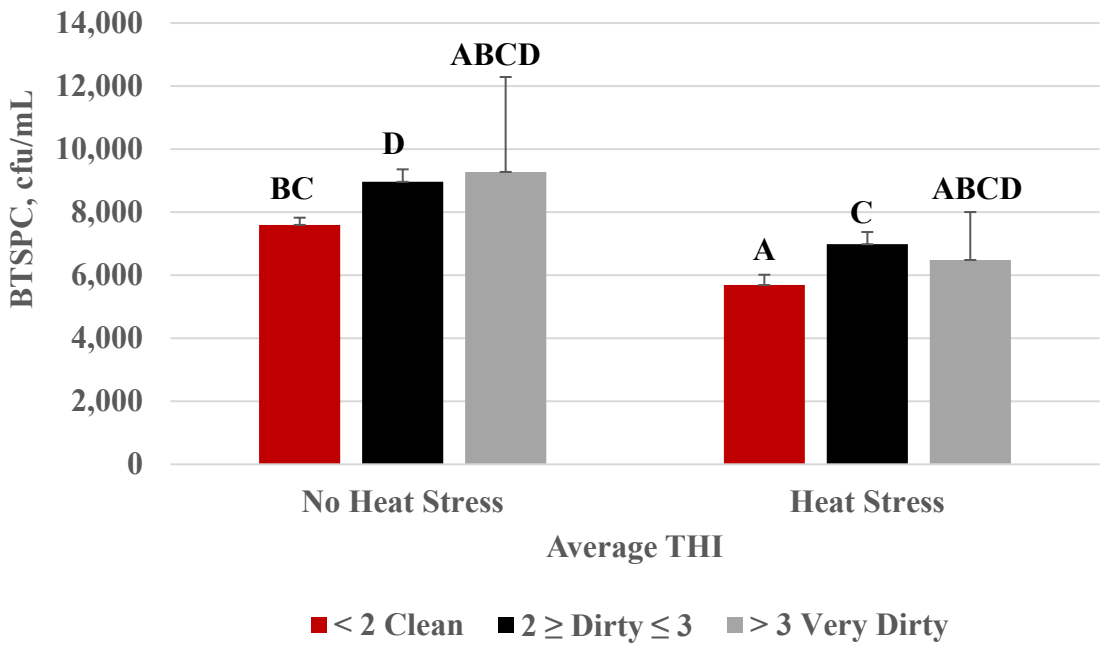


Figure 4.7: Monthly average Bulk Tank Standard Plate Count (BTSPC) by Udder Cleanliness Score (UClean) and regional average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Udder Cleanliness Scores were categorized as Clean (UClean < 2), Dirty (2 ≥ UClean ≤ 3), or Very Dirty (UClean > 3).

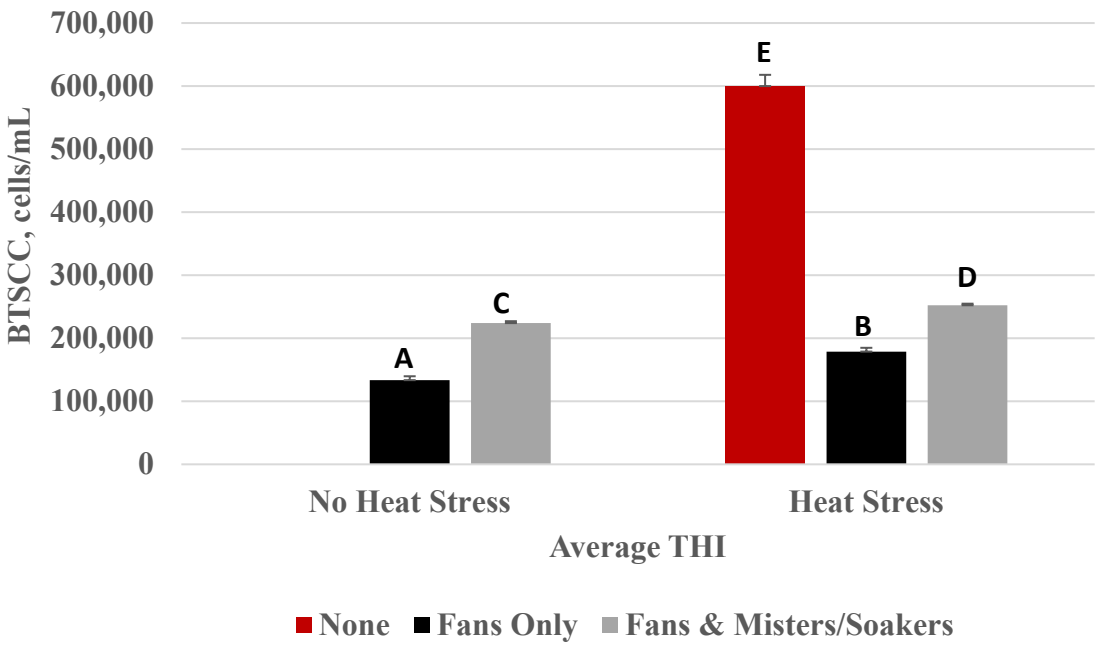


Figure 4.8: Monthly average Bulk Tank Somatic Cell Count (BTSCC) by Heat Abatement Practices and regional monthly average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Monthly average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Heat abatement practices were classified as None, Fans Only, or Fans and Misters/Soakers.

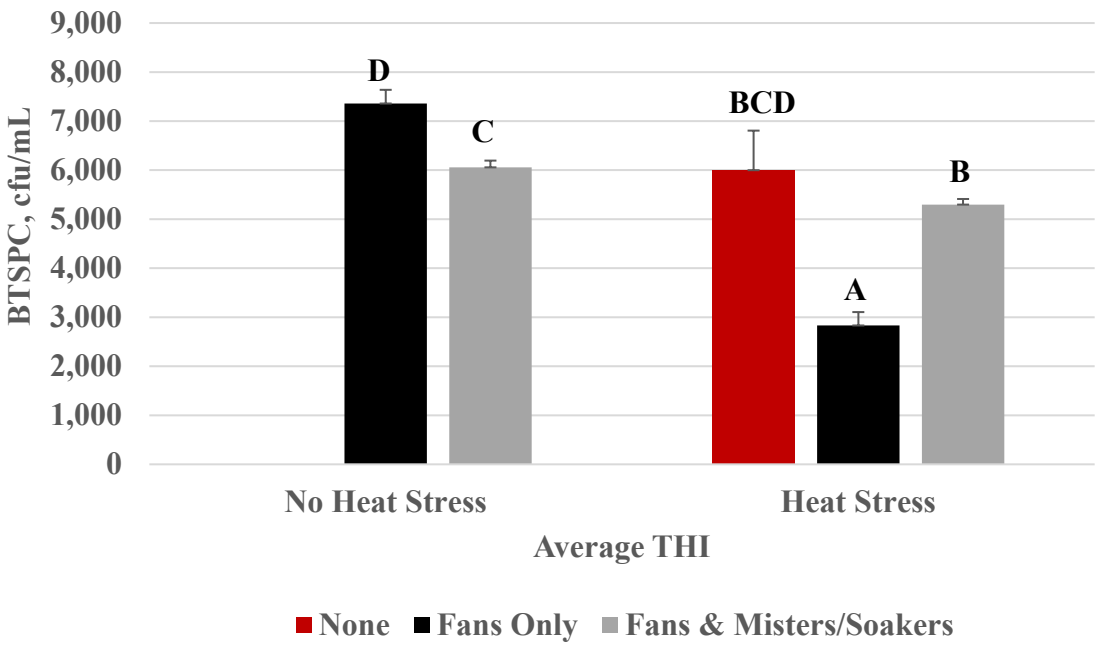


Figure 4.9: Monthly average Bulk Tank Standard Plate Count (BTSPC) by Heat Abatement Practices and regional monthly average Temperature Humidity Index (THI=(average dry bulb temperature (°C) (1 – average relative humidity) (average dry bulb temperature – 58)) at the time of farm evaluation. Monthly average THI was classified as No heat stress (THI < 68), or Heat stress (THI ≥ 68). Heat abatement practices were classified as None, Fans Only, or Fans and Misters/Soakers.

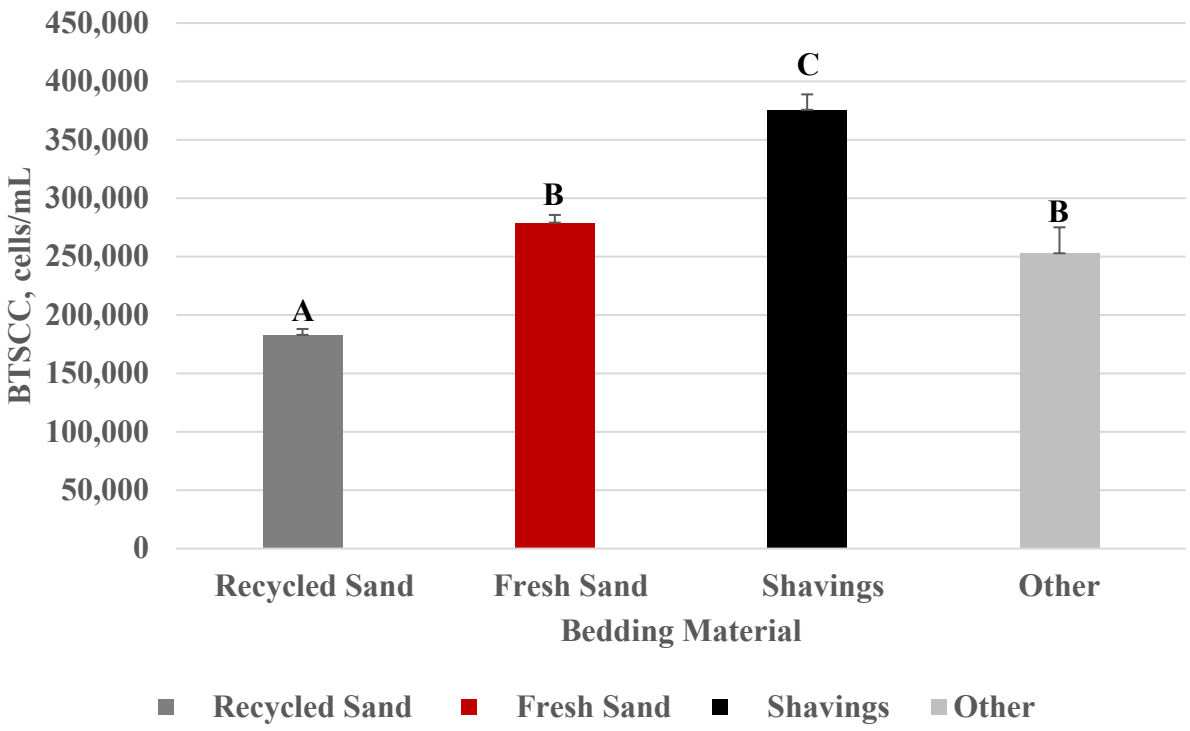


Figure 4.10. Effects of bedding material type in lactating cow housing on BTSCC.

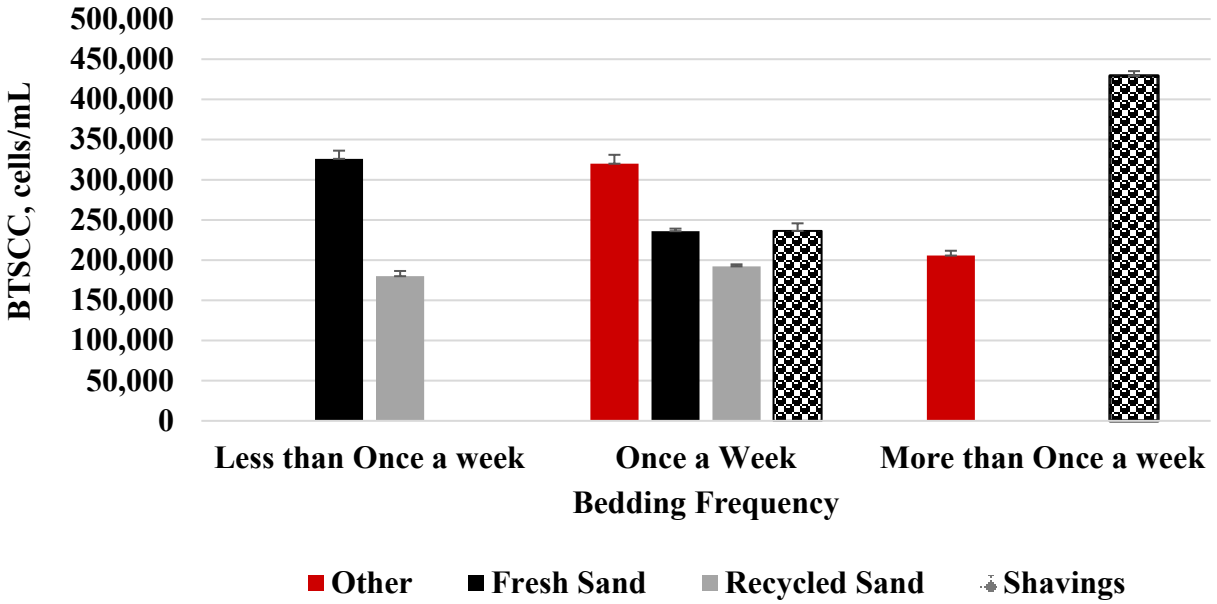


Figure 4.11: Monthly Bulk Tank Somatic Cell Count (BTSCC) by Bedding Type (Fresh Sand, Recycled Sand, Shavings, Other) and Bedding Frequency (Less than once a week, Once a week, or More than once a week).

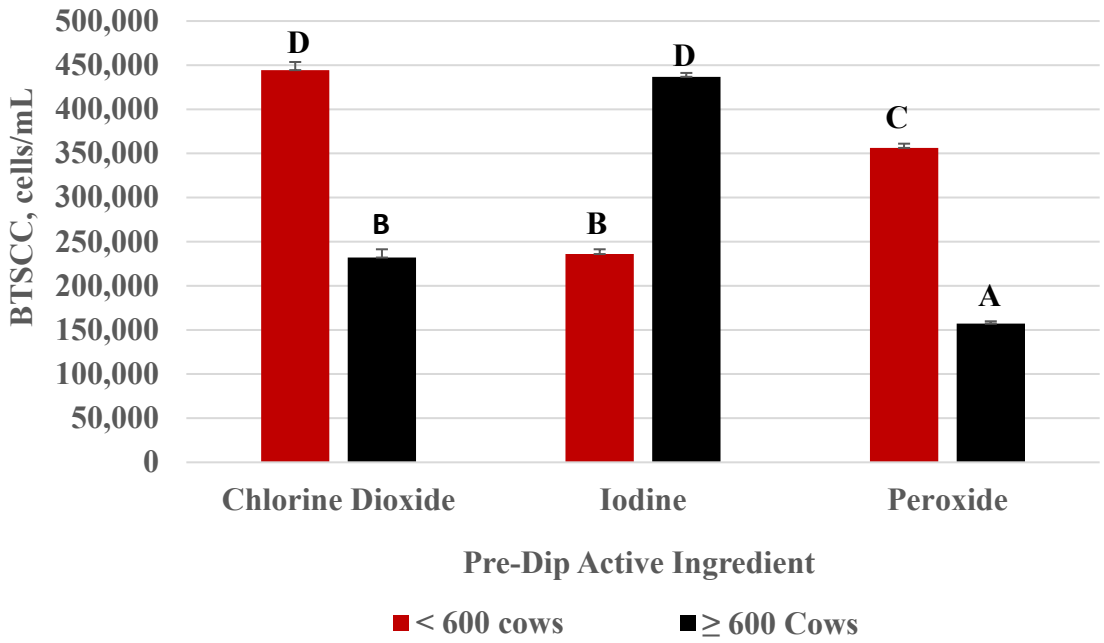


Figure 4.12: Monthly Bulk Tank Somatic Cell Count (BTSCC) by Pre-Dip Active Ingredient (Chlorine Dioxide, Iodine, or Peroxide) and Herd Size (< 600 cows=Small) or (≥ 600 cows = Large).

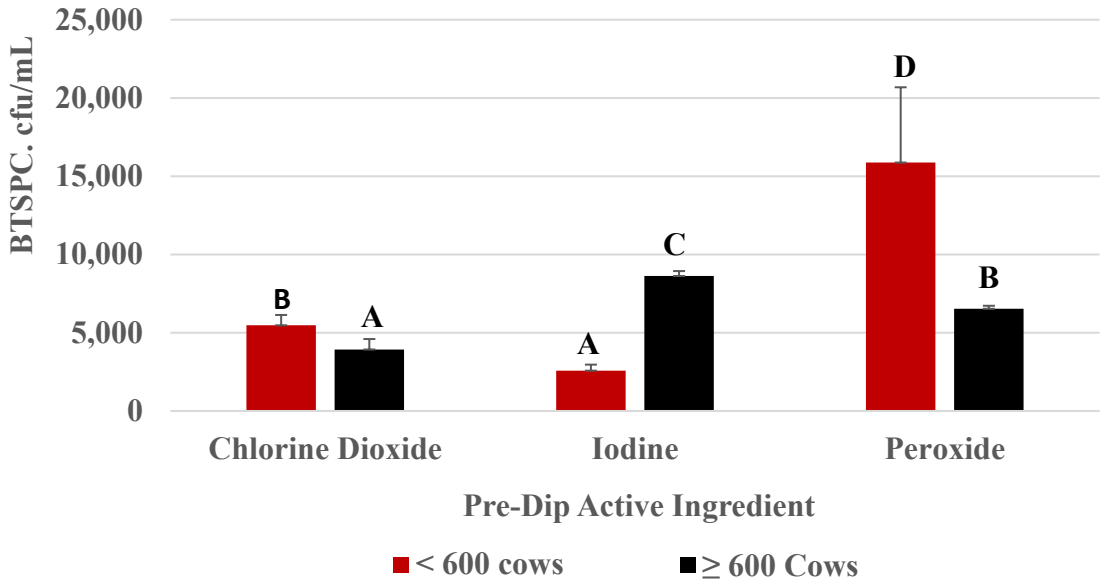


Figure 4.13: Monthly Bulk Tank Standard Plate Count (BTSPC) by Pre-Dip Active Ingredient (Chlorine Dioxide, Iodine, or Peroxide) and Herd Size (< 600 cows=Small) or (≥ 600 cows = Large).

REFERENCES

Allen, Diana B., E. J. DePeters, and R. C. Laben. "Three times a day milking: effects on milk production, reproductive efficiency, and udder health." *Journal of dairy science* 69, no. 5 (1986): 1441-1446.

Barkema, H. W., Y. H. Schukken, T. J. G. M. Lam, M. L. Beiboer, G. Benedictus, and A. Brand. "Management practices associated with low, medium, and high somatic cell counts in bulk milk." *Journal of dairy science* 81, no. 7 (1998): 1917-1927.

Bertocchi, L., A. Vitali, N. Lacetera, A. Nardone, G. Varisco, and U. Bernabucci. "Seasonal variations in the composition of Holstein cow's milk and temperature–humidity index relationship." *Animal* 8, no. 4 (2014): 667-674.

Bey, R., Jeffrey K. Reneau, and Ralph J. Farnsworth. "The role of bedding management in udder health." In *Annual Meeting-National Mastitis Council Incorporated*, vol. 41, pp. 45-55. National Mastitis Council; 1999, 2002.

Blakely, C., G.M. Pighetti, P.D. Krawczell, R.A. Almeida, C.S. Petersson-Wolfe, K. Enger, J.M. Bewley, S. H. Ward, A. Stone, and S. P. Oliver. "Practices Surveyed in the Southeast USA that Impact Milk Quality." *NMC Annual Meeting Proceedings*, (2016)

Bradley, A. J., J. E. Breen, B. Payne, P. Williams, and M. J. Green. "The use of a cephalonium containing dry cow therapy and an internal teat sealant, both alone and in combination." *Journal of Dairy Science* 93, no. 4 (2010): 1566-1577.

Bray, D.R., and J.K. Shearer. 2012. Proper milking procedures. 1–2. Accessed March 24, 2020. https://edis.ifas.ufl.edu/pdffiles/DS/DS12900.pdf

Bushnell, R. B. "Premilking teat sanitation and its effect on mastitis and milk quality." In *Annual meeting-National Mastitis Council, Inc (USA)*. 1985.

Cicconi-Hogan, K. M., M. Gamroth, R. Richert, P. L. Ruegg, K. E. Stiglbauer, and Y. H. Schukken. 2013. Risk factors associated with bulk tank standard plate count, bulk tank coliform count, and the presence of Staphylococcus aureus on organic and conventional dairy farms in the United States. J Dairy Sci 96:7578-7590.

Cook, N. B., T. B. Bennett, K. M. Emery, and K. V. Nordlund. "Monitoring nonlactating cow intramammary infection dynamics using DHI somatic cell count data." *Journal of dairy science* 85, no. 5 (2002): 1119-1126.

De Pinho Manzi, Marcela, Diego Borin Nóbrega, Patrícia Yoshida Faccioli, Marcella Zampolli Troncarelli, Benedito Donizete Menozzi, and Hélio Langoni. "Relationship between teat-end condition, udder cleanliness and bovine subclinical mastitis." *Research in veterinary science* 93, no. 1 (2012): 430-434.

Dufour, S., A. Fréchette, H. W. Barkema, A. Mussell, and D. T. Scholl. "Invited review: Effect of udder health management practices on herd somatic cell count." *Journal of dairy science* 94, no. 2 (2011): 563-579.

Elmoslemany, Ahmed Morsy, G. P. Keefe, I. R. Dohoo, J. J. Wichtel, H. Stryhn, and R. T. Dingwell. "The association between bulk tank milk analysis for raw milk quality and on-farm management practices." *Preventive veterinary medicine* 95, no. 1-2 (2010): 32-40.

Enger, B. D., L. K. Fox, J. M. Gay, and K. A. Johnson. "Reduction of teat skin mastitis pathogen loads: differences between strains, dips, and contact times." *Journal of dairy science* 98, no. 2 (2015): 1354-1361.

Enger, Kellie M. "The Impact of Parlor Equipment and Milking Procedures on Milk Quality in the Southeast US." PhD diss., Virginia Tech, 2017.

Fahr, R. D. "Influencing milk quality and composition: options and limits." *Arch Tierz* 45 (2002): 51-9.

Fairchild, T. P., B. J. McArthur, J. H. Moore, and W. E. Hylton. "Coliform counts in various bedding materials." *Journal of dairy science* 65, no. 6 (1982): 1029-1035.

Food Animal Production Medicine, University of Wisconsin-School of Veterinary Medicine, 2015, *Teat Scorer*, May 1, 2020 https://www.vetmed.wisc.edu/fapm/svm-dairy-apps/teat-scorer/

Food Animal Production Medicine, University of Wisconsin-School of Veterinary Medicine, 2015, *Milking Prep Lag Timer*, May 1, 2020; https://www.vetmed.wisc.edu/fapm/svm-dairy-apps/milking-prep-lag-timer/

Galton, D. M., L. G. Peterson, and W. G. Merrill. "Evaluation of udder preparations on intramammary infections." *Journal of Dairy Science* 71, no. 5 (1988): 1417-1421.

Galton, D. M., R. W. Adkinson, C. V. Thomas, and T. W. Smith. "Effects of premilking udder preparation on environmental bacterial contamination of milk." *Journal of dairy science* 65, no. 8 (1982): 1540-1543.

Godden, S., P. Rapnicki, S. Stewart, J. Fetrow, A. Johnson, R. Bey, and R. Farnsworth. "Effectiveness of an internal teat seal in the prevention of new intramammary infections during the dry and early-lactation periods in dairy cows when used with a dry cow intramammary antibiotic." *Journal of Dairy Science* 86, no. 12 (2003): 3899-3911.

Harmon, R. J. "Physiology of mastitis and factors affecting somatic cell counts." *Journal of dairy science* 77, no. 7 (1994): 2103-2112.

Hogan, J. S., K. L. Smith, K. H. Hoblet, D. A. Todhunter, P. S. Schoenberger, W. D. Hueston, D. E. Pritchard et al. "Bacterial counts in bedding materials used on nine commercial dairies." *Journal of dairy science* 72, no. 1 (1989): 250-258.

Hogan, J. S., V. L. Bogacz, L. M. Thompson, S. Romig, P. S. Schoenberger, W. P. Weiss, and K. L. Smith. "Bacterial counts associated with sawdust and recycled manure bedding treated with commercial conditioners." *Journal of dairy science* 82, no. 8 (1999): 1690-1695.

Hogan, Joe, and K. Larry Smith. "Managing environmental mastitis." *Veterinary Clinics: Food Animal Practice* 28, no. 2 (2012): 217-224.

Hogeveen, H., J. D. Miltenburg, S. den Hollander, and K. Frankena. "Milking three times a day and its effect on milk production and udder health." *Bulletin/International Dairy Federation* (2001).

Hutton, C. T., L. K. Fox, and D. D. Hancock. "Mastitis control practices: differences between herds with high and low milk somatic cell counts." *Journal of Dairy Science* 73, no. 4 (1990): 1135-1143.

Isaksson, A., and O. Lind. "Teat reactions in cows associated with machine milking." *Journal of Veterinary Medicine Series A* 39, no. 1-10 (1992): 282-288.

Janzen, J. J., J. R. Bishop, A. B. Bodine, C. A. Caldwell, and D. W. Johnson. "Composted dairy waste solids and crushed limestone as bedding in free stalls." *Journal of Dairy Science* 65, no. 6 (1982): 1025-1028.

Jayarao, B.M., S.R. Pillai, A.A. Sawant, D.R. Wolfgang, and N.V. Hegde. 2004. Guidelines for monitoring bulk tank milk somatic cell and bacterial counts. *J. Dairy Sci.* 87:3561-73.

Kaskous, S. and R. M. Bruckmaier. 2011. Best combination of pre-stimulation and latency period duration before cluster attachment for efficient oxytocin release and milk ejection in cows with low to high udder-filling levels. J. Dairy Res. 78:97-104.

Klei, Linda R., Joanna M. Lynch, David M. Barbano, Pascal A. Oltenacu, Anthony J. Lednor, and David K. Bandler. "Influence of Milking Three Times a Day on Milk Quality1." *Journal of Dairy Science* 80, no. 3 (1997): 427-436.

Loker, S., F. Miglior, A. Koeck, TF-O. Neuenschwander, Catherine Bastin, J. Jamrozik, L. R. Schaeffer, and D. Kelton. "Relationship between body condition score and health traits in first-lactation Canadian Holsteins." *Journal of dairy science* 95, no. 11 (2012): 6770-6780.

Masiello, S. N., N. H. Martin, R. D. Watters, D. M. Galton, Y. H. Schukken, M. Wiedmann, and K. J. Boor. 2014. Identification of dairy farm management practices associated with the presence of psychrotolerant sporeformers in bulk tank milk. J Dairy Sci 97:4083-4096.

Mein, G., David MD Williams, and Douglas J. Reinemann. "Effects of milking on teat-end hyperkeratosis: 1. Mechanical forces applied by the teatcup liner and responses of the teat." In *Annual Meeting-National Mastitis Council Incorporated*, vol. 42, pp. 114-123. National Mastitis Council; 1999, 2003.

Morse, D., M. A. DeLorenzo, C. J. Wilcox, Robert J. Collier, R. P. Natzke, and D. R. Bray. "Climatic effects on occurrence of clinical mastitis." *Journal of dairy science* 71, no. 3 (1988): 848-853.

National Oceanic and Atomospheric Administration (NOAA) – May 10, 2020, https://www.ncdc.noaa.gov/

Neijenhuis, F., K.C. de Koning, G. Klungel, H.W. Barkema, and H. Hogeveen. 2000b. The effects of machine milking on teat condition. 51th Meeting European Association Animal Production (EAAP), The Hague, The Netherlands.

Norman, H., Guinan, F., Walton, L. and Durr, J., 2020. *Somatic Cell Counts Of Milk From DHI Herds*. [online] Queries.uscdcb.com. Available at: <https://queries.uscdcb.com/publish/dhi/current/sccx.html> [Accessed 24 March 2020].

Olechnowicz, Jan, and Jedrzej M. Jaskowski. "Impact of clinical lameness, calving season, parity, and month of lactation on milk, fat, protein, and lactose yields during early lactation of dairy cows." *Bull Vet Inst Pulawy* 54, no. 4 (2010): 605-10.

Paduch, J.H., Mohr, E. and Krömker, V., 2012. The association between teat end hyperkeratosis and teat canal microbial load in lactating dairy cattle. *Veterinary Microbiology*, *158*(3-4), pp.353-359.

Peeler, E. J., M. J. Green, J. L. Fitzpatrick, K. L. Morgan, and L. E. Green. "Risk factors associated with clinical mastitis in low somatic cell count British dairy herds." *Journal of dairy science* 83, no. 11 (2000): 2464-2472.

Peters, R. R., S. Komaragiri, M. J. Paape, and L. W. Douglass. "Evaluation of 1.6% phenol as a premilking and postmilking teat dip in preventing new bovine intramammary infections." *Journal of dairy science* 83, no. 8 (2000): 1750-1757.

Rasmussen, Morten Dam. "A review of milking preparation: the science." In *Annual Meeting of the National Mastitis Council*, pp. 104-110. 2000.

Reneau, J. K. "Prepping cows: who needs it." In *Proceedings NMC 40th annual meeting*, vol. 40, pp. 33-42. 2001.

Reneau, J. K., and J. P. Chastain. "Premilking cow prep: adapting to your system." In *Proc. Regional Meeting of the Natl. Mastitis Council*, p. 46. 1995.

Reneau, J. K., and J. P. Chastain. "Premilking cow prep: adapting to your system." In *Proc. Regional Meeting of the Natl. Mastitis Council*, p. 46. 1995.

Reneau, Jeffrey K., Anthony J. Seykora, Bradley J. Heins, Russell F. Bey, and Ralph J. Farnsworth. "Relationship of cow hygiene scores and SCC." In *Annual Meeting-National Mastitis Council Incorporated,* vol. 42, pp. 362-363. National Mastitis Council; 1999, 2003.

Rodrigues, A. C. O., D. Z. Caraviello, and P. L. Ruegg. "Management of Wisconsin dairy herds enrolled in milk quality teams." *Journal of Dairy Science* 88, no. 7 (2005): 2660-2671.

Rowbotham, R. F., and P. L. Ruegg. "Association of bedding types with management practices and indicators of milk quality on larger Wisconsin dairy farms." *Journal of dairy science* 98, no. 11 (2015): 7865-7885.

Sant'Anna, A. C., and MJR Paranhos da Costa. "The relationship between dairy cow hygiene and somatic cell count in milk." *Journal of dairy science* 94, no. 8 (2011): 3835-3844.

Schewe, R. L., J. Kayitsinga, G. A. Contreras, C. Odom, W. A. Coats, P. Durst, Ernest Peter Hovingh et al. "Herd management and social variables associated with bulk tank somatic cell count in dairy herds in the eastern United States." *Journal of dairy science* 98, no. 11 (2015): 7650-7665.

Schreiner, D. A., and P. L. Ruegg. "Relationship between udder and leg hygiene scores and subclinical mastitis." *Journal of dairy science* 86, no. 11 (2003): 3460-3465.

Schukken, Y. H., F. J. Grommers, D. Van de Geer, H. N. Erb, and A. Brand. "Risk factors for clinical mastitis in herds with a low bulk milk somatic cell count. 2. Risk factors for Escherichia coli and Staphylococcus aureus." *Journal of Dairy Science* 74, no. 3 (1991): 826-832.

Shearn, M.F.H. and J.E. Hillerton. 1996. Hyperkeratosis of the teat duct orifice in the dairy cow. J Dairy Res. 63:525-532

Silk, A. S., L. K. Fox, and D. D. Hancock. "Removal of hair surrounding the teat and associated bacterial counts on teat skin surface, in milk, and intramammary infections." *Journal of Veterinary Medicine, Series B* 50, no. 9 (2003): 447-450

Smith, D. L., T. Smith, B. J. Rude, and S. H. Ward. "Comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows." *Journal of dairy science* 96, no. 5 (2013): 3028-3033.

Smith, J. W., L. O. Ely, W. M. Graves, and W. D. Gilson. "Effect of milking frequency on DHI performance measures." *Journal of Dairy Science* 85, no. 12 (2002): 3526-3533.

Stiglbauer, K. E., K. M. Cicconi-Hogan, R. Richert, Y. H. Schukken, P. L. Ruegg, and M. Gamroth. "Assessment of herd management on organic and conventional dairy farms in the United States." *Journal of Dairy Science* 96, no. 2 (2013): 1290-1300.

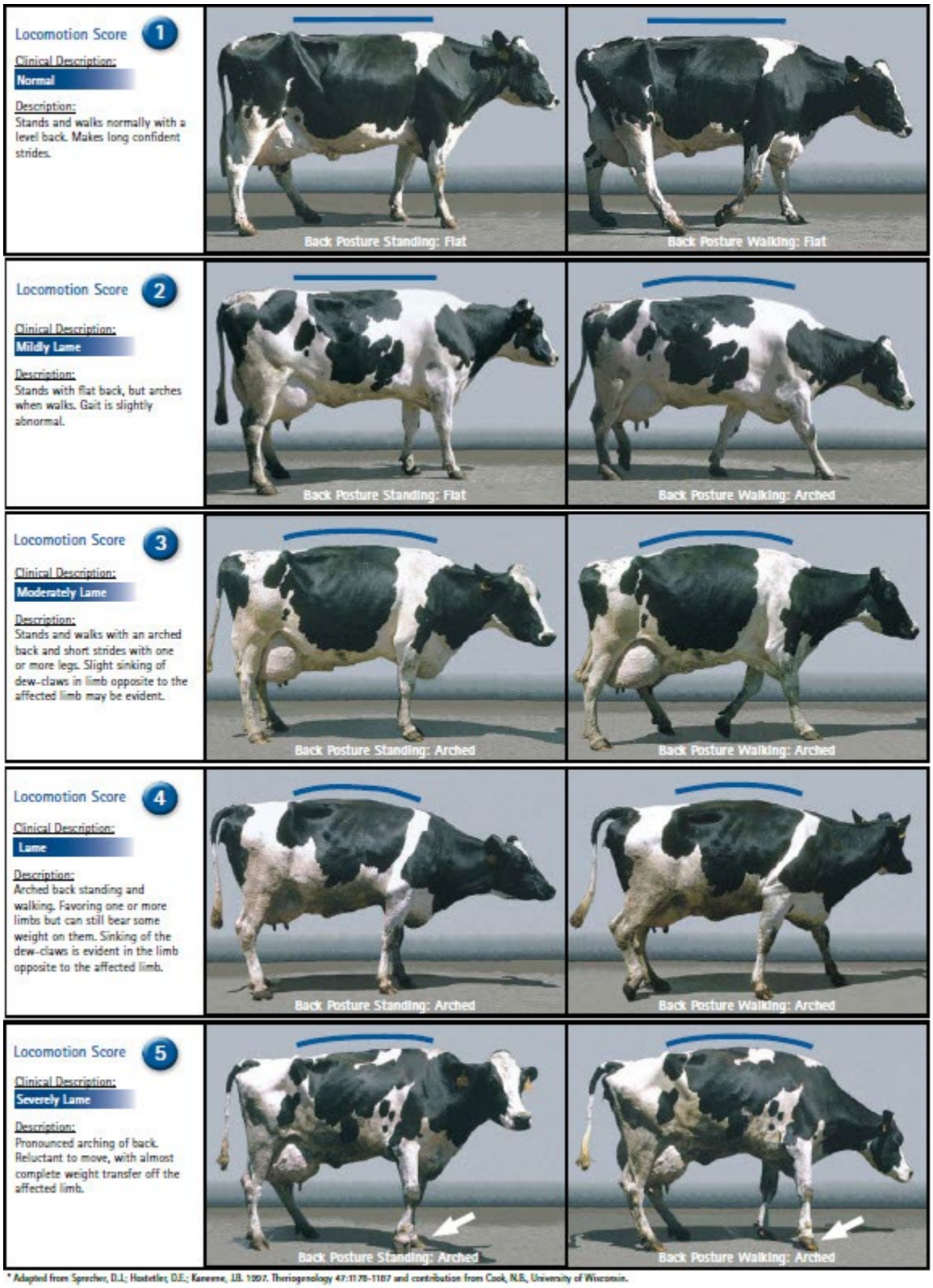
Ward, W. R., J. W. Hughes, W. B. Faull, P. J. Cripps, J. P. Sutherland, and J. E. Sutherst. "Observational study of temperature, moisture, pH and bacteria in straw bedding, and faecal consistency, cleanliness and mastitis in cows in four dairy herds." *Veterinary Record* 151, no. 7 (2002): 199-206.

Wenz, J. R., S. M. Jensen, J. E. Lombard, B. A. Wagner, and R. P. Dinsmore. "Herd management practices and their association with bulk tank somatic cell count on United States dairy operations." *Journal of dairy science* 90, no. 8 (2007): 3652-3659.

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

APPENDICES

Appendix A



* Adapted from Sprecher, D.J.; Hostetler, D.E.; Kaneene, J.B. 1997. Theriogenology 47:1179–1187 and contribution from Cook, N.B., University of Wisconsin.

Appendix B

No Matter How You Look At It...

Body Condition Scoring

ELANCO ANIMAL HEALTH

Is An Important Part of Modern Dairy Management.

In the dairy cow, body condition is an indicator of the amount of stored energy reserves and changes with different stages of lactation. Fresh cows in peak lactation tend to be in a negative energy balance and therefore lose body condition. Late lactation cows, dry cows and low producers are in a positive energy balance and gain condition. There is no one ideal body condition score. There is a range of desirable scores which change for individual cows over the different stages of each lactation.

Dairy farmers should regularly evaluate the body condition of their cows and heifers so they can fine-tune feeding and management practices. Adequate body reserves are necessary to maintain health, production and reproductive efficiency. Underconditioned cows are prone to reduced milk production and poor persistency of lactation. Overly conditioned cows are predisposed to calving difficulties, fatty liver syndrome, impaired reproduction and metabolic disorders.

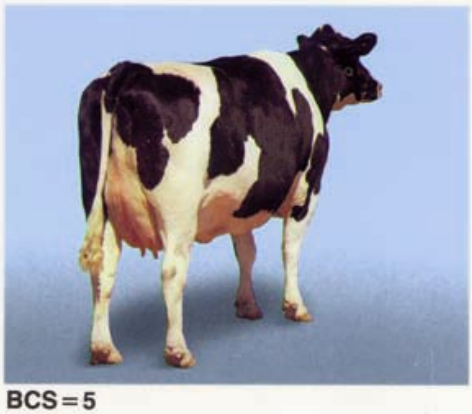
Body condition scoring of cattle is an essential management tool for the progressive dairy farmer. It can be mastered with a little training and good observation skills, using both sight and touch to evaluate each cow.

BCS = 3

BCS = 1

BCS = 4

BCS = 2



BCS = 5

Photos by Craig Johnson

No Matter How You Look At It...

Body Condition Scoring

...Is An Important Part of Modern Dairy Management.

BCS = 1

Deep cavity around tailhead. Bones of pelvis and short ribs sharp and easily felt. No fatty tissue in pelvic or loin area. Deep depression in loin.

BCS = 2

Shallow cavity around tailhead with some fatty tissue lining it and covering pin bones. Pelvis easily felt. Ends of short ribs feel rounded and upper surfaces can be felt with slight pressure. Depression visible in loin area.

BCS = 3

No cavity around tailhead and fatty tissue easily felt over whole area. Pelvis can be felt with slight pressure. Thick layer of tissue covering top of short ribs which can still be felt with pressure. Slight depression in loin area.

BCS = 4

Folds of fatty tissue are seen around tailhead with patches of fat covering pin bones. Pelvis can be felt with firm pressure. Short ribs can no longer be felt. No depression in loin area.

BCS = 5

Tailhead is buried in thick layer of fatty tissue. Pelvic bones cannot be felt even with firm pressure. Short ribs covered with thick layer of fatty tissue.

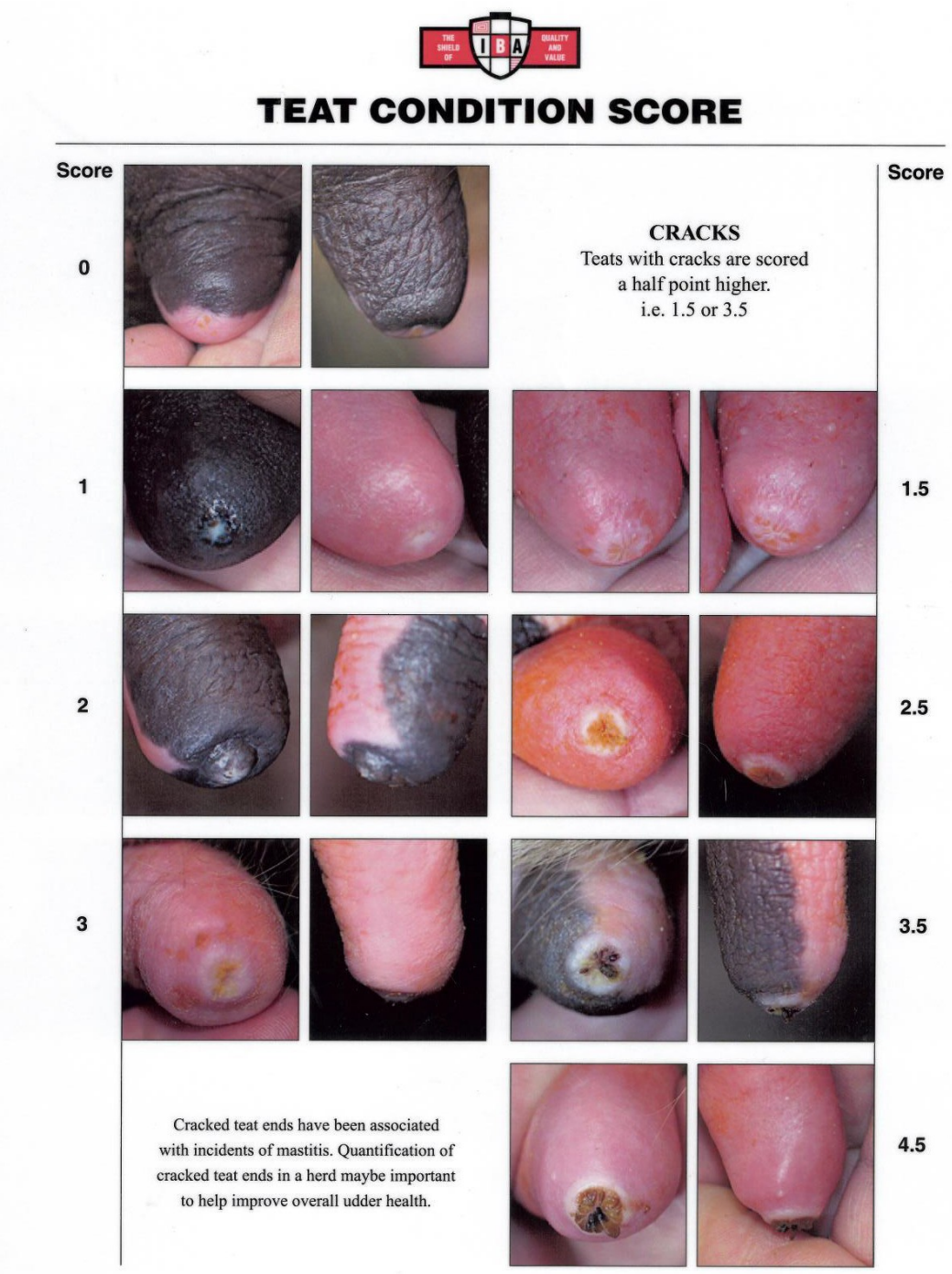
Elanco Animal Health
A Division of Eli Lilly and Company
Lilly Corporate Center
Indianapolis, Indiana 46285, U.S.A.

ELANCO
ANIMAL HEALTH ™

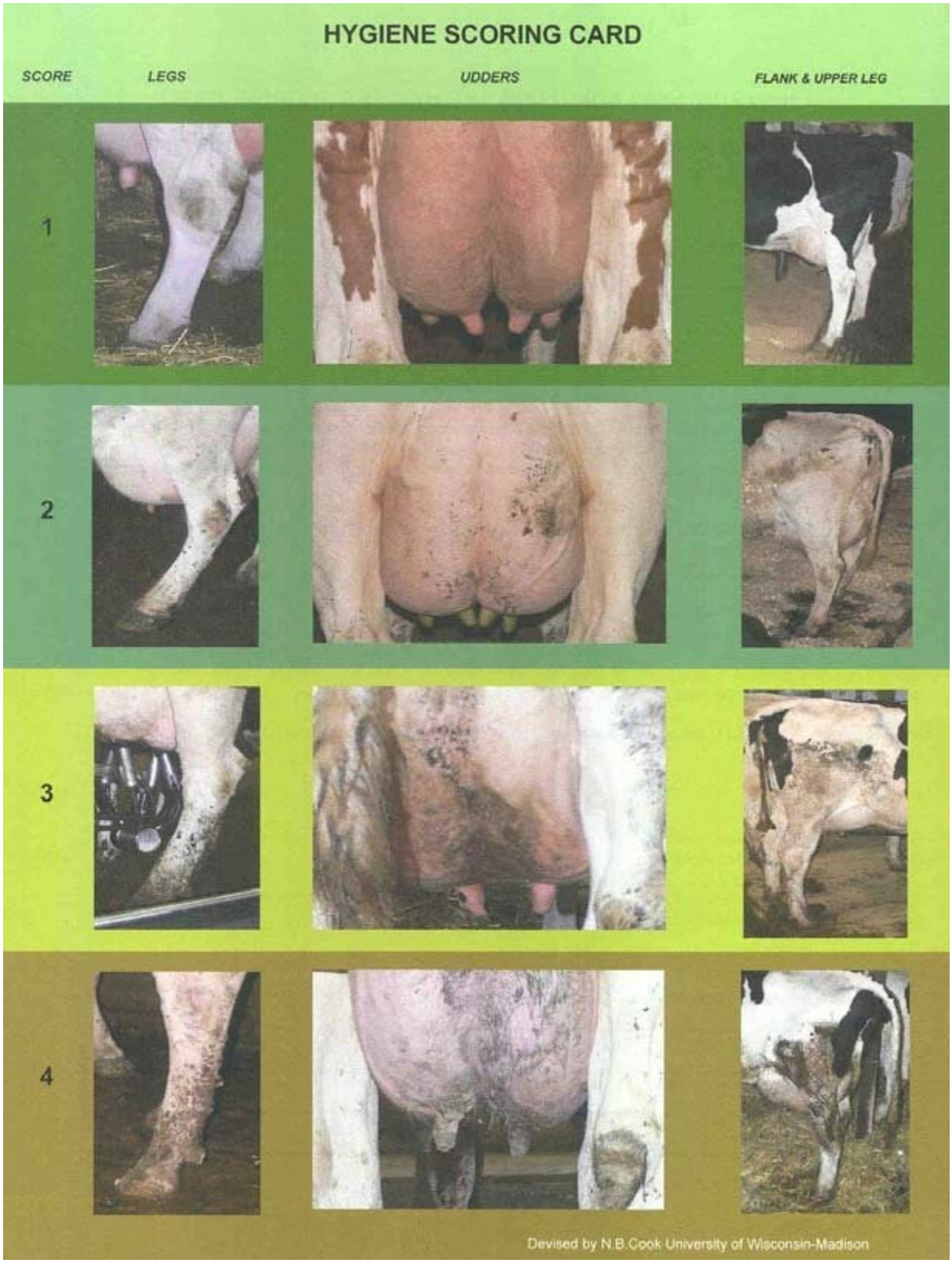
AI 7140

Photos by Craig Johnson

Appendix C


THE SHIELD OF IBA QUALITY AND VALUE
TEAT CONDITION SCORE
Score
Score
0
1
1.5
2
2.5
3
3.5
4.5
CRACKS
Teats with cracks are scored
a half point higher.
i.e. 1.5 or 3.5
Cracked teat ends have been associated with incidents of mastitis. Quantification of cracked teat ends in a herd maybe important to help improve overall udder health.

Appendix D


HYGIENE SCORING CARD
SCORE
LEGS
UDDERS
FLANK & UPPER LEG
1
2
3
4
Devised by N.B.Cook University of Wisconsin-Madison

Appendix E

NCMQ - Producer Questionnaire

Q1 Farm ID Number:_____

Q2 Date (yyyymmdd):_____

Q3 Start Time (military time):_____

Q4 Interviewer (First name, Last name):_____

Q5

Number of cows currently milked:		Number of calves:	
Number of dry cows:		Number birth to weaning:	
Number of milkings/ day		Number of weaned heifers	
Farm Recordkeeping System:		Number of weaning to breeding:	
Current SCC		Number bred heifers:	

Q6 What breeds? Check all that apply

- ❑ Holstein
- ❑ Jersey
- ❑ Ayrshire
- ❑ Brown Swiss
- ❑ Guernsey
- ❑ Other _____

Q7 Are the heifers raised entirely on this operation?

- ❍ Yes
- ❍ No

  - Heifers leave the farm at (months of age) _____

  - Heifers return to the farm at (months of age) _____

Q8 Does the co-op or processor you sell your milk to offer an incentive for achieving a particular bulk tank SCC?

❍ Yes

❍ No

Q9 Does the co-op or processor you sell your milk to offer an incentive for achieving a particular bulk tank Bacteria load (e.g. Standard Plate Count, SPC; Preliminary Incubation (PI) Count)?

❍ Yes

❍ No

Housing

Q10 Which of the following best describes the housing system for your lactating dairy cows?

	Spring (March - May)	Summer (May - August)	Fall (September - November)	Winter (December - February)
Total Confinement (no pasture access)	❑	❑	❑	❑
Mostly Confinement with less than four hours access to dry lot or pasture	❑	❑	❑	❑
Partial confinement with at least four hours access to dry lot or pasture	❑	❑	❑	❑
Exclusively pasture	❑	❑	❑	❑

Q11 Are any of the following special groups of cows housed separately from lactating cows? If yes, indicate the type of housing and bedding (if applicable)…. If no, skip to Q24

	Lactating cows	Far-off dry cows	Close-up dry cows (2-3 weeks prior to calving)	Springing heifers	Calving Pen	Fresh Cows	Hospital or Dump Pen
Free stall	❑	❑	❑	❑	❑	❑	❑
Tie stall	❑	❑	❑	❑	❑	❑	❑
Bedded pack	❑	❑	❑	❑	❑	❑	❑
Compost bedded pack	❑	❑	❑	❑	❑	❑	❑
Pasture w/ portable shade access	❑	❑	❑	❑	❑	❑	❑
Pasture with non-portable shade access (e.g. trees, permanent structure)	❑	❑	❑	❑	❑	❑	❑
Pasture w/o shade access	❑	❑	❑	❑	❑	❑	❑
Outdoor lot	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑

Q12 If in a tie stall or free stall, what base material is used?

	Lactating cows	Far-off dry cows	Close-up dry cows (2-3 weeks prior to calving)	Springing heifers	Calving Pen	Fresh Cows	Hospital or Dump Pen
Concrete	❑	❑	❑	❑	❑	❑	❑
Rubber mat	❑	❑	❑	❑	❑	❑	❑
Rubber filled mattress	❑	❑	❑	❑	❑	❑	❑
Water bed	❑	❑	❑	❑	❑	❑	❑
Deep bedded sand, sawdust, or straw	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑

Q13 If bedding material is needed, which of the following is used?

	Lactating cows	Far-off dry cows	Close-up dry cows (2-3 weeks prior to calving)	Springing heifers	Calving Pen	Fresh Cows	Hospital or Dump Pen
Limestone	❑	❑	❑	❑	❑	❑	❑
Straw bedding	❑	❑	❑	❑	❑	❑	❑
Sand, fresh	❑	❑	❑	❑	❑	❑	❑
Sand, recycled	❑	❑	❑	❑	❑	❑	❑
Sawdust or wood shavings	❑	❑	❑	❑	❑	❑	❑
Straw	❑	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑	❑

Q14 Are any of the following groups of cows housed separate from each other?

	Yes	No
Far off dry cows are housed separately from close-up dry cows	❍	❍
Fresh cows are housed separately from hospital/dump cows	❍	❍
Fresh cows are housed separately from other lactating cows?	❍	❍
First lactation cows are separated from older lactating cows	❍	❍
Mastitis treated (e.g. milk withhold) cows are separated from lactating cows?	❍	❍
High SCC (e.g. chronic, contagious, Staph aureus mastitis) cows are separated from lactating cows?	❍	❍

Q15 How often do you flush or scrape standing areas?

❍ Automatic system, number of times per day? _____

❍ Manual system, number of times per day _____

Q16 How often do you manually scrape standing areas in the pen that cannot be done automatically (e.g. cross-over alleys, in front of waterers, etc.)? _____

Q17 How often do you flush/scrape the transfer alleys to the milking parlor (excluding holding pens)?

❍ Automatic system, number of times per day? _____

❍ Manual system, number of times per day _____

Q18 For a stall based system, how often do you rake out stalls and remove cow patties?

_____

Q19 For your primary lactating cow facility, how often is new bedding material added?

_____

Q20 Are any conditioners or treatment applied to the bedding?

- ❍ Yes, hydrated lime
- ❍ Yes, ag lime
- ❍ Yes, other (write in type below) _____
- ❍ No

Q21 How often are conditioners or treatments applied? _____

Q22 Are fans/water systems used in barns?

	Fan system	Misters	Soakers
❑ Parlor	❑	❑	❑
❑ Housing	❑	❑	❑
❑ Holding Pen	❑	❑	❑

Q23 If yes, fans are turned on based on:

- ❍ Calendar year _____
- ❍ Visual observation of the cows
- ❍ Temperature _____
- ❍ Other _____

Q24 If yes, water systems are turned on based on:

- ❍ Calendar year _____
- ❍ Visual observation of the cows
- ❍ Temperature _____

Other _____

Q25 If cows have access to outside areas, do they have access to the following water sources?

	Yes	No
Pond	❍	❍
Center Pivot	❍	❍
Stream	❍	❍
Free-standing water after a storm	❍	❍
Other _____	❍	❍

Milking

Q26 Who milked the majority of the cows on this operation during the past year?

- ❍ Owner/Operator
- ❍ Family member(s) of owner
- ❍ Hired worker(s) non-family members

Q27 What time of day are your cows milked? _____

Q28 Are fresh cows milked more frequently?

- ❍ Yes
- ❍ No

Pre Wipe – cleaning teats of debris prior to predip

❑ **N/A**

Q29 Do you use a wet or dry towel to pre wipe teats?

	Cloth towel	Paper Towel	Wet wipe	Sponge	Water hose
Single use	❍	❍	❍	❍	N/A
Multiple use	❍	❍	❍	❍	N/A
Commercial Disinfectant	❍	❍	❍	❍	❍
Homemade disinfectant	❍	❍	❍	❍	❍

Pre-Dip – Dipping teats with disinfectant prior to attaching milking unit

❑ **N/A**

Q30 What type of pre-dip do you use and how is it applied?

	Sprayer	Cup	Foam
Commercial Disinfectant	❍	❍	❍
Homemade disinfectant	❍	❍	❍

Dry Teats – drying teats after cleaning prior to attaching milking unit

❑ **N/A**

Q31 How do dry or clean teats before milking unit is attached?

	Air dry	Cloth Towel	Paper Towel
Single use	❍	❍	❍
Multiple use	N/A	❍	❍

Post-dip – disinfectant applied after removal of milking unit

❑ **N/A**

Q32 What type of post-dip do you use and how is it applied?

	Sprayer	Cup	Foam	Powder
Commercial Disinfectant	❍	❍	❍	❍
Homemade disinfectant	❍	❍	❍	❍

Q33 Did you stop using a wet post-milking disinfectant product during extremely cold temperatures?

❍ Yes

❍ No

Q34 Barrier teat dips are used on (check all that apply)

❍ Used on all cows, all of the times

❍ Used on all cows during the winter or adverse weather

❍ Used only on selected cows (e.g. Mastitis)

❍ Used only at dry off

❍ No barrier teat dip used on this farm

❍ Other _____

Standard operating procedure for milking

Q35 Is there a standard operating procedure developed for milking?

❍ Yes

❍ No

Q36 If yes, is the milking procedure written?

❍ Yes

❍ No

Q37 Is the milking procedure available in the parlor?
- ❍ Yes
- ❍ No

Q38 Is the milking procedure available in the primary language spoken by the milking personnel?
- ❍ Yes
- ❍ No

Equipment and cleaning

Q39 How frequently does the owner/manager observe milking? (If they don't milk themselves)
- ❍ Never
- ❍ When there is a problem
- ❍ Less than once a month
- ❍ About once each month
- ❍ About once each week
- ❍ About once each day, only one milking time
- ❍ About once each day, alternating between different milking times
- ❍ Each milking

Q40 Do milkers wear latex or nitrile gloves during milking cows over the last 12 months?
- ❍ Always
- ❍ Sometimes
- ❍ Never

Q41 How are the milking units cleaned between cows (check all that apply)?
- ❍ They are not
- ❍ Automatic back flush with disinfectant
- ❍ Automatic back flush with water
- ❍ Manually dipping units in bucket
- ❍ Rinsed with hose if dirty

Q42 Do you use automatic take-offs for your milking units?
- ❍ Yes
- ❍ No

Q43 If automatic take-offs are used, how often are the units set to manual or the unit replaced on cows after being automatically removed?
- ❍ Often
- ❍ Rarely
- ❍ Never

Q42 How frequently is the milking deck washed where the cows stand? (RA)

- ❍ Floors are washed during and between milking groups
- ❍ Floors are washed only between groups
- ❍ Floors are washed as needed during milking
- ❍ Floors are washed after each milking
- ❍ Floors are not washed between every milking

Q43 How frequently is the milking system/pipeline washed? _____

Q44 What steps are included in washing the pipeline (check all that apply)?

- ❑ Rinse
- ❑ Hot wash/detergent
- ❑ Acid rinse
- ❑ Acid rinse combined with sanitizer
- ❑ Sanitizer

Q45 If sanitizing cycle is used, when does it occur?

- ❍ Before every milking
- ❍ After every milking
- ❍ Before and after every milking
- ❍ A separate sanitizing cycle is not run

Q46 How often is milking equipment cleaned and inspected?

	Pulsators	Vaccum control	Rubber components	Overall milking system
Never	❍	❍	❍	❍
< 1/year	❍	❍	❍	❍
1/year	❍	❍	❍	❍
2/year	❍	❍	❍	❍
4/year	❍	❍	❍	❍
1/month	❍	❍	❍	❍
2/month	❍	❍	❍	❍
Each milking	❍	❍	❍	❍
other	❍	❍	❍	❍

Q47 Are the following milking system checks performed by on-farm personnel or a qualified technician?

	On farm personnel	Qualified technican	Both
Pulsators cleaned and inspected	❍	❍	❍
Vacuum control / regulator inspected	❍	❍	❍
System maintenance check and evaluation	❍	❍	❍
Cracks and aging in rubber components	❍	❍	❍

Mastitis

Q48 Who of the following are responsible for diagnosing mastitis? (NAHMS)

- ❑ Owner
- ❑ Milkers
- ❑ Manager/Herdsman
- ❑ Other _____

Q49 How many people treat cases of mastitis on your farm?_____
_____

Q50 How do you check for clinical mastitis (check all that apply)?

- ❑ See abnormal milk on filter
- ❑ Check for abnormal milk once per day or less
- ❑ Check for abnormal milk every milking
- ❑ CMT positive
- ❑ Swollen quarter
- ❑ Decreased milk yield and sick cow
- ❑ Veterinarian diagnosis
- ❑ Other _____

Q51 When would you start IMM antibiotic therapy for clinical mastitis?

- ❍ Electrical conductivity or any other automatic parameter changed
- ❍ A few flakes present in milk that disappear after a few strips
- ❍ A moderate number of flakes still present after 10-15 strips, but no thick or stringy clots in milk
- ❍ Thick or stringy clots in milk and/or the quarter is red, hot and swollen
- ❍ Sick cow (dehydrated, lethargic, drop in milk production) with abnormal milk and/or quarter
- ❍ Wait a few days to see if signs continue
- ❍ After culturing
- ❍ Other _____

Q52 What products do you use to manage a case of clinical mastitis?

Product name	How is the product administered?	What is the dose given per day	How many days do you give this product	What % cases do you use this product on?

Q53 Are any of these additional procedures used for clinical mastitis (check all that apply)?

- ❑ Strip quarter frequently
- ❑ Oxytocin
- ❑ Call veterinarian
- ❑ Dry off quarter if non-responsive to therapy
- ❑ Early dry off if non-responsive to therapy
- ❑ Other _____

Q54 How many cases of clinical mastitis were treated over the past month? _____

Q55 Is this number of treated clinical cases greater or less than most months?

- ❍ Greater than
- ❍ Less than
- ❍ About the same

Q56 Is this number of treated cases based on records or memory?

- ❍ Records
- ❍ Memory

Q57 How do you recognize subclinical mastitis (check all that apply)? (PR)

- ❑ CMT Positive
- ❑ Other cowside SCC test
- ❑ Automatic/Inline testing (e.g. electrical conductivity, individual milk components, SCC)
- ❑ Monthly DHIA SCC
- ❑ Don't know what subclinical mastitis is
- ❑ Never have subclinical mastitis
- ❑ Don't check for subclinical mastitis

Q58 Do you treat subclinical mastitis?

- ❍ Always
- ❍ Sometimes
- ❍ Never

Q59 What traditional products do you use to manage a case of subclinical mastitis?

Product name	How is the product administered?	What is the dose given per day	How many days do you give this product	What % cases do you use this product on?

Q60 Are any additional procedures used to treat subclinical mastitis (check all that apply)?

- ❑ Strip quarter frequently
- ❑ Oxytocin
- ❑ Call veterinarian
- ❑ Dry off quarter if non-responsive to therapy
- ❑ Early dry off if non-responsive to therapy
- ❑ Other _____

Q61 Do you have written treatment protocols for clinical mastitis?

- ❍ Yes
- ❍ No

Q62 Do you keep a record of clinical mastitis cases treated with antibiotics?

- ❍ Yes
- ❍ No

Q63 How do you record cases of clinical mastitis treated with antibiotics (check all that apply)?

- ❑ Cow numbers are recorded on a piece of paper or dry erase board while cows are being treated
- ❑ Written records on a notepad or calendar by date
- ❑ Written records are kept for individual cows
- ❑ Electronic records are kept by calendar date
- ❑ Electronic records are kept for individual cows
- ❑ Excel
- ❑ Other _____
- ❑ N/A

Q64 What types of information are recorded (check all that apply)?

- ❑ Date
- ❑ Cow
- ❑ Quarter
- ❑ Severity of signs
- ❑ Treatment applied
- ❑ Organism (if cultured)
- ❑ Other _____
- ❑ N/A

Milking Reports

Q65 Do you participate in Dairy Herd Improvement Association testing for SCC?

- ❍ Yes (If Yes, ask them to sign a letter of agreement to access their DHI records.)
- ❍ No

Q66 How often do you monitor bulk tank reports?

- ❍ Rarely
- ❍ If there is an issue
- ❍ Check about once a month
- ❍ Check about once a week
- ❍ Check each delivery
- ❍ Monitor each delivery using a spreadsheet

Q67 In the past 12 months, have you made any management changes to deal with mastitis?

- ❍ Yes
- ❍ No

Q68 If yes, what was the reason for change?

- ❑ Increased clinical mastitis in the herd
- ❑ Increased SCC
- ❑ Bulk tank SCC greater than goal of _____
- ❑ Bulk tank SCC greater than 750,000
- ❑ Other _____

Q69 What changes were made?

Q69 Do you discard milk from high SCC cows?

- ❍ Yes, If yes, describe when. _____
- ❍ No

Q70 When selecting sires, which of the following do you include in your genetic selection decisions?

- ❑ SCS - Somatic cell score
- ❑ PL - Productive Life
- ❑ Semex scoring system - Immunity Plus
- ❑ Net Merit Index
- ❑ TPI/JPI or similar index
- ❑ Other _____
- ❑ None of the above

Q71 When are the udders typically singed or clipped?

- ❑ Around calving
- ❑ At dry off
- ❑ During the dry period
- ❑ Spring
- ❑ Summer
- ❑ Fall
- ❑ Winter
- ❑ Other _____

Q72 During the past 12 months, have you vaccinated your cows to control mastitis? (NAHMS)

- ❍ Yes
- ❍ No

Q73 Which mastitis vaccine have you used?

	Yes or No	# Injections x Volume
Coliform vaccine (e.g. J5, J-Vac, Endovac-Bovi)		
Staph. aureus		

Q74 For cows or heifers purchased or raised off-site, which of the following practices have routinely been used in the past 12 months (check all that apply)?

- ❑ Quarantine animals from the herd for 2-3 weeks to observe for disease
- ❑ Check SCC in lactating cows
- ❑ Culture milk quarters
- ❑ None of the above

Q75 How are cows dried off (check all that apply):

- ❑ Set Schedule (so many days prior to calving) How many days before dry off? _____
- ❑ Reduce the quality / energy content of feed
- ❑ Minimum milk production level
- ❑ Abruptly stopping milking
- ❑ Reducing milk production first

Q76 Milk production was reduced by which of the following methods:

- ❑ Skip milkings before complete dry off (e.g. milk once a day)
- ❑ Reduce the quality / energy content of feed
- ❑ Restrict access to feed
- ❑ Restrict access to water
- ❑ Other _____
- ❑ N/A

Q77 What percentage of cows received intramammary antibiotics at dry off during the last 12 months?

- ❍ 0%
- ❍ 100%
- ❍ < 100%, Write in the percentage treated below _____

Q78 What percentage of cows received intramammary teat sealants at dry off during the last 12 months?

- ❍ 0%
- ❍ 100%
- ❍ < 100%, Write in the percentage treated below _____

Q79 What percentage of cows received external teat sealants at dry off during the last 12 months?

- ❍ 0%
- ❍ 100%
- ❍ < 100%, Write in the percentage treated below _____

Q80 If selective use of intramamary antibiotics, internal teat sealants, or external teat sealants was done (e.g. <100%), how were cows selected?

	IMM Antibiotics	Internal Teat Sealant	External Teat Sealant
High SCC	❑	❑	❑
History of mastitis (clinical/chronic)	❑	❑	❑
Milk production	❑	❑	❑
During adverse weather only	❑	❑	❑
During one or more seasons	❑	❑	❑

Q81 Do you use alcohol pads before administering dry-cow IMM antibiotics? (NAHMS)

❍ Yes

❍ No

Q82 Of all cows treated during the past 12 months with dry-cow IMM antibiotics, which of the following products were used? (NAHMS)

❑ Spectramast DC (ceftiofur hyrochloride)

❑ Cefa-Dri/Tomorrow (cephapirin benzathine)

❑ Boviclox, Dry-Clox, Dry-Clox Intramammary Infusion; Orbenin-DC (cloxacillin benzathine)

❑ Gallimycin-Dry (erythromycin)

❑ Biodry (novobiocin)

❑ Hanford's/US Vet Go Dry (penicillin G procaine)

❑ Quartermaster Dry Cow Treatment (penicillin G procaine/dihydrostreptomycin)

❑ Albadry Plus Suspension (penicillin G procaine/novobiocin)

❑ Other _____

❑ N/A

Q83 Were any IMM antibiotics administered to dairy heifers during the past 12 months? (NAHMS)

❍ Yes

❍ No

Q84 If yes, what percentage of heifers were treated? _____

Q85 Were milk cultures performed on any of the following during the last 12 months? (NAHMS)

	Yes	No
Individual cows	❑	❑
Bulk tank milk	❑	❑
String samples (samples representing a group/pen of cows)	❑	❑

Q86 During the past 12 months, what types of cows were typically selected for milk culturing? (NAHMS)

	Yes	No
Fresh cows	❑	❑
All clinical mastitis cases	❑	❑
Chronic clinical mastitis cases	❑	❑
Clinical mastitis cases that did not respond to treatment	❑	❑
High somatic cell count cows	❑	❑
Other	❑	❑

Q87 During the past 12 months, were any of the milk cultures performed by: (NAHMS)

	Yes	No
Farm personnel, done on farm	❑	❑
A state or university diagnostic lab	❑	❑
A commercial lab	❑	❑
A private veterinary lab (veterinary clinic)	❑	❑

Q88 How many samples were cultured over the past month?

Q89 Was the number of samples cultured the past month similar to other months of the year?

❍ Yes

❍ No

Nutrition

Q90 Which of the following management practices do you regularly use for your transition cows - close up and fresh cows?

- ❑ A specific close up ration is fed
- ❑ A calcium gel is given near calving
- ❑ Check for sub-clinical ketosis using cow-side or other tests
- ❑ Temperature check post calving
- ❑ Monitoring technology data (activity, rumination, etc.)
- ❑ Other _____

Q91 What type of ration do you feed to your lactating herd?

- ❍ Total mixed ration
- ❍ Grazing
- ❍ Grazing with supplementation
- ❍ Component feeding
- ❍ Other _____

Q92 How many times a day are cows fed and at what time? _____

_____

Q93 How many times a day do you push up feed?_____

_____

Q94 Do you feed for refusal?

- ❍ Yes
- ❍ No

Q95 If grazing, do you graze rotationally or continuously?

- ❍ Rotationally
- ❍ Continously

Q96 If rotationally grazing, how many hours/days/time between rotations from pasture to pasture?

_____

_____

Q97 What is your stock rate per acre?

_____

_____

Q98 Do you use feed additives to manage SCC?

❍ Yes, What products? _____

❍ No

Q99 Do you have regularly scheduled visits from your veterinarian?

❍ Yes, How often (# times/year)? _____

❍ No

Training

Q100 Were personnel trained in the following procedures during the past 12 months?

			Person providing training					
	Y	N	Owner	Manager/herdsperson	Other employee	Veterinarian	University/extension	Industry personnel
Milking	❍	❍	❑	❑	❑	❑	❑	❑
Mastitis detection	❍	❍	❑	❑	❑	❑	❑	❑
Intramammary infusion	❍	❍	❑	❑	❑	❑	❑	❑

Q101 During the past 12 months, how frequently were milkers trained?

❑ Trained new personnel

❑ Regularly scheduled training during the year

❑ When there was a problem

❑ Other _____

Q102 Which of the following milker training methods were used during the past 12 months?

	Yes	No
Video/web based training	❑	❑
Discussion/lecture	❑	❑
On the job training	❑	❑

Q103 How many meetings regarding milk quality have you attended in the past 12 months?

_____

_____

Q104 How many meetings regarding milk quality have your employees attended in the past 12 months?

_____

_____

Q105 What would you like to see or do at the next milk quality or extension meeting?

_____
_____

Q106 What is your position on the farm?

- ❍ Owner (solely or jointly)
- ❍ Manager
- ❍ Non-family business
- ❍ Other _____

Q107 Time finished (military time)_____
_____

This section is to be filled out by the person conducting the survey

Q108 Producer data quality

- ❍ Good to excellent
- ❍ OK
- ❍ Poor

Q109 Comments regarding this questionnaire or operation:

_____
_____
_____
_____