2018

COMPARING DAIRY FARM PERFORMANCE AND HEAT STRESS ABATMENT STRATEGIES IN THE UNITED STATES USING SUMMER TO WINTER RATIOS

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Digital Object Identifier: https://doi.org/10.13023/ETD.2018.123

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THESIS

A dissertation submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

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2018

ABSTRACT OF THESIS

COMPARING DAIRY FARM PERFORMANCE AND HEAT STRESS ABATMENT STRATEGIES IN THE UNITED STATES USING SUMMER TO WINTER RATIOS

Heat stress abatement is a challenge for producers in the United States, especially in the southern states. Dairy producers could benefit by having a simply metric to measure heat stress abatement strategies with the goal of motivating improvement in heat stress management. Managing heat stress is key to ameliorating the effects on dairy cow performance. A study was performed to explore the use of a heat stress metric called the Summer to Winter performance ratio (S:W ratio), to quantify and compare farm performance variables among regions of the United States. Summer to Winter ratios were closest to 1.0 in the northern regions and furthest from 1.0 in the southern regions for all performance variables other than milk fat and protein percentage. This suggests that summer performance varies by region and shown using the S:W ratio. A second study compared S:W ratios among Southeast states and then applied the performance ratio to heat abatement strategies in Southeast states. The S:W ratio varied by performance measure and heat abatement strategies but tended to be best for herds implementing cow cooling strategies. The studies in this thesis demonstrated S:W ratios can identify heat stress differences by region and heat abatement strategies by herds.

KEYWORDS: benchmark, thermoregulation, management, dairy cattle

Jenna Guinn

April 18, 2018

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ACKNOWLEDGEMENTS

My plans after college never included grad school. It wasn't until I had been working at Alltech for almost two years did I realize I wanted something more. I wasn't finished learning. After hearing about an opening working with Dr. Bewley and the Southeast Quality Milk Initiative (SQMI), with a little encouragement, I decided to jump in, because it was now or possibly never. I'm thankful that as a shy undergraduate who had no idea what she wanted to do with her life, Dr. Bewley had confidence in me that I could take on a research project of my own. This pointed me towards a path that little did I know would continue years later when he encouraged me to pursue graduate school. He saw the potential that I didn't see, and through my two years working on this degree, I have grown so much as a person and have done things that I would have never thought I would. I have grown more confident and comfortable networking with strangers, presenting scientific research, talking to farmers, and being a leader to others. I am very grateful to Dr. Bewley for this. These aspects that grad school provided me is what I am most thankful for, giving me confidence that I can do anything in my career that I set my mind to.

Thank you to Dr. Costa, who began working with me mid-project and came in like he had been around the whole time. I'm so thankful that he was there to take over and provide me with so much guidance and knowledge in just a short period of time. His laid-back attitude, confidence in me, and added challenge to push me forward is what got me through the finish line. I couldn't have done it without his help. I know that we will stay in touch and hopefully work together in the future.

To Dr. Harmon, if I hadn't taken your Milk Secretion class during undergrad, I wouldn't have pursued my dairy interest! I can't express my gratitude enough for your love of teaching and sincerity to your students. You were a mentor for so many people and an example for all to learn from. I was also lucky enough to learn from you when you taught the dairy micro class over the summer. That was fun and again, I learned so much! While my thesis was focused on heat stress, my true love is for milk quality and mastitis! Thanks for being such a role model.

I wouldn't have had the opportunity to attend grad school if it wasn't for SQMI. The position being related to milk quality is what convinced me to apply. I learned so much from the entire group and had such a fun time at conferences. Overseeing and going on all the farm visits is what really made my grad school experience. The relationships I built with the dairy farmers were special to me, and I learned so much from them. They are truly what drives me to my passion for the industry. At times it was hard to remember why I was there but being on farms reminded me quickly that I was where I was supposed to be.

To my friends and family (you know who you are), I appreciate all the kind words of encouragement and listening to me complain about how stressful things were at times. These conversations were the little steps that pushed me forward towards my goals and helped me to accomplish them. While I was unsure at times, you all never doubted my ability to get through the hard work. Thanks for keeping me grounded by doing fun things with me while I was a stressed grad student, and for putting up with my lack of free time! Surely there's a saying about getting through grad school with the same friends you started with means they'll be around for a lifetime! Or maybe not…but it's true!

Mom and Dad, thanks for supporting me not only these past two years but my entire life. I'm lucky to have two parents who love me and support my crazy dreams of hanging out with dairy cows. You all encouraged me to follow this path and I couldn't have made it through without you all. I have you all to thank for everything I have accomplished. Love you all.

To my wonderful husband, Lucas. You probably dealt with this journey the most, in a not so enjoyable way. You were there to put up with the moodiness and stress through it all! I can't thank you enough for moving to Lexington so that I could go to grad school, and for putting up with me this whole time! We are now stronger because of it. Thanks for being my shoulder to lean on! I love you.

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FREQUENTLY USED ABBREVIATIONS

BGHI = Black globe heat index

BTSCC = Bulk tank somatic cell count

DMI = Dry matter intake

FSH = Follicle stimulating hormone

GnRH = Gonadotropin-releasing hormone

LCT = Lower critical temperature

LH = Luteinizing hormone

RH = Relative humidity

SCC = Somatic cell count

SCS = Somatic cell score

S:W Ratio = Summer to Winter ratio

TAI = Timed artificial insemination

THI = Temperature-humidity index

UCT = Upper critical temperature

CHAPTER ONE

REVIEW OF LITERATURE

INTRODUCTION

Heat stress was defined as combined external forces on a homeothermic animal that acts to destabilize body temperature (Yousef, 1985), to an extent where the animal can not dissipate enough metabolically produced or absorbed heat to maintain thermal equilibrium (Bernabucci et al., 2014). Heat stress is an increasingly challenging issue in the dairy industry, as environmental temperatures have increased globally close to 0.7°C from the year 2000, and by the end of the century are anticipated to increase by another 1.8-4°C due to climatic change (IPCC, 2014). In recent years, research on dairy cattle has focused on selection for milk production traits obtained through an increase in feed intake, subsequently causing a rise in metabolic heat production and becoming more susceptible to heat stress (Kadzere et al., 2002). Milk production in the US has increased by 13% from about 9,000 to 10,400 (kg/cow) through the past decade (USDA, 2018a). This has led to dairy cattle experiencing heat stress earlier in the summer, particularly for higher producing animals (Kadzere et al., 2002). When milk yield is increased from 35 to 45 kg/d, the heat stress threshold decreases by 5°C (Berman, 2005). The evidence that as milk production increases, sensitivity to heat stress increases (Kumar et al., 2011) proposes a need for researchers to discover methods for reducing the effects heat stress on performance in the dairy herd.

Cattle are homeotherms, or organisms that use metabolic activity to maintain stable internal temperatures. When the environment reaches temperatures higher than a cows thermoneutral zone of 5-25ºC (Figure 1.1) they are unable to thermoregulate effectively, resulting in compromised performance (Berman, 1968). Metabolic processes, feed intake, and digestive requirements increase with increasing milk yield, therefore increasing overall body heat (West, 2003). Heat stress directly and indirectly affects nutrition, productivity, physiology, health, and behavior of lactating dairy cattle, in turn negatively affecting farm profitability (Cook et al., 2007, Tucker et al., 2008, Rhoads et al., 2009). Physiologic mechanisms for coping with heat stress include, increased respiration rate, sweating, and reduced milk production and reproductive performance (Fuquay, 1981, St-Pierre et al., 2003, West, 2003, Polsky and von Keyserlingk, 2017). Coping mechanisms based on behavior changes includes, changes in drinking and feed intake, increased standing time and shade seeking, and decreased activity (De Rensis and Scaramuzzi, 2003, West, 2003, Schütz et al., 2009).

Reduction in milk production, reproductive performance, and milk quality caused by heat stress reduces farm profitability for dairy producers. As a result of these factors and more, heat stress is estimated to cost the US dairy industry $900 million annually, and likely much higher today (St-Pierre et al., 2003). Additionally, Mukherjee et al. (2013) reported the average estimated gain in gross revenues based on data from farms in FL and GA using fans and sprinklers combined, was estimated at $106,830 per year, with input costs for fans and sprinklers at $51 annually. This illustrates the need for evaporative cooling strategies for heat abatement. Flamenbaum and Galon (2010) estimated a cost of $36 per farm annually as the cost for installing intensive cooling equipment which gives a return on investment of $11 per year for every $1 invested. Heat stress associated problems are wide spread in the dairy industry, making it imperative to learn how to effectively manage it on farms. The purpose of this review was to explore the effects of heat stress on the lactating dairy cow and effective on-farm management strategies to ameliorate the negative effects of heat stress.

Thermoneutral Zone of Dairy Cattle

Establishing the threshold at which cattle undergo heat stress is the first step in understanding how to manage it. Original research reports the thermoneutral zone of cattle as ranging from the lower critical temperature (LCT) to the upper critical temperatures (UCT) of 5°C and 25°C, respectively (McDowell et al., 1976). When temperatures exceed this zone, dairy cattle are unable to thermoregulate effectively, putting them in a state of heat stress (Figure 1.1). In attempt to thermoregulate, dairy cattle begin panting and sweating, in turn using up more energy. When temperatures rise above the UCT, respiration rate during heat stress exceeds 60 breaths/min, compared to a normal baseline of 20 to 50 breaths/min (De Rensis et al., 2017). Rectal temperatures reach temperatures above 39°C during heat stress, compared to a normal baseline of 38.3 to 38.9°C (De Rensis et al., 2017). Minimum physiological costs and maximum productivity can be achieved when environmental factors remain in the cows thermoneutral zone (Johnson, 1987), but this can depend on the age, species, breed, feed intake, and composition of the diet (Yousef, 1985). Level of milk production can also affect the threshold for experiencing heat stress. Higher producing cows, and thus multiparous cows, are more sensitive to the effects of heat stress compared to lower producing or primiparous cows. As milk yield increases from 35 to 45 kg/d, the heat stress threshold is decreased by 5°C (Berman, 2005, Bernabucci et al., 2014). This is because higher producing cows have a higher metabolic heat load produced through processes such as body tissue synthesis, lactogenesis, and milk secretion (Kadzere et al., 2002, Collier et al., 2011). For instance, the heat produced by lactating cows producing 18.5 and 31.6 kg/d of milk produces 27.3 and 48.5% more metabolic heat caused by digestion and hormonal control, compared to non-lactating cows (Purwanto et al., 1990). The combination of environmental temperatures exceeding the thermoneutral zone, and excess metabolic heat from milk production, causes cattle to exhibit coping mechanisms in attempt to thermoregulate.

Heat Dissipation Mechanisms

For cattle to maintain thermoneutrality, physiologic and behavioral mechanisms are used to dissipate heat. Physiologic mechanisms for coping with heat stress include increased respiration rate, sweating, reduced milk production, and reproductive performance (Polsky and von Keyserlingk, 2017). Coping mechanisms based on behavior changes include changes in drinking and feed intake, increased standing time, shade seeking, and decreased activity (De Rensis and Scaramuzzi, 2003, West, 2003, Schütz et al., 2009).

Cattle rely on heat loss from radiation, convection, evaporation and conduction to thermoregulate. If enough heat is accumulated from solar radiation, the environment, and metabolic processes that the dairy cow can no longer dissipate it, then heat will be stored and heat stress ensued (Finch, 1986). About 15% of metabolic heat is used by the respiratory tract and the rest is transferred to the skin (Kadzere et al., 2002). From there, heat is dissipated by non-evaporative cooling (radiation, convection or conduction), or by evaporative cooling (sweating or panting) (Kadzere et al., 2002). Non-evaporative mechanisms occur at lower temperatures, whereas evaporative cooling occurs at higher temperatures (Berman et al., 1985). Evaporative cooling from the skin surface is most effective in a hot, dry environment and air velocity enhances the cooling effects (Kadzere et al., 2002). Relative humidity (RH) limits the rate of heat loss by evaporative cooling because it limits evaporation from the skin and respiratory tract (Silva et al., 2007). In one study, maximum rate of water evaporated from cattle was 1.5 kg/h (Berman et al., 1985). Johnson and Vanjonack (1976) demonstrated that increases in relative humidity caused decreases in evaporative cooling, increased rectal temperature, and decreased feed intake, leading to reduced milk production.

Cattle also change their behavior to cope with heat stress. Lying time is reduced, as cattle are more likely to stand in attempt to cool themselves by increasing body surface area exposed to air movement, and increasing water loss and radiating surface (Silanikove, 2000, Berman, 2003, Maia and Loureiro, 2005). Studies have shown a 30% reduction in lying time as ambient temperatures increase (Cook et al., 2007). As core body temperature increased above 38.8ºC, with an environmental Temperature-Humidity Index (THI) above 68, cattle remained 50% more likely to be standing than lying (Allen et al., 2015). Negatively, standing reduces blood flow to the mammary gland compared to lying, making it harder to produce milk (Rulquin and Caudal, 1992). Further studies revealed that daily total lying time for thermoneutral periods was 9.9 h/d, compared to 7.8 h/d when heat stressed (Herbut and Angrecka, 2018). Additionally, lying in the alleyways at night in attempt to cool, increased by 15 min/d, and total lying time in stalls was reduced by 38 min/d (Herbut and Angrecka, 2018). Overall, daily activity is negatively correlated with increasing environmental heat load, leading to declines in performance.

EFFECTS OF HEAT STRESS ON PERFORMANCE

Effects on Milk Production

As stated by Wheelock et al. (2010), heat stress will become an increasingly relevant concern in the future as milk production and metabolic heat production rise. As expected, US milk production per cow has increased by 12% over the past decade (USDA, 2018a), because of the advances in nutrition, technology and biotechnology, and genetic progress towards higher milk production. For cows to perform at a profitable level, it is essential to improve management practices to permit expression of this potential. One of the most difficult periods to do this is during periods of heat stress. Cows genetically selected for milk production still experience a drop in milk during hot weather (Kadzere et al., 2002). When the heat of the environment exceeds the thermoneutral zone of the dairy cow, metabolic rate decreases, and reduced feed intake leads to a reduction in milk yield (Berman, 1968). A study conducted in Egypt by Nasr and El-Tarabany (2017) with production records from multiple herds over a 4-year period were separated into low medium and high THI groups based on average monthly THI. Milk yield decreased by 14.29% from low to high THI groups. Additionally, Könyves et al. (2017), reported milk production through each season, revealing higher production in the spring than summer and fall ($P < 0.05$). Cows in the summer had lowest milk yields, which is attributed to many direct and indirect factors.

One of many factors causing reduced milk production is the reduction in dry matter intake (DMI) during periods of heat stress. By reducing DMI, the animal is preventing additional heat from digestion, and to manage metabolic heat production

(Collier et al., 1982). These changes are a strategy to maintain a normal body temperature (Beede and Collier, 1986a). Biologically, feed intake is reduced when high temperatures cause the cooling center of the hypothalamus to signal the medial satiety center, inhibiting the appetite center, triggering hypophagia (Albright and Alliston, 1971). This results in insufficient nutrients available for the mammary gland to produce milk (West, 2003, Rhoads et al., 2009). Further, Silanikove (1992) reported that the appetite decrease caused by increased body temperature could be related to gut fill. Feed intake initially decreases when temperatures reach 25°C, declining more rapidly over 30°C, with decreases up to 40% at 40°C (National Research Council, 1989). Schneider et al. (1988) conducted chamber experiments and found that cows exposed to heat stress ate less and drank more water, thus producing 18% less milk than cows in thermoneutrality. Additionally, DMI decreased by 48% and milk yield by 53% for cows exposed to four days of moderate heat stress (THI 72 to 84; (Liu et al., 2017).

Exceeding the effects of DMI on milk production, cattle exhibit metabolic changes to repartition energy to processes other than synthesizing milk (Rhoads et al., 2009). For example, glucose is used up by tissues, restricting the amount available for the mammary gland (Wheelock et al., 2010). Further evidence suggests that heat stressed cows use more energy for fatty acid synthesis rather than for mammary growth because fatty acid precursors were found to be lower in cooled cows than non-cooled cows (Adin et al., 2009). Blood flow to the mammary gland is imperative for the uptake of nutrients to synthesize milk (Prosser et al., 1996) and was affected by reduced DMI when it tended to be lower for cows in heat stress with ad libitum intake, but similar for pair-fed cows in thermoneutrality Lough et al. (1990).

As a result of a reduction in DMI, cattle enter a state of negative energy balance when heat stressed (Dash et al., 2016). Energy requirements for maintenance intensify as thermoregulation becomes inefficient. For example, non-cooled cows displayed lower plasma glucose, beta-hydroxy butyrate, non-esterified fatty acids and triglyceride concentrations compared to cooled cows (Marins, 2017), most likely because of reduced DMI and less energy going to milk production (Tao et al., 2018). Feed intake and metabolic rate of high producing cows can be two to four times higher than at maintenance, causing high producing cows to show a dramatic decrease in roughage intake and rumination leading to a decrease in ruminal pH (Collier et al., 1982). This could in turn decrease rumen motility and rumination (Nardone et al., 2010, Soriani et al., 2013), affecting health and increasing the risk of metabolic disease (Kadzere et al., 2002).

One way to minimize the effects of the reduced DMI during heat stress periods is to increase the nutrient density of the diet by feeding high quality forage, concentrates and supplemental fats (Dash et al., 2016). To alleviate the drop in DMI, producers typically decrease forage components of the feed and increase concentrates to give higher energy density (Renaudeau et al., 2012). However, this can cause protein digestion to break down urea and increase concentrations of non-protein nitrogen in the blood which correlates with an increase in rectal temperature (Hassan and Roussel, 1975). Consequently, some approaches to lessen the effects of reduced DMI, can intensify the effects of heat stress (Polsky and von Keyserlingk, 2017).

Dry matter intake reduction has been considered a direct effect of heat stress on milk production, suggesting that heat stress indirectly affects milk production. However, some evidence argues that heat stress also has direct effects on milk production. Several factors affect milk production, making it difficult to quantify the direct effects caused by heat stress. Contrasting to previously mentioned studies, there is evidence that heat stress has a direct effect on milk production. Johnson and Vanjonack (1976) reported that 3-10% of the change in milk production was caused by climate factors. In another study on mid-lactation heat stressed cows, DMI accounted for only 50% of the drop in milk production, proposing that other factors influenced the remaining reduction (Wheelock et al., 2010). Additionally, severely heat stressed cows experienced a higher drop in milk yield than a pair-fed group consuming the same amount of feed (Baumgard and Rhoads, 2012, Cowley et al., 2015). In a similar study, DMI decreased greater than 35% in heat stressed cows and milk yield decreased by 40% and 21% for heat stressed and pair-fed cows, respectively (Rhoads et al., 2009). This suggests that DMI and the direct effects of heat stress reduce milk yield, however specific mechanisms caused by heat stress are not completely understood and deserve further investigation.

Many factors also play a role in decreasing production in dairy cows affected by heat stress. Stage of lactation has an influence on the amount of milk lost due to heat stress (Tao et al., 2018). The first 60 days are the most critical for managing heat stress to minimize the effects on milk production (Sharma et al., 1983). During this time, cows are generally in a negative energy balance and use body stores to make up for the excess energy lost. Both early lactation cows exposed to heat stress conditions and pair-fed cows exposed to thermoneutral conditions had similar declines in milk yield (Lamp et al., 2015), demonstrating that early-lactation cows lost milk solely from the effect of reduced DMI (Tao et al., 2018). Contrastingly, results from another study showed the impact of heat stress on milk production of early lactation cows was less than the impact on mid-lactation cows and late-lactation cows (Maust et al., 1972), with the conclusion that higher producing cows are more sensitive to heat stress. Overall, it is important to control heat stress throughout the entire lactation because of the negative energy balance at the beginning worsening the effects on milk yield, but also from the heightened sensitivity to heat stress during peak lactation.

Lastly, calving season can influence milk production. For instance, calving in the summer resulted in less milk produced during early lactation in a Mediterranean climate than cows that calved in the winter (Barash et al., 1996). Furthermore, several herds in Florida plan calving for fall and winter (De Vries and Risco, 2005), resulting in later lactation cows producing less milk during summer months (Ferreira and De Vries, 2015) with the goal of minimizing milk loss. Overall, the direct and indirect factors of heat stress negatively affect the productivity of the dairy cow through decreased milk production.

Effects on Milk Composition and Quality

Effects on Milk Fat and Protein Composition

Data on the effects of heat stress on milk component changes for fat and protein % are inconsistent, with studies suggesting reductions in components and increases, or no change when cows were exposed to heat stress conditions. On the other hand, milk components may be reduced solely because of lower milk yield seen in the summer months (Tao et al., 2018). Milk quality is important for producers to earn monetary bonuses through lower SCC’s and increased butterfat, increasing farm profitability.

Milk fat was lower in summer compared to winter (Bernabucci et al., 2015) whereas others found no difference between seasons (Hammami et al., 2015) or higher concentrations of milk fat in summer compared to cooler weather (Smith et al., 2013). Milk fat was decreased up to 40% when dry bulb temperature rose from 18 to 30.8°C (McDowell et al., 1976). In controlled studies, milk fat % for non-cooled heat stressed cows was reduced (Moody et al., 1971), similar (Flamenbaum et al., 1995), or higher (Garner et al., 2016), compared to cooled cows or cows in a thermoneutral environment. (Bouraoui et al., 2002, Gantner et al., 2011). In a study conducted by Smith et al. (2013), comparing heat stress effects on milk components between Holsteins and Jerseys, fat % increased for heat stressed Holsteins from 3.3 to 3.7% but stayed the same for heat stressed Jerseys at 4.6%, which could be due to stage of lactation, diet or heat abatement, and indicates that there are differences between breeds. In a study conducted in a temperate climate, by Hammami et al. (2013), fat yield consistently decreased as THI increased. Nasr and El-Tarabany (2017) categorized monthly THI into groups and fat % was shown to decrease from the low group (THI < 70) to the high group (THI 80 to 85) from 3.91% to 3.74%, respectively. Thus, it is inconclusive the effect that heat stress has on % of fat in milk as it varies dependent on nutrition management, and possibly climate, thus further studies should investigate the mechanisms for changes in milk fat %.

Likewise, milk protein % was similarly inconsistent from Summer to Winter. In some studies, protein % was lower in summer compared to winter (Smith et al., 2013, Bernabucci et al., 2015), or unchanged between seasons (Hammami et al., 2015). In studies controlling the microclimate at the cow level, cows under thermoneutral conditions had lower protein % (Cowley et al., 2015, Gao et al., 2017), similar (Weng et al., 2017) or higher (Tarazón-Herrera et al., 1999) milk protein, compared to non-cooled, heat stressed cows. Protein % decreased by 17% when dry bulb temperature rose from 18 to 30.8°C (McDowell et al., 1976). Milk protein % declines during heat stress are also reported by others (Bouraoui et al., 2002, Gantner et al., 2011). In the previously mentioned study by Smith et al. (2013), protein % decreased from 3.2 to 3.1% and 3.6 to 3.5% for Holsteins and Jerseys experiencing heat stress, respectively. Furthermore, Nasr and El-Tarabany (2017) categorized monthly THI into groups and THI effects on milk protein % were the lowest in the moderate THI group at 3.12% (THI 70-80) but showed no difference in the low (THI < 70) and high THI (THI 80-85) groups (3.22 vs. 3.18, respectively), with no explanation of why this may have occurred.

Disagreement in results from varying studies for milk fat and protein could be caused by factors other than heat stress such as diets consumed, stage of lactation, level of heat stress, experimental models used, cooling facilities, length of treatments, and more (Tao et al., 2018). Causes for the reductions in milk protein synthesis during periods of heat stress are ultimately unknown, but likely caused by multiple biological systems. Gao et al. (2017) found that heat stress reduced milk yield by 17%, milk protein by 4.1%, milk protein yield by 19%, 4% fat-corrected milk by 23% compared to pair-fed cows in a thermoneutral zone. Further, they saw decreases in plasma glucose, and nonesterified fatty acids. This points to an increase in systemic amino acid utilization during heat stress, ultimately limiting amino acid supply to the mammary gland, and reducing milk protein synthesis (Gao et al., 2017). Others (Rhoads et al., 2009), propose that the alteration in the somatotropic axis might explain the decline in milk protein yield, or because of lower production of casein formation enzymes. The downregulation of mammary protein synthetic activity could also be the result of milk protein decline. This is demonstrated by Cowley et al. (2015), using a pair-fed model which explained that reductions were not only a result of reduced DMI, but directly affected by heat stress conditions, as also explained by others using pair fed models (Rhoads et al., 2009, Wheelock et al., 2010). Additionally, mammary gland blood flow reduces protein precursor supply and nutrient partitioning to the mammary gland, altering protein synthesis (Gao et al., 2017). Fat yield decreases could be explained by a decrease in forage intake with low fiber levels, and protein decreases could be attributed to reduced DMI and energy intake when the animal is under heat stress. For instance, Rhoads et al. (2009) reported milk fat increases during periods of heat stress and a conclusion that it may be related to the increase of free fatty acids during negative energy balance during severe heat stress. Overall, several speculations on what causes the changes or lack of, in fat and protein components of milk exist. Further research would be warranted to confirm these.

Effects on Somatic Cell Count

Controlling somatic cell count (SCC) is a year-round challenge for most producers, and hot humid weather intensifies this challenge. It is also true that mastitis is the costliest disease in the dairy industry (Hogeveen et al., 2011), increasing the need to provide management solutions. Changes in SCC throughout the year shows a seasonal pattern of being higher in the summer and lower in the winter (Schukken et al., 1993, Riekerink et al., 2007, Archer et al., 2013). Heat stress is one contributing factor to this pattern. Other factors include stage of lactation (Green et al., 2006), mixing of groups (Harmon, 1994), and changes in diets (Ferreira and De Vries, 2015). Elevated SCC alters milk quality, causes a reduction in milk production (Hand et al., 2012), and reduces shelf life (Barbano et al., 2006). Bulk tank somatic cell count (BTSCC) over specified limits results in the producer losing bonuses, presenting the need to counteract heat stress effects on SCC (Dekkers et al., 1996).

Producers in the northern hemisphere often experience high BTSCC in summer months from July to October, forty-eight to 71% of herds in a Canadian study experienced an increase in summer BTSCC (Sargeant et al., 1998). Within these herds, 26% experienced summer BTSCC increases in > 75% of the years they've been in operation, and 71% of herds experienced summer BTSCC increased in 50% or more of the years of operation (Shock et al., 2015). Igono et al. (1988) found SCC to be lowest during winter and highest in summer. They also saw trends in milk production and SCC being inversely related. Although hot weather relates to increases in SCC, Ferreira and De Vries (2015) concluded that farms producing lower milk volumes tended to have higher BTSCC throughout the year, suggesting there is a "dilution effect," of BTSCC in relation to milk volume, which may explain in part the increase in BTSCC during the summer months.

Hammami et al. (2013) reported increased somatic cell score (SCS) at the lowest and the highest thermal indices during cold stress and heat stress. Additionally, other studies have shown increases in SCS during periods of heat stress (Igono et al., 1988). An increase in SCS during hot weather, besides other factors, could be explained by depressed immune function increasing the risk of infection (Do Amaral et al., 2011, Hammami et al., 2013) or from the increased pathogen load in the cow's environment

(Godden et al., 2003). Nasr and El-Tarabany (2017) reported that from low to high THI, SCC increased by 36%.

Many factors can affect clinical and subclinical mastitis such as parity, stage of lactation, type of housing, pasture access, management, and environmental factors such as temperature, humidity, and season (Smith et al., 1997). Clinical mastitis has been shown to have the highest incidence in the summer (Erskine et al., 1988, Morse et al., 1988, Hogan et al., 1989a, Cook et al., 2002, Bertocchi et al., 2014) with *Streptococcus uberis* and *Escherichia coli* as the most prevalent pathogens (Riekerink et al., 2007). The higher incidence of clinical mastitis during the summer could be explained by the lack of leukocyte migration to the mammary gland reacting to a chemotactic challenge (Elvinger et al., 1992). As a result, a compromised immune system could be partially responsible for the increase in SCC and clinical mastitis infections during the summer months (Tao et al., 2018).

Coliform counts are highest in bedding material in the summer (Smith et al., 1985, Erskine et al., 1988). Riekerink et al. (2006), reported individual cow SCC > 250,000 peaking from August to September which could partially be explained by the increased number of cows with incidence rate of clinical mastitis during this time. For the incidence rate of clinical mastitis for most pathogens, they found peaks in December or January, in contrast to studies that found rates to be higher for coliforms and streptococci in the summer. In total confinement, herds are more exposed to pathogens such as *Escherichia coli* because of its presence in bedding during hot humid days (Riekerink et al., 2006). *Streptococcus uberis* incidence rates peaked in August for pasture herds, *Escherichia coli* incidence rates peaked in October for herds that confined their cows at night, and *Escherichia coli* incidence rates for herds in total confinement peaked in June. The authors concluded that *Streptococcus uberis* was more associated with pasture based systems and *Escherichia coli* with confinement systems because of exposure to the pathogen in the bedding in Canada (Riekerink et al., 2006). In this same study, BTSCC peaked late summer or fall. Additionally, individual cow SCC peaked in August as well which could be explained by the increased incidence of *Streptococcus uberis* (Riekerink et al., 2006).

During an intramammary lipopolysaccharide challenge, cooled and non-cooled cows experienced an increase in SCC during the first 12 hours following the challenge and after the first 48 hours no difference between treatments were reported (Monteiro et al., 2016). Non-cooled cows showed a quicker decline in SCC during the first 12 hours after the challenge than cooled cows and had higher lymphocytes, neutrophils, Fe, and Zn (Monteiro et al., 2016). Conclusions from this data may suggest that non-cooled cows require more immune cells and dietary microminerals to respond to inflammation (Tao et al., 2018). The relationship between heat stress and SCC is complex with varying research findings, but most likely the relationship stems from a suppressed immune system and the heightened risk of exposure to increased pathogen load in a hot and humid environment. To reduce the negative effects of heat stress on milk quality, cooling strategies should be considered.

Effects on Reproduction

Dairy cattle fertility is influenced by factors such as genetics, nutrition, hormone level, management, and environment, with non-genetic variables and environment contributing the most (Dash et al., 2016). Reduced fertility is commonly observed during summer months, but has been shown to persist into the autumn months even after heat stress has subsided (Hansen and Arechiga, 1999). In addition, heat stress affects reproduction in the lactating dairy cow in many ways, such as through the lack of estrus expression, metabolic disturbance, and altering the uterine environment that results in an increased number of days open, reduced conception rates, an increase in anestrus including anovulatory follicles, changes in follicle growth, reduced oocyte quality and reduced life of the embryo (Hansen and Arechiga, 1999, Wolfenson et al., 2000, Kadzere et al., 2002).

Changes in summer reproduction include metabolic changes from reduced feed intake, endocrine system changes in the secretion of hormones, and direct effects on the hypothalamic-pituitary ovarian (HPO) axis on secretions of cortisol and prolactin (De Rensis and Scaramuzzi, 2003). According to De Rensis and Scaramuzzi (2003), heat stress leads to infertility by two independent pathways (Figure 1.2); the direct effect of hyperthermia on the reproductive axis, and the indirect effect associated with reductions in appetite and DMI, relating to negative energy balance. Hyperthermia caused by increased internal temperatures causing lethargy (Pennington et al., 1985) and leading to reduced reproductive performance through poor estrus detection, fewer cows inseminated, and inseminating at the wrong time (De Rensis and Scaramuzzi, 2003). Another effect of hyperthermia is a compromised uterine environment (Roman-Ponce et al., 1978) leading to infertility through failure to implant, and embryo loss (De Rensis and Scaramuzzi, 2003).

Independent of hyperthermia, reduced appetite leads to a reduction in DMI (Fuquay, 1981, Hansen and Arechiga, 1999), increasing the effects of the negative energy balance especially when transitioning to lactation. The negative energy balance leads to a reduction in GnRH and LH secretion by the hypothalamic-pituitary axis (Gilad et al., 1993, Wolfenson et al., 1995, Wolfenson et al., 1997), caused by decreased concentrations of IGF-1 and insulin and increased concentrations of GH and NEFA in the blood (Jonsson et al., 1997, Hamilton et al., 1999, De Rensis et al., 2002). This ultimately leads to reduced estradiol secreted by the dominant follicle, leading to poor estrus detection, reduced oocyte quality, and sometimes ovulatory failure (De Rensis and Scaramuzzi, 2003). A reduction in estrus behavior has been argued to be the result of reduced DMI and the subsequent effects on hormone production (Westwood et al., 2002).

Behavioral Influences on Estrus Detection

The reduction in estrus detection in summer compared to winter can be caused by changes in physical behavior, and changes in metabolism. Estrus is expressed by a period of high activity of a mammal (ranging 10 to 12 h) with the goal of mating at the time of ovulation, 19.4 ± 4.4 h after the end of high activity (De Rensis et al., 2015, Silper et al., 2015). Up to 80% of estrus behaviors are not detected in hot weather as a result of a reduction in activity, anestrus, and silent heats (Gwazdauskas et al., 1981, Thatcher and Collier, 1986, Hansen and Arechiga, 1999).

In a Virginia study, the number of mounts in warm months was almost 50% lower than in cool months (Dransfield et al., 1998). In Florida, 76-86% of estrus periods were undetected from June to September, and 44-65% were undetected from October to May (Thatcher and Collier, 1986). The decrease in visible signs of heat stress could be a result of physical lethargy from being over heated (Hansen and Arechiga, 1999). Starting at a THI of 65 (accounting for ambient temperature and relative humidity, but will be discussed further later in this review), physical signs of mounting of cows continuously decreased as THI increased (Schüller et al., 2016). Consequently, cows may be compensating by reducing activity in attempt to decrease heat production. Timed artificial insemination (TAI) protocols have been developed to reduce the need for visual detection of estrus and increase pregnancy rates (Collier et al., 2006). This has brought positive results but not enough to match pregnancy rates during winter months (Edwards and Hansen, 1997). Changes in mounting behavior due to lethargy is common, and metabolic and hormonal changes also affect the change in estrus.

Metabolic and Hormonal Changes Affecting Estrus

Estrus behaviors are not detected because of the effects of heat stress (Thatcher and Collier, 1986), occurring presumably because of lowered estradiol concentrations (Roth et al., 2001). Low estradiol reduces signs of estrus, gonadotropin surge, ovulation, transport of gametes, thus reducing fertilization (Wolfenson et al., 2000).

Being in a negative energy balance postpartum also negatively affects estrus, and as heat stress extends this imbalance, anestrus will be increasingly worse in the summer (De Rensis and Scaramuzzi, 2003). This behavior results in less inseminations and pregnancies. De Rensis and Scaramuzzi (2003) concluded that because luteinizing hormone (LH) levels are low during hot weather, the dominant follicle develops with less LH present, resulting in reduced estrus behavior. Luteinizing hormone secretion and dominant follicle size is reduced because of the negative energy balance caused by the relationship between dry matter intake, milk production, and stage of lactation (Ronchi et al., 2001).

Follicles size decreased when comparing cows experiencing a THI of 67 to a THI of 74; the authors assumed that the smaller follicle size caused by heat stress resulted in less estradiol synthesis by the follicle, in turn lowering blood flow to the uterus (Schüller et al., 2016). Detrimental effects to the estrus cycle from heat stress occur primarily from being in a negative energy balance, and lowered concentrations of estradiol and LH, delaying maturation of the dominant follicle. Past and current literature presents evidential data of reduced reproductive performance primarily through reduced conception and pregnancy rates.

Effects on Conception and Pregnancy Rate

Conception rate can be defined as the number of pregnant cows divided by the number of total services multiplied by 100 (Schüller et al., 2017). Over the past 60 years, the industry has seen conception rate in high yielding cows decrease from 55% to 35% (Schüller et al., 2014). This decline is related to physiological changes (Wiltbank et al., 2006), increases in genetic merit, changes in management, and increasing milk production (Honig et al., 2016). De Rensis and Scaramuzzi (2003) reported conception rate decreases by 20 to 30% in summer compared to cooler months (De Rensis and Scaramuzzi, 2003). Data from Florida reported conception rate decreasing by 53% (De Vries and Risco, 2005). In Egypt, conception rate decreased from 35.8 to 29.4% at a THI of 70 (El-Tarabany and El-Bayoumi, 2015). Schüller et al. (2014) identified a THI of 73 as the threshold for negatively affecting conception rate in the study period. Additionally, cows exposed to a THI of 73 or greater for nine hours or more on day of breeding were 26% less likely to get pregnant than cows exposed to THI of 73 for less than nine hours. In the same study, from day 21 to 1 before breeding, cows exposed to a mean THI of 73 or greater were 61% less likely to get pregnant than cows exposed to a lower THI. From day 42 to 1 they were 31% less likely to get pregnant under the same conditions, and from day 1 to 21, they were 48% less likely to get pregnant when mean THI was 73 or higher. Schüller et al. (2014) concludes that heat stress affects conception in the period of three weeks before to three weeks after day of service.

In the subtropical climate of Australia, the risk of declining conception rate ranged from experiencing heat stress 3 to 5 weeks before and 1 week after day of service, and a THI of 72 on day of service (Morton et al., 2007). Contrastingly, in the mild, temperate climate of North-Eastern Spain, conception rate are shown to decrease when THI $\geq$ 75, three days before day of service, with greater decline of 23 to 30.6% when THI reaches above 80 (García-Ispierto et al., 2007). More recently, Schüller et al. (2016) reported the lowest conception rate during study period at THI of 72 on day of estrus and observed reduced conception rate at THI levels as low as 56, in a temperate climate.

Herd pregnancy rate is defined as the product of insemination rate and pregnancy rate per insemination (Edwards and Hansen, 1997), or the % of non-pregnant cows that become pregnant during each 21-day period (Dash et al., 2016). López-Gatius et al. (2004) demonstrated that the pregnancy rate for cows inseminated in the summer decreased by 3.7% compared to winter inseminations.

In the subtropical climate of Australia, first service pregnancy rate showed significant declines when THI rose above 72 (25°C and 50% RH) (McGowan et al., 1996). In Egypt, pregnancy rate decreased from 16.1 to 12.1% at a high THI between 80 and 85 (El-Tarabany and El-Bayoumi, 2015). Pregnancy rates decreased continuously once THI reached as low as 51 until a THI of 73, with the lowest conception rate at a THI

≥ 72 on day of estrus (Schüller et al., 2017). Reduced pregnancy rate during summer is caused by the delay in rebreeding during summer (Dash et al., 2016). The effects of heat stress on conception rate and pregnancy rate in dairy cattle are increasing, as performance demands increase, and temperatures become higher. Overall, heat stress negatively affects reproductive performance by the direct effect of hyperthermia on the reproductive axis, and the indirect effect associated with reductions in appetite and DMI, in turn causing lack of estrus expression, metabolic disturbance, and alterations in the uterine environment.

ENVIRONMENTAL MODIFICATION TO MANAGE HEAT STRESS

Heat Abatement Strategies

Various management practices have been recognized to lessen the negative effects heat stress has on performance of the lactating dairy cow. This includes genetic selection for heat tolerance, nutritional management, environmental modification or cow cooling strategies, and timed artificial insemination (TAI) protocols which have been reviewed by (Dash et al., 2015, Das et al., 2016). For purposes of this review, the focus will be on environmental modification.

Implementation of cow cooling mechanisms to protect from the economical pitfalls caused by heat stress is recommended. Shade, fans, natural ventilation and water cooling systems (misters and sprinklers) are among the most used and practical. Of all US dairies in 2007, 94% used at least one of these systems for heat abatement (USDA, 2010). However, the success and efficiency of these systems vary greatly from farm to farm.

Shade

Implementing shade structures protects the cow from solar radiation, acting as the first line of defense for controlling heat stress, and is simple and economical. Cows without access to shade have decreased ruminal contractions, increased rectal temperature, and lower milk yield than cows with access to shade (Collier et al., 1981). In a study by Roman-Ponce et al. (1977), cows having access to shade had lower rectal temperatures than cows with no access to shade (38.9 and 39.4°C, respectively). They had lower respiration rates (54 and 82 breaths/min, respectively), and produced 10% more milk than cows without shade. From a reproduction standpoint, Badinga et al. (1993) reported dominant follicles of cows exposed to shade were larger than follicles of cows with no shade available (16.4 vs 14.5 mm, respectively). Shade structures can be as simple as an environment with trees, or a transportable shade cloth for cows on pasture, but typical farm management in the US includes an enclosed facility to provide shade from solar radiation.

In a study by Correa-Calderon et al. (2004), control Holstein and Brown Swiss had access only to shade, and treatment groups included a group cooled with spray and fans, and a group exposed to an evaporative cooling system combining sprinklers and fans. Respiration rates of the control group were 20.5 breaths/min higher than the spray and fans group, and 32 breaths/min higher than the evaporative cooled group, with no results reported on significant differences among breeds. Similarly, when comparing a shaded group of cows to a control group with no heat abatement, respiration rate was reduced 30% (Kendall et al., 2007). In the same study, shaded cows displayed lower body temperatures (38.6°C) than controls (38.9°C) during the 90-minute treatment period. The shaded area was 0.9°C cooler than the control group area, with the THI being 68.8 and 68.5 for control and shade group, respectively. Milk production, milk composition (fat %, protein %, lactose %), and SCC showed no difference between control and shade groups (Kendall et al., 2007).

Implementing the correct amount of shade is also important to consider when cooling cattle. Cows spend twice as much time in a 9.6 m^2 shade than a 2.4 m^2 shade space (Schütz et al., 2010). Respiration rate was reduced for cows in 2.4 m^2 shade (57 breaths/min), and 9.6 m^2 shade (51 breaths/min) compared to cows in no shade (62 breaths/min) (Schütz et al., 2010). Cows chose shade over sprinklers (62 vs. 38%) and shade over ambient conditions (65 vs. 35%) when presented with the option of shade or sprinklers after walking 2.0 or 0.3 km to be milked. This increased with increasing air temperature, solar radiation, and wind speed. However, with every 1% increase in humidity, the preference for shade alone decreased by 1.5% (Schütz et al., 2011). Sprinklers reduced respiration rates, but cows still preferred shade (Schütz et al., 2011).

Past and current literature revealed effectiveness of shading and natural ventilation in confinement, however for maximum benefits, combining shade with an additional system such as fans and sprinklers for evaporative cooling is recommended. Shade itself has not shown success in preventing a drop in milk production most likely because it does not reduce radiant temperature or affect air temperature (Flamenbaum et al., 1986).

Evaporative Cooling

Shade is essential for controlling exposure to solar radiation, but it limits the amelioration of heat stress, thus additional heat abatement mechanisms are needed to adequately cool cows in hot, humid climates such as the southeastern US. In confinement systems, natural ventilation is essential, unless a tunnel ventilated, or cross-ventilated system is in place. In the southeastern US, typical facility structures include free stall bases and loose housing barns with high ceilings, containing open or capped ridge vents to enhance natural ventilation for cow cooling. The high ceilings allow for hot air to rise and release through the ridge vent and for cross ventilation to move cool air and wind through the barn (West, 2003), enabling access to fresh air, and some cooling effects. To effectively dissipate heat from the cow, it's essential to consider the ambient temperature, relative humidity and solar radiation (West, 2003).

Barn orientation can improve heat abatement or cause detrimental effects because of the impact the sun's rays have on heating the surface of stalls and bedding. Study results from (Angrecka and Herbut, 2016) have shown that stalls could be heated up to 40°C or 58°C in extreme conditions. Combining this and the cows body temperature, heat transfer from the cow to the environment is difficult, according to behavioral observations. The barn was oriented east to west, and during noon hours, stalls on the northern and southern ends increased by about 10°C. Interestingly, clouds reduced the temperature of stall surfaces by 2.5°C even during only 10 min of exposure. Using shades around the building during noon hours could limit the increase in stall temperatures, allowing cows to more efficiently transfer body heat to the environment (Angrecka and Herbut, 2016).

Researchers in Israel sought out to decrease the seasonality of cow performance with the goal of enhancing producer profitability. Israel's climate is described as subtropical and dry, with cool rainy winters, and hot, dry or humid summers, differing between the coastal or desert regions (Flamenbaum and Galon, 2010). Evaporative cooling applied in a confinement setting works by wetting the animals skin surface, and then using the forced ventilation of fans to cool the animal. Mukherjee et al. (2013) reported the average estimated gain in gross revenues based on data from farms in Florida and Georgia using fans and sprinklers combined, was $106,830 per year. This illustrates the effectiveness and need for evaporative cooling strategies to be implemented on farm.

Evaporative cooling initiated by sprinkler systems was estimated to increase milk yield for cows producing 45 kg/d, by 140 kg in the Missouri to Tennessee area, 230 kg in southern Georgia, and 320 kg in Louisiana and Texas over a 122 d summer period (Hahn and Osburn, 1970). Original work by Seath and Miller (1948) compared the effects of cow cooling by using fans or sprinklers, or the combination of both. Cows in the no cooling treatment showed the least decline in rectal temperature, followed by cows cooled with either fans or sprinklers, and using a combination of fans and sprinklers showed the greatest decline in rectal temperature, thus representing the best cooling technique. Further research has shown that the combination of shade and sprinklers yielded a respiration rate of 24 breaths/min compared to sprinklers alone at a rate of 30 breaths/min (Kendall et al., 2007). Respiration rates were reduced by 60 and 67% for sprinklers and sprinklers and shade combined, respectively, compared to controls with no heat abatement. Temperature-humidity indices for control cows, shade alone, sprinklers alone, and shade and sprinklers were 68.8, 68.5, 67.1, and 65.9, respectively (Kendall et al., 2007). Night cooling can also help cows tolerate hot daytime temperatures. Igono et al. (1992) reported cooling of < 21°C for three to six hours will help alleviate the effects on milk yield. Cows should be cooled during the day but enhancing cooling at night can be beneficial. In general, proper heat abatement strategies are essential for keeping cows cool during summer months and optimizing performance.

Porto et al. (2017) investigated the effects of a fog and forced ventilation cooling system over the resting area and a sprinkler system with forced ventilation over the feed bunk on behavior. Results showed that a fogging/ventilation system over the resting area encouraged lying in stalls, and the sprinkler/ventilation system over the feed bunk did not influence standing behavior and made only a small change on feeding activity.

Comparing only fans and fans combined with misters over the resting area resulted in increased lying time in the ventilated and wetted pen (11.8 h/d) than the ventilated pen (10.7 h/d) (Calegari et al., 2014). Milk yield was higher during the first hot period in the wetted pen compared to the fan cooled pen by almost 2 kg/d (Calegari et al., 2014). Only numerical differences in SCC between the two treatments were reported, with the wetted pen having a higher SCC. The use of inorganic sand bedding and regulation of water, most likely contributed to the lack of increase (Calegari et al., 2014). Investing in evaporative cooling as opposed to fans only minimizes the alteration in lying behavior during periods of heat stress. Similarly, Frazzi et al. (2002) and Calegari et al. (2005) showed that cooling only the feeding area will not eliminate the effects of heat stress completely.

Combining the cooling power of fans and sprinklers is ideal, but it is also important to identify how long sprinklers should run to effectively and efficiently cool the animals. In humid climates, repeated wetting and forced ventilation has proven to be most efficient at cooling cows exposed to heat stress, compared to using only fans (Berman, 2008). Wetting cows for 20 or 30 s was more effective than wetting for just 10 s (Flamenbaum et al., 1986). Additionally, cooling 5 times a day for 30 minutes each time kept body temperatures below 39°C for the whole day (Flamenbaum et al., 1986). More recently, Flamenbaum and Galon (2010) found that cows cooled for 4.5 and 7.5 h/d experienced less of a reduction in milk yield than cows cooled for 0 hours per day. Cooling management in Israel typically includes a 5-minute-long cycle of 30 s watering then 2.5 min of forced ventilation (Flamenbaum et al., 1986). Five to seven sessions a day for 30 to 45 minutes each, positively influenced milk production and heat stress management during periods of heat stress. Flamenbaum et al. (1986) also demonstrated that wetting cows for 10, 20 or 30 s, 10 s was least effective, with no difference between 20 and 30 s. Twenty seconds was concluded as most ideal because of less water usage.

Honig et al. (2016) conducted a study to assess the effects of five versus eight cooling sessions per day and the effects on reproductive measures. The eight cooling sessions treatment group had shorter first follicle wavelengths, increased blood flow to the dominant follicle, showed no effect of blood flow to the ovary during 1st and 2nd waves, but from day 20 to the end of the cycle, had better blood flow to the preovulatory follicle compared to the five cooling sessions group. This allows for a shorter dominance period. The longer the dominance period, the greater chance of older follicles ovulating, which can lead to reduced fertility. Cooling eight times compared to five, shortened the estrous cycle with a shorter dominance period, and less chance of older follicles ovulating (Honig et al., 2016).

A study by Tresoldi et al. (2018) sought out to evaluate how spraying water one time would affect the surrounding air temperature, time it takes the coat to dry, and physiological responses to heat load in dairy cattle. Results showed that the longer the spray duration, the better the cooling benefits and changes in surrounding air temperature. No difference in drying time of the coat was reported, except on windier days. Igono et al. (1987) established that cows cooled by ducted air and having sprinklers on for 20 min then off for 10 min produced 2 kg/d more milk and had rectal temperatures consistently below 39°C compared to cows only exposed to shaded areas. In the humid climate of Kentucky, a study by Turner et al. (1992) utilized sprinklers and fans which increased milk yield by 15.9%, and 9.2% more feed was consumed compared to a control group. Similarly, a Florida study reported that spraying with water for 1.5 min every 15 min resulted in an 11.6% increase in milk yield and decreased respiration rates from 95 to 57 breaths/min (Strickland et al., 1988). Based only on milk yield, they calculated a $96/cow/yr return during a 210-d period.

Droplet size is also important to consider when using sprinkler systems. Larger droplets that soak cows to the skin are more effective at cooling than misters (Armstrong, 1994), especially in humid climates. Misters tend to add to the humidity of the surrounding air, impeding evaporation from the cows' body. Contrastingly, results from a study conducted in Alabama saw no difference in milk production and feed intake when using fans and sprinklers versus fans and misters (Lin et al., 1998), which may not be the case in areas with higher humidity. Berman (2008) measured the temperature of hair surface and skin on wetted cows exposed to < 0.1 m/s and then at 0.5 to 3 m/s air velocity. Results indicated that at an air velocity of 0.5 m/s, wet hair temperature was

2.1°C cooler than dry hair, and wet skin temperature was 1.5°C cooler than dry skin temperature. Wet skin and hair temperature returned to dry temperature within 15 minutes, revealing that repeated wetting is essential to staying cooler. No differences between wind speeds of 1 and 2 m/s (Berman, 2008) were observed.

From a behavior perspective, cows exposed to no water spraying moved slower in association with increased respiration rates, compared to moving normally when 0.4 or 4.5 L/m of spray was available (Chen et al., 2016b). Cows lowered heads five times more during 4.5 L/m of spray compared to 0.4 L/m or no spray which could have been to protect sensitive areas, but overall, they did not entirely avoid the higher-impact spray. Interestingly, the ear had greater sensitivity to mechanical stimulation than the shoulder when tested using von Frey monofilaments to measure sensitivity (Chen et al., 2016b).

Additional studies have presented observations of cows keeping their heads away from sprinkling water (Schütz et al., 2010), or lowering them (Kendall et al., 2007, Chen et al., 2016a). Contrastingly, in a study by Chen et al. (2013), cows stood near the feed bunk 1.6 times more when sprinklers were present than when they were not. They spent 40% more time feeding when they had access to sprinklers (Chen et al., 2013). These results suggest that because a reduction in feed intake reduces milk production (Wheelock et al., 2010), the cooling of sprinklers can ameliorate the effects of reduced dry matter intake on milk production (Chen et al., 2013). Further work by Chen et al. (2016a) revealed a 3.3 to 3.7 kg/d increase in milk yield by cows exposed to spraying versus cows exposed to no spray. In another study, cows with no sprinklers showed respiration rate increases by 9 breaths/min above baseline (Chen et al., 2015). A flow rate of 0.4, 1.3, and > 4.5 L/min gave respiration rates at baseline, decreased by 9, and decreased by 13 breaths/min, respectively. Results showed that as air temperature increased by 7°C, respiration rate and body temperature was elevated by 19 breaths/min. Water system flow rate, droplet size, wetting duration, and barn orientation are all factors to consider when cooling cows with sprinkler systems, research agrees that the method of evaporative cooling is the most effective at improving cow performance during periods of heat stress.

Although dairy cattle show some aversion to sprinklers, evidence supports that evaporative cooling systems with shade exposure most effectively reduce the effects of heat stress compared to shade, fans or shade and fans as cooling systems. Additionally, more frequent, and longer duration bouts of cooling were more beneficial. In confinement systems, it is important to orient barns so that wind direction is taken advantage of and building structures to allow for proper air flow is essential. Lastly, droplet size is important to consider for evaporative cooling systems as misters and foggers may work well in drier climates, but sprinkler or soaker systems are more ideal for humid climates.

QUANTIFYING HEAT STRESS

Temperature-Humidity Index

To prevent the physiologic, physical, and behavioral changes caused by heat stress, it is important to accurately define when heat stress is occurring. Research has focused on cow-level methods such as measuring body temperature and rectal temperature to indicate when performance begins to decline, and by utilizing environmental equations such as the THI and the Black Globe Humidity Index (BGHI) to indicate periods of heat stress in dairy cattle.

The temperature-humidity index has been widely used as an indicator of heat stress (Hammami et al., 2013), as it has shown to predict milk loss (Bohmanova et al., 2007, Dikmen and Hansen, 2009), is correlated with production performance (Silva et al., 2007), and reduced performance overall (West, 2003). The THI was first introduced by Thom (1958) for its use in humans, then calculated for cattle by Berry et al. (1964). The combination of the effects of ambient temperature and RH form the equation and is used to describe the climate and quantify heat stress (Herbut and Angrecka, 2018). The THI equation commonly used is shown as:

$$THI = (1.8 \times T°C + 32) – (0.55 – 0.0055 \times RH\%) \times (1.8 \times T°C – 26),$$

where T = ambient temperature in °C and RH% = relative humidity as a percentage (NRC, 1971).

A THI of 70 indicates thermoneutrality for the cow, with 75 to 78 being in a state of heat stress and above 78 in extreme distress (Lemerle and Goddard, 1986). More commonly, others consider the threshold as 72 (22°C and 100%, 25°C at 50% humidity, or 28°C at 20% relative humidity) (Johnson, 1985, Du Preez et al., 1990, Igono et al., 1992, Armstrong, 1994). Symptoms of heat stress for dairy cattle, and buffaloes based on THI levels is shown in Figure 1.3. Because of the steady increase in milk yield over the years, Collier et al. (2011) re-evaluated the THI and reports data from the University of Arizona showing that high yielding cows dropped in milk production by 2.2 kg/d every 24 h at a daily THI of 68. This demonstrates that the THI threshold is well below the industry standard of 72 and suggests that cooling systems should be turned on earlier than has been reported previously.

Some authors reported that the THI 24 to 48 h before a drop in milk yield was the best indicator for milk loss, further indicating that heat abatement strategies should be implemented earlier to prevent the effects of heat stress on performance (Collier et al., 1981, West, 2003, Spiers et al., 2004). Similarly, West (2003), determined that milk yield was reduced by 0.88 kg per unit increase of THI two days following mean THI, and DMI decreased by 0.85 kg for each increase in 1ºC for ambient temperature. The decline in milk yield and DMI was much less when measured on the same day as mean THI. The delay in effects on production could be caused by changes in feed intake, delay in nutrient utilization, or endocrine changes (West, 2003). Ravagnolo and Misztal (2000) reported that a THI of 72 or higher resulted in a milk yield reduction of 0.2 kg per unit increase of THI. As a result, the THI was established as an indicator of reduced milk production caused by heat stress (Ravagnolo and Misztal, 2000). However, others view the THI as a rough indicator of milk production, and that internal body temperature is a better indicator (Polsky and von Keyserlingk, 2017).

The THI equation does not account for solar radiation, wind speed, effects of the cow including age, breed etc., and assumes that all cows are affected the same by the environment (Hammami et al., 2013). These factors may limit the use of THI as an indicator of heat stress. Multiple variations of the THI equation exist, and account for the differences in humidity or dry-bulb temperature of different regions. Bohmanova et al. (2007) compared seven THI formulas and determined that humidity was the limiting factor for heat stress in humid climates, and dry bulb temperature was the limiting factor in dry climates. Wind speed is another factor that could be included in the equation as it can affect temperature (Mader et al., 2006). Furthermore, maximum THI (maximum temperature and minimum RH) was found to be a better indicator of heat stress than mean THI (Ravagnolo et al., 2000, García-Ispierto et al., 2007, Bernabucci et al., 2014), because it is more realistic in the way that high temperatures are always associated with lower RH. Further, results showed that maximum THI was found to have higher sensitivity to milk yield compared to daily average THI (Ravagnolo et al., 2000). Minimum THI would better describe ambient conditions at night (Vitali et al., 2009).

Choosing the location in which THI data is recorded is also important when considering the climatic effects of heat stress. Although the THI provided by a local weather station accurately represents the climate of the environment surrounding housing facilities, using the THI from a weather station may not accurately represent the climate inside of facilities. For example, the microclimate of cows in confinement may vary from the environment surrounding the facility due to changes brought by cooling systems such as number and size of fans and sprinklers, cow stocking density, the position of animals throughout the facility, shade, RH, and barn orientation in relation to ventilation from wind (Collier et al., 2006, Schüller et al., 2013). Scanavez et al. (2016) measured THI in housing with data from a logger and found that average THI was significantly greater when measured at the cow-level (91.9) than at the pen-level (85.1) or station-level (85.1). A recent study by Shock et al. (2016) in Canada, concluded that temperature and THI in the barn were higher than at the nearest meteorological station, and freestall housing had THI 2.3 units lower than tiestall housing for mean THI, illustrating that housing differences can affect THI. Contrastingly, an on-farm study in Georgia by Freitas et al. (2006) concluded that the climate data from the nearest weather station was an adequate substitute for environmental conditions measured inside the housing facility.

Temperature-humidity index data from weather stations are useful but it is important to take into consideration the microclimate surrounding the cow if possible.

The THI is a reliable tool to identify periods of heat stress through temperature and humidity, however, the THI may not accurately represent the individual cows' microclimate, and variations of the equation may prove accurate only in specific climates.

Additional Indices

The THI represents the most widely used indicator of heat stress, but because of limitations, others have explored further options. One being the Black Globe Humidity Index (BGHI) which considers the dry-bulb temperature, humidity, solar radiation, and air movement. When compared to THI, BGHI had higher correlations with rectal temperature and milk yield under heat stress conditions, when exposed to solar radiation (Buffington et al., 1981). However, under shade conditions where cows are less exposed to solar radiation, they found no difference between BGHI and THI. Although cows in the US are primarily raised in confinement, this illustrates the need for shade structures for pasture raised cows. More recently, (Collier et al., 2011) re-evaluated the use of the BGHI, and found no evidence that BGHI was a better indicator than THI for estimating milk loss, possibly resulting from a small number of observations giving low correlations. Adding a factor such as skin temperature could improve the BGHI equation and account for the large variation that is not explained by the current equation (Collier et al., 2011).

Silva et al. (2007) compared six environmental stress indices to explore which was best correlated with rectal temperature, and respiration rate. Results revealed that THI and BGHI had the lowest correlations and the Equivalent Temperature Index (dry bulb temperature, wind speed, relative humidity), and the Heat Load Index (black globe temperature, wind speed, relative humidity), had the highest correlations to rectal temperature and respiration rate. This might be explained by the increased thermal radiation the animals are exposed to in a tropical environment, compared to the temperate or subtropical climate of the US. Similar to the study by Buffington et al. (1981), milk production was lower at 15 kg/cow on average, and Collier et al. (2011) points out that BGHI correlations to milk yield under shade might be higher for higher producing cows that are more sensitive to heat stress. Cows in this tropical environment might be more adapted to the tropical climate, causing the low correlations for BGHI which accounts for solar radiation.

Body temperature has also been used as an indicator of heat stress because of its sensitivity to ambient conditions (Araki et al., 1984). A rise of 1°C or less reduces performance in most livestock species therefore body temperature is a sensitive indicator because it is typically constant under normal conditions (McDowell et al., 1976). Johnson and Ragsdale (1963) established that milk yield decreased by 1.4 kg and total digestible nutrient intake decreased by 1.8 kg for every 0.55ºC increase in rectal temperature, showing sensitivity of rectal temperature on performance. Studies by Igono et al. (1985) revealed that milk temperature was a good predictor of heat stress, as is rectal temperature. However, Caruolo et al. (1982) found low correlations with milk temperature. Milk temperature had similar patterns as seasonal THI and photoperiod in three production level groups (Igono et al., 1988) and was easier to take than rectal temperatures. Studies investigating the use of various methods for detecting heat stress have shown inconsistencies in results, most likely caused by the varying environmental conditions and climate surrounding the animals tested. Further research is necessary to separate these environmental variances and the influence they have on the ability to measure heat stress load.

Rectal temperature (Igono et al., 1985), body temperature (Araki et al., 1984), and skin temperature using infrared technology (Collier et al., 2011) have also been shown to indicate heat stress. Using infrared technology to measure the surface temperature of skin can eliminate the variation of the environment and would more accurately account for the microclimate of individual animals (Collier et al., 2011). A skin temperature humidity index, including an infrared skin surface temperature may be more accurate than BGHI and THI, however further investigation would be warranted. Quantifying heat stress is essential to controlling it, but with the variation in thermal indices, physical variables, and varying climatic conditions, it is difficult to accomplish. A method focusing on performance declines in the summer, such as the Summer to Winter ratio (S:W Ratio) may be a good alternative indicator of how cows are dealing with summer conditions.

The Summer to Winter Ratio

Quantifying heat stress on farm can be difficult. Obtaining the THI from a weather station may not accurately depict the microclimate in the cow's housing environment, as discussed previously, because THI can be higher at the cow level than the station level (Scanavez et al., 2016). Measuring heat stress at this point in time at the cow level would be time intensive, subjective and not realistic on farm. It is plausible for a producer to quantify other measures of performance and health, for example, scoring for body condition to identify disease or feeding management issues, locomotion scoring to identify lameness and cow comfort and housing management issues, and obtaining

SCC data to measure the level of mastitis. This data can benefit the producer by presenting opportunities for improvement with the goal of increasing profit. Heat stress identification is not quantifiable in a way that a producer can visually see performance declines from hot to cool seasons, and the economic decline associated with it. A possible tool to alleviate this issue and provide producers with heat stress data is the S:W ratio (Flamenbaum and Ezra, 2007a). The purpose of the ratio is to quantity how well dairy producers are cooling their cows in the summer months. The closer the ratio is to 1, the less seasonality of performance variables (Flamenbaum and Ezra, 2007b). Enabling farmers to visualize how summer heat stress is affecting performance of their herd and affecting their profit, the more likely they may be willing to make management decisions to improve heat abatement or implement cooling systems.

The energy-corrected milk (ECM) summer average and winter average in Israel in 2005 were used to calculate ECM S:W ratio and results revealed that 70% of farms in cool regions and only 30% of farms in extremely hot regions had an ECM S:W ratio above 0.96 (Flamenbaum and Ezra, 2007b). As discussed previously, typical Israeli cooling systems includes wetting cows in combination with forced ventilation, five times a day for 30 minutes each time, and as a result lactating cows were able to keep body temperatures under 39°C (Flamenbaum and Galon, 2010). In this study, researchers grouped herds into top and bottom S:W ratio groups based on high or low S:W ratio values. The S:W ratios for the low group had reduced conception rates and lower milk production in the summer, with similar winter production, compared to the high S:W ratio group. The assumption established was that herds in the top S:W ratio group likely had better summer cooling management than the low S:W ratio group, because both groups had similar winter production. Additionally, the high S:W ratio grouped cows that calved in summer or spring had milk production at peak lactation compared to cows in the bottom S:W group. Conception rates decreased 30% in summer compared to winter for the high S:W ratio group and by 50% in the low S:W ratio group. Furthermore, in Israel in 2005, small family farms (50 cow average), had S:W ratios for ECM, milk fat at protein yield, SCC, and conception rate at 0.93, 0.94, 0.96, 1.2, and 0.40, respectively, compared to cooperative farms (300 cow average), who had S:W ratios of 0.93, 0.95, 0.96, 1.05, and 0.51 for ECM, milk fat and protein yield, SCC, and conception rate, giving the assumption that larger farms are more likely to utilize cooling systems (Flamenbaum and Ezra, 2007a).

Additionally, a Master's thesis exploring the use of the S:W ratio in the US reported similar S:W results for reproduction and milk variables when comparing western regions of the US (Robertson, 2012). Summer conception rate in the north was greater than conception rate in the south, as expected, for top and bottom S:W ratio ranked farms. Top 10% S:W conception rate ratio herds in the southwest had a larger drop in summer conception rate than top ranked herds in the northwest. Furthermore, differences in S:W ratio for pregnancy rate, conception rate, and monthly test day milk production were seen between top and bottom 20% herds, respectively. No differences were shown in S:W ratio for fat %, protein % or SCC (Robertson, 2012). The use of the S:W ratio demonstrates potential in identifying herds or areas where heat stress management is needed. Little research has been conducted to explore the use of the S:W ratio, especially in the US but the capability of this measure to improve on farm heat abatement could be equally as beneficial as it has been in Israel. Further work should investigate the use of this performance ratio and how it would provide insight to how seasonality of performance variables affect profit and how heat abatement strategies can ameliorate these effects.

HEAT STRESS IN VARYING CLIMATES

The climate of the US varies drastically among regions, from temperate to subtropical. Heat stress can be experienced in all climate zones, particularly in the southern US (Beede and Collier, 1986a), where the humid subtropical climate is described as having warm temperatures and full humidity (Kottek et al., 2006). However, cooler northern regions of the US with temperate climates described as having short warm summers can also experience heat stress (Polsky and von Keyserlingk, 2017). There is evidence that cows in temperate climates might be less acclimated to heat than cows in tropical, subtropical, or Mediterranean climates because of performance losses at lower THI thresholds (Beede and Collier, 1986b, Hammami et al., 2013, Schüller et al., 2014).

Performance declines of cattle in temperate climates gives evidence that cows are still undergoing some heat stress. Milk production has been shown to decrease by 33% when temperatures consistently rose above 30°C (Bianca, 1965) and reductions in conception rate by over 7% when THI rises above 80 in the temperate climate of North-Eastern Spain (García-Ispierto et al., 2007). Surprisingly, Schüller et al. (2014) reported the deterioration of conception rate at THI levels as low as a THI of 56, in a temperate climate. Cattle in temperate climates are likely to be housed on pasture, perhaps without shade, and one study concluded that cattle in the temperate climate of Belgium used shade 65% more at a heat load index of 79, compared to cows with no access to shade, which reduced respiration rates, rectal temperatures and fecal cortisol metabolites (Veissier et al., 2017). Therefore, it is evident that cows in temperate environments housed on pasture with no shade, experience heat stress at low THI thresholds.

Dairy cattle of the subtropical climate are exposed to high temperatures and humidity persisting for extended periods of time during summer months, with little to no alleviation at night (Johnson, 1987). The southern US is affected by heat stress more than the rest of the country because of the climate, specifically from the effects of high humidity (Beede and Collier, 1986a). St-Pierre et al. (2003) estimated milk losses from 436 kg to 1,233 kg/cow/yr in states of the southeastern US, and data from Florida showed a milk yield reduction of 15% on average in summer compared to winter (De Vries and Risco, 2005). Heat stress can persist for several months in the southeastern US (West, 2003). The state of Georgia for instance has 138 d per year with a THI > 72. Ravagnolo and Misztal (2000) used this to estimate that lactating cows will be exposed to 828 THI units above its comfort zone per year. This corresponds to a loss of 165 kg of milk per cow per year, estimated at a loss of 0.2 kg per THI unit over 72. Nationally, the average dairy cow is exposed 14.1% of all annual hours to conditions of heat stress (El-Tarabany and El-Bayoumi, 2015).

In a temperate climate, a 33% reduction in milk yield when temperatures consistently rose above 30°C was seen (Bianca, 1965). Furthermore, Bianca (1965) reported a 3, 7, and 16% drop in milk yield for Holsteins, Jerseys and Brown Swiss respectively, when the temperature was 29°C with 40% relative humidity (THI = 70). In the same study, at 29°C, when humidity reached 90%, milk production dropped 31, 25, and 17% for Holsteins, Jerseys and Brown Swiss cows (THI = 83) (Bianca, 1965).

During the month of July, cows in the subtropical humid climate of Florida are in a constant state of heat stress, and cows in the state with the highest average temperature in July, Arizona, are exposed to heat stress for nearly 8 h/d (St-Pierre et al., 2003). Similarly, the subtropical environment of Louisiana has experienced a milk production loss of 2,072 kg/cow/yr, compared to the cooler climate of Wyoming experiencing a loss of 68 kg/cow/yr (St-Pierre et al., 2003). Even in Canadian summers cows can experience almost 50% of days in a state of thermal stress (Ominski et al., 2002). Further research in the subtropical environment has revealed similar reductions in milk production in Israel (Flamenbaum and Galon, 2010). Ultimately, regardless of the climate type, heat stress affects dairy cattle performance by reduced milk production, reduced reproduction, and causes changes in milk quality.

CONCLUSIONS

Summer heat stress detrimentally affects performance of the lactating dairy cow. Effects such as reduced milk production, reduced fertility, and reduced milk quality are among the most important and cause the greatest economic strain on dairy farmers. Cows are unable to dissipate the additional heat load during hot, humid weather, and in turn reduce their DMI. The direct and indirect effects of heat stress cause physiological mechanisms to generate a lethargic and immunocompromised animal. Many indicators of heat stress load have been proposed, the THI has been widely used to indicate periods of heat stress but may not accurately depict the microclimate surrounding the cow. A possible tool to alleviate this issue and provide producers with heat stress data is the S:W ratio. The purpose of the ratio is to quantity how well dairy producers are cooling their cows in the summer months. Additional research should be conducted to explore the use of the S:W ratio to enhance the understanding of lost performance and profit in the summer and motivate implementation of on-farm heat abatement management strategies.

Figure 1.1. Illustration of the association an animal's core body temperature, heat production, and environmental temperature in relation to being in a state of hypothermia, hyperthermia, or zone of thermoneutrality adapted and described by Curtis (1983).

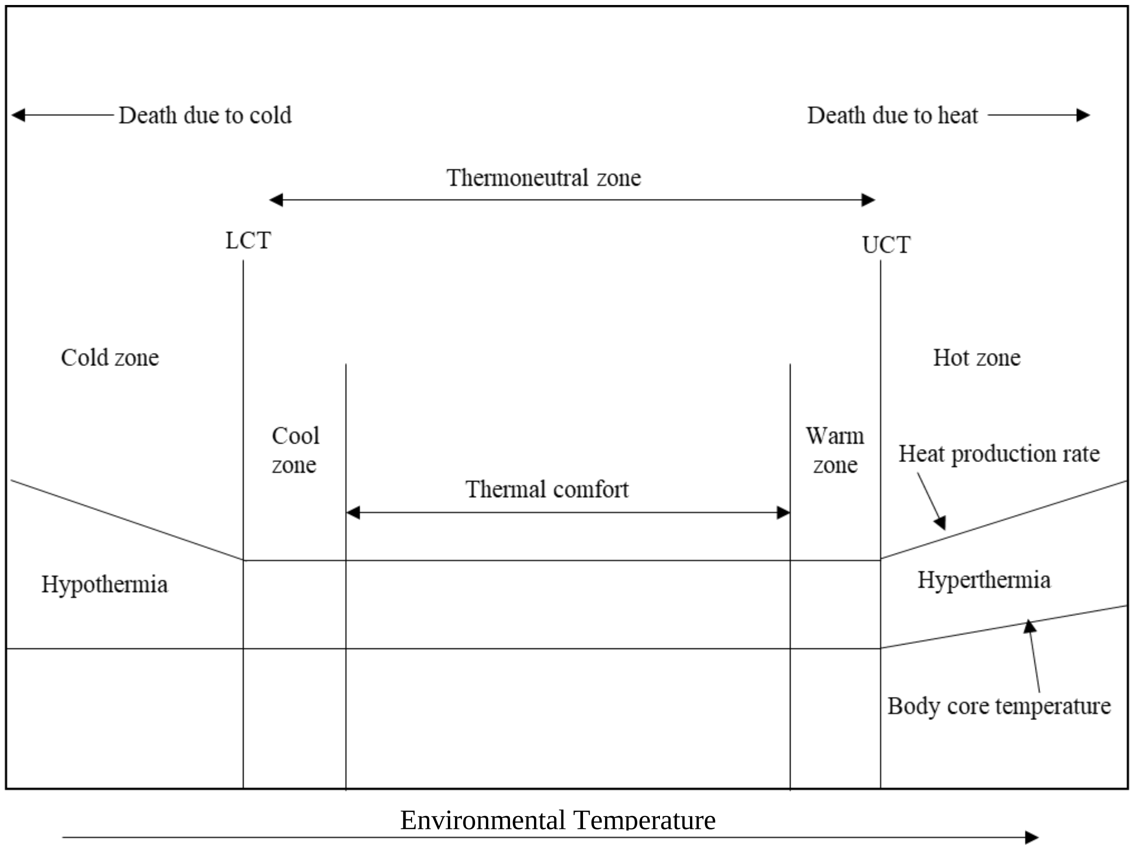


Figure 1.2. Heat stress leads to infertility by two independent pathways; the direct effect of hyperthermia on the reproductive axis, and the indirect effect associated with reductions in appetite and DMI, described and adapted from De Rensis et al. (2017).

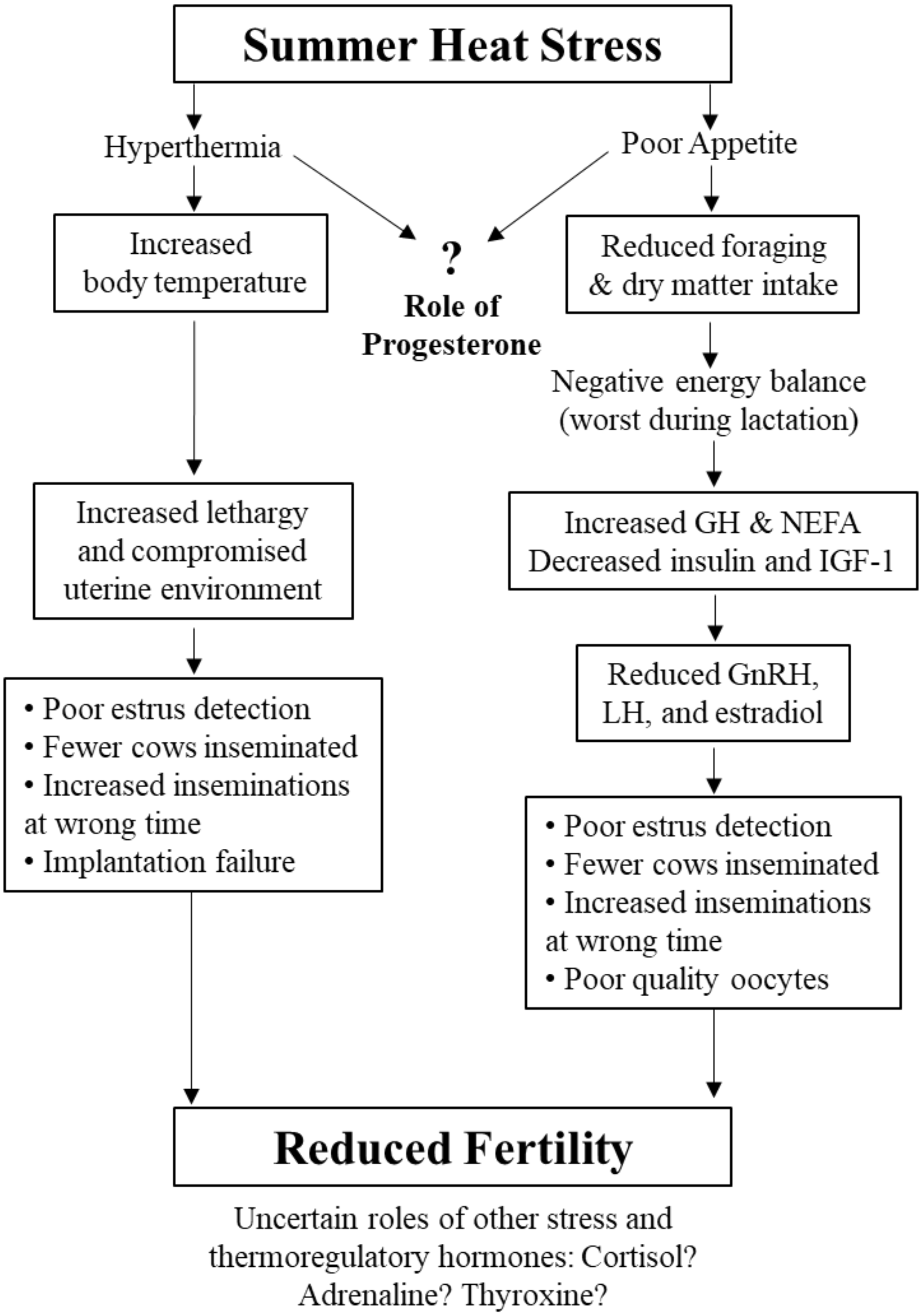


Figure 1.3. Heat stress symptoms of cattle and buffalo at varying Temperature-Humidity Index (THI) zones described and adapted from Dash et al. (2016).

THI	Stress level	Symptoms in cattle
< 72	None	• Optimum productive and reproductive performance
72-78	Mild	• Shade seeking behavior • Increase in respiration rate • Dilation of blood vessels
79-88	Moderate	• Increase in respiration rate and saliva secretion • Reduction in feed intake and water consumption • Increased body temperature • Reproductive performance severely affected
89-98	Severe	• Rapid increase in respiration and excessive saliva production • Reproductive performance significantly decreased
> 98	Danger	• Heat stress is extreme, and death may occur

CHAPTER TWO

Comparing dairy farm milk production, milk quality, and reproductive performance among United States regions using Summer to Winter ratios

INTRODUCTION

The United States is made up of several diverse climates from subtropical to temperate, affecting the environment of the dairy cow in multiple ways. Generally, the distribution of the US dairy cow population is focused in northern states, however dairy farming still plays a substantial role in the economies of southern states, such as Florida and Georgia (Mukherjee et al., 2013). Ambient temperature and humidity play the most important roles in contributing to heat stress, especially in high producing cows (Berman, 2005). Dairy cattle respond to heat stress through changes in physiological mechanisms, resulting in seasonality of performance.

Dairy cattle raised in a subtropical climate, such as the southern US, is described as humid subtropical having warm temperatures and high humidity (Kottek et al., 2006). Dairy cattle are exposed to high temperatures and humidity persisting for extended periods of time during summer months, with little to no alleviation at night (Johnson, 1987). St-Pierre et al. (2003) estimated milk losses from 436 kg to 1,233 kg per cow per year in the southeastern US, and results from a Florida study revealed a 15% reduction in milk yield in summer compared to winter (De Vries and Risco, 2005). Additionally, cows in Florida in July are exposed to constant temperatures outside of the thermoneutral zone, whereas in the drier climate of the Southwest, cows in the state with the highest average temperature in July, Arizona, are exposed to heat stress for around 8 h/d (St-Pierre et al., 2003). Similarly, the subtropical environment of Louisiana has experienced a milk production loss of 2,072 kg/cow/yr, compared to the cooler climate of Wyoming experiencing a loss of 68 kg/cow/yr (St-Pierre et al., 2003). Additionally, cattle in milder temperate climates also experience heat stress. Evidence of lower THI thresholds affecting performance suggests that cows in temperate climates might be less acclimated to heat (Beede and Collier, 1986a, Hammami et al., 2013, Schüller et al., 2014). Even in Canadian summers just above the US border in southern Winnipeg, cows can experience reduced DMI, and increased vaginal temperatures and respiration rates (Ominski et al., 2002).

Dairy cattle performance declines in temperate climates provide evidence that cows are still undergoing some heat stress in cooler climates. Schüller et al. (2014) reported the deterioration of conception rates at THI levels as low as 56, in a temperate climate. Veissier et al. (2017) concluded that cattle in the temperate climate of Belgium housed on pasture, used shade 65% more at a heat load index of 79 (index combining black globe temperature, relative humidity, and wind speed), compared to cows with no access to shade. This resulted in reduced respiration rates, rectal temperatures, and fecal cortisol metabolites.

The THI has been widely used as a metric to indicate level of heat stress (Hammami et al., 2013), as it is inversely related to milk loss (Bohmanova et al., 2007, Dikmen and Hansen, 2009) and is correlated with production performance (Silva et al., 2007), and reduced performance overall (West, 2003). The THI equation is: THI = (1.8 x T°C + 32) – (0.55 – 0.0055 x RH%) x (1.8 x T°C – 26), where T = hourly ambient temperature in °C and RH% = hourly relative humidity as a percentage (NRC, 1971). However, the THI may not accurately represent the individual cow's microclimate. Kaufman et al. (2018) concluded that vaginal temperature could be used to determine thermal load because it had the strongest relationship with THI. Rectal temperature (Igono et al., 1985), vaginal temperature (Araki et al., 1984), and skin temperature using infrared technology (Collier et al., 2011) have also been shown to indicate heat stress. So far, these measures are what can be used to identify periods of heat stress and quantify the effects on dairy cattle, however these methods may be unrealistic to implement on farm. With this in mind, a metric called the Summer to Winter (S:W) ratio was developed to evaluate the seasonal effects of heat stress on performance.

The S:W ratio was established by the Extension Service of the Ministry of Agriculture and Israel Cattle Breeders Association as a metric to identify the effects of summer heat stress on dairy cow performance and can further be used to estimate alleviation of heat stress by cow cooling strategies (Flamenbaum and Ezra, 2007b). Summer performance variables (numerator) are compared to winter performance variables (denominator) and the closer the ratio is to one, the less heat stress may be experienced by cows within the herd. A ratio under one indicates reduced performance in the summer compared to the winter, except for SCS which will show ratios higher than one as SCS typically increases in the summer.

The current study presents the use of the S:W ratio as a metric to quantify the effects of heat stress on cow performance in the US. The S:W ratio could take the place of potentially unreliable heat stress indices, or time and labor intensive means for identifying heat stress, as a simple on-farm measure to quantify the effects of heat stress by indicating reductions in performance. The objective of this study was to establish and compare S:W ratios for performance variables among US regions. The underlying goal of the S:W ratio is to motivate producers to implement on farm heat abatement to reduce seasonality of lactating cow performance. In Israel, the harsh climate combined with milk pricing incentives have forced producers to implement intensive cooling systems, and in turn they are producing more milk (Flamenbaum and Galon, 2010). The S:W ratio could be used the same way in the US to identify farms that need to improve heat abatement strategies. By utilizing the S:W ratio to quantify performance losses on farm, producers could recognize economic losses by visually seeing record of reduced performance and associating the values with lost revenue. This in turn might enhance management improvements, as it has in Israel. We predicted that herds in the northern, temperate climate would have ratios closer to one indicating less seasonality in performance, compared to herds in the southern, subtropical climate, because of milder temperatures with less humidity, or the possibility that current heat abatement strategies in the south are inadequate at ameliorating the effects of heat stress.

MATERIALS AND METHODS

Monthly performance data obtained by the Dairy Herd Information Association (DHIA) from 2007 to 2016 were recorded for all US DHIA herds processing records through DRMS (Dairy Records Management Systems, Raleigh, NC). The study was approved under the University of Tennessee- Knoxville IRB protocol # 14-09538 B-XP.

Only Holstein herds with 6 to 13 test dates per year were included in the dataset. Additionally, herds were required to have 2 to 4 test dates per season. To obtain S:W ratios, test day performance data was averaged by herd, season, and year, excluding spring and fall. Summer means were divided by winter means for each performance variable, resulting in one S:W ratio for each variable by year for each herd. Performance variables included in the analysis were energy-corrected milk (ECM), mean 150-day milk, milk fat %, milk protein %, somatic cell score (SCS), conception rate, pregnancy rate, and heat detection rate (HDR). Season dates were based on the astronomical definition of the northern hemisphere with summer as June 21 to September 21 and winter as December 21 to March 19, as defined by (NOAA, 2017). December was adjusted to equal the same experimental winter year as the following January to account for crop season. For example, December 2015 was considered as winter 2016, to be included in the same season as the following January.

States were grouped into regions based on climate zone classification (USDA, 2018b); Figure 2.1) as Northeast (humid continental climate with mild summers), Midwest (humid continental climate), Northern Plains (cold semi-arid to humid continental climate), Southeast (humid, subtropical climate), Southern Plains (primarily humid subtropical climate; (ISC-Audubon, 2018).

Performance records included a total of 16,589 herds [Northeast (n = 7,959), Midwest (n = 6,568), Northern Plains (n = 303), Southeast (n = 1,371), and Southern Plains (n = 388) regions]. Pacific Northwest and Southwest were excluded from the dataset attributable to inadequate sample size in the DHIA DRMS data base.

Weather data was retrieved through the cli-MATE application from the Midwestern Regional Climate Center (Champaign, IL). Data obtained included hourly temperature and relative humidity from one weather station per state. Each weather station was chosen based on the county with the highest milk cow inventory from the most current census in 2012 (NASS, 2012). If no weather station was available for that county, the closest county with suitable weather data from a weather station was chosen. Hourly THI data was obtained and mean per day. Daily THI means were averaged by state for the summer and winter season of each year. The THI equation used in this study was: THI = (1.8 x T°C + 32) – (0.55 – 0.0055 x RH%) x (1.8 x T°C – 26), where T = hourly ambient temperature in °C and RH% = hourly relative humidity as a percentage (NRC, 1971).

Statistical Analysis

All procedures were performed using SAS 9.3 (SAS Institute, Inc., Cary, NC). Descriptive statistics were performed for all variables. Milk and reproductive performance data were edited by removing variables equal to 0, indicating likely inaccurate data. Additionally, herd outliers were identified, and values less than the 1^{st} percentile or greater than the 99^{th} percentile for the entire data set, these data points were removed for performance variables, mean herd size, and mean DIM. Furthermore, summer and winter mean DIM, herd size, and mean 150-day milk were averaged by herd and year to be included as covariates in the model for each variable. After calculating the S:W ratio for each performance variable (summer as the denominator and winter as the numerator), the 1^{st} and 99^{th} percentiles were removed across the dataset for each variable to exclude outliers.

Herd test day performance variables in summer and winter were used to calculate S:W ratios for each region. The GLM procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC) was used to compare test day ECM, SCS, fat %, protein %, conception rate, pregnancy rate, and HDR S:W ratios for herds within each US region from 2007 to 2016. The effects of year, mean DIM, mean 150-day milk, mean herd size, and number of milkings were included as covariates in the model and stepwise-backward elimination was performed for each variables to exclude variables that were not contributing significantly to the model ($P > 0.3$). All covariates other than number of milking's were included in all models because of biological significance. Significant differences were considered at $P < 0.05$. A GLM model using the LSMEANS statement was used to generate least squares means separations between summer and winter for each variable.

RESULTS AND DISCUSSION

Descriptive data for each performance variable by region and all seasons are shown in Table 2.1. Summer and winter mean separations by region for each performance variable make up the final dataset and are shown in Table 2.2. Mean (±SD) DIM, mean herd size, and mean 150-day milk were 187 ± 27.08, 136 ± 171.28, and 33 ± 5.06 kg for the final dataset. Mean, median, maximum, and minimum herd size for the entire dataset was 136, 79, 1,486, and 22 cows, respectively (Table 2.3). Descriptive data for THI results are shown in Table 2.4. Numerically, the Northeast, Northern Plains, and Midwest had higher THI values for every year presented, compared to the Southeast, and Southern Plains regions.

Milk Production

Descriptive Findings

Energy-corrected milk during the 10-yr period observed in this study was different among the regions analyzed, with the overall mean ECM being 30.89 ± 0.004 kg of milk per day for all regions combined (Table 2.1).

ECM S:W Ratio Model

The mean S:W ratio for ECM combined for all regions was 0.93 ± 0.001. The EMC S:W ratio varied among regions ($P < 0.001$), where the Southern Plains region had the lowest and the Northeast and Midwest had the highest S:W ratios for ECM (0.88 ± 0.003 vs. 0.94 ± 0.001; $P < 0.01$; Table 2.3). Speculatively, this may indicate a higher level of heat stress affecting milk production in some areas of the country, with the climate, most likely in combination with potentially less success in heat abatement management practices, playing a role in milk loss.

In all regions, milk production was numerically lower in summer compared to winter with and without accounting for DIM, indicating seasonality in milk production. One factor causing reduced milk production is the reduction in dry matter intake (DMI) indirectly caused by heat stress. Reducing DMI is a strategy to maintain a normal body temperature (Beede and Collier, 1986a), and results in insufficient nutrients available for the mammary gland to produce milk (West, 2003, Rhoads et al., 2009). In addition, there is evidence that heat stress has a direct effect on milk production. Johnson and Vanjonack (1976) reported that 3 to 10% of the change in milk production was caused by climate factors. In another study on mid-lactation heat stressed cows, DMI accounted for only 50% of the drop in milk production, proposing that other factors influenced the remaining reduction (Wheelock et al., 2010).

Dairy cattle in a subtropical climate are exposed to high temperatures and humidity during summer months, with the expectation of experiencing heat stress. This supports the S:W ratios being lower for the Southeast and Southern Plains regions. Dairy cattle raised in the temperate climate of northern regions can experience heat stress, supporting the results of the best S:W for ECM being the Northeast and Midwest temperate climates in this study (Polsky and von Keyserlingk, 2017). This suggests that cows in temperate climates might be less acclimated to heat than cows in subtropical climates because of performance losses at lower THI thresholds (Beede and Collier, 1986b, Hammami et al., 2013, Schüller et al., 2014). The subtropical environment of Louisiana has experienced a milk production loss of 2,072 kg/cow/yr, compared to the cooler climate of Wyoming experiencing a loss of 68 kg/cow/yr (St-Pierre et al., 2003), similar to the larger reduction in ECM production in the Southern Plains compared to the Northern Plains, in the current study. Furthermore, descriptive THI data for the Northern Plains was 67, and 76 for the Southern Plains region, in the summer averaged across the 10 yr study length. The Northern Plains had the highest S:W ratio for ECM, indicating the least seasonality in ECM production, implying less heat stress experienced by cattle in the region.

Milk Quality

Descriptive Findings

Results for milk quality are represented by SCS. Somatic cell score was different for the herds analyzed, and the mean SCS for all regions combined was 2.69 ± 0.001 (Table 2.1). The effects of heat stress on milk components were measured by milk fat and protein %. Overall, mean fat % was 3.74 ± 0.001% and mean protein % was 3.06 ± 0.001% for all regions combined (Table 2.1).

Somatic Cell Score S:W Ratio Model

The mean S:W ratio for SCS for all regions was 1.06 ± 0.001. Once more, S:W ratios above one indicate a higher SCS in the summer, but reverse when considering S:W ratios for other variables. Interesting, as expected SCS were higher than one, demonstrating a national trend of increase of SCS during the summer.

The SCS S:W ratio was different among regions ($P < 0.001$). The Northern Plains was the lowest and the Southern Plains was the highest S:W ratios for SCS (1.01 vs. 1.08 ± 0.00 respectively; Table 2.2). The Northern Plains SCS S:W ratio was closest to one, indicating minimal seasonality in SCS. In the Southern Plains, SCS increased 7% in the summer compared to winter, potentially indicating that heat abatement may play a major role explaining these results, however this is not biologically relevant as an increase in SCS from 250,000 to 267,500 is not an alarming change for producers. Contrastingly in the Northern Plains, SCS did not vary between winter to summer, these findings should be further investigated especially in combination with farm management characteristics. Further explaining higher summer SCS in the southern US, Ferreira and De Vries (2015), concluded that farms producing lower milk volumes tended to have higher BTSCC throughout the year, suggesting there is a "dilution effect," causing the appearance of higher SCS because of a lower milk volume. While this pattern is shown as the Southern Plains having the lowest S:W ratio for ECM, showing lowest milk production and also the highest SCS showing the highest SCS in the summer, these results can not conclude this as the changes in S:W ratios for SCS were not biologically different.

Somatic cell counts typically rise during summer months, as the S:W ratios in this study document. This agrees with a study by Nasr and El-Tarabany (2017) who reported that from low to high THI, SCC increased by 36%. In the current study, the Northern Plans had a mean THI of 73.6 in the summer over the 10 years, and the Southern Plains had a mean THI of 64.7, showing the largest change in THI from the regions with the lowest to highest S:W ratio for SCS. It was expected for the harshest climate to have the highest S:W ratio for SCS. Further, Hogan et al. (1989b) found that bacterial counts in bedding were higher in summer and fall, and that teat end exposure to the bedding was associated higher rates of clinical mastitis. This likely happens because of the increased bacterial load in humid and moist environment, where bacteria can thrive and are more available to enter the mammary gland (Godden et al., 2003). Additionally, a compromised immune system could be partially responsible for the increase in SCC and clinical mastitis infections during the summer months (Do Amaral et al., 2011, Hammami et al., 2013, Tao et al., 2018). Results from this study showed slight numerical increases in SCS but not biologically relevant changes.

Mastitis control programs are important to implement all year, but especially in the summer when risks are high, as found in this study. Keeping a clean, dry environment in housing facilities and in the milking parlor is key. Intramammary infections have been shown to increase with higher pathogen load on teat ends (Neave et al., 1969), therefore premilking teat sanitation would benefit in preventing the spread of infection (Pankey, 1989). This and other management practices to prevent mastitis during the summer months should be evaluated to reflect this seasonality of SCS in the regions.

Milk Fat and Protein % S:W Ratio Models

The S:W ratio for fat % combined for all regions was 0.94 ± 0.001, and was different among regions ($P < 0.001$). Following the same trend but opposite effect as the

ECM and SCS S:W ratio, the Northern Plains had the lowest and the Southern Plains and Southeast had the highest S:W ratios for fat % (0.93 ± 0.002 vs. 0.95 ± 0.002 and 0.95 ± 0.001; Table 2.2), showing a greater drop in fat % for the Northern Plains during the summer, with less of an effect on the two southern most regions.

Milk protein % gave similar results as fat %. The S:W ratio for protein % combined for all regions was on average 0.96 ± 0.001. Milk protein % S:W ratio was different between the regions ($P < 0.001$). Following the same trend, the Northern Plains region had the lowest, and the Southeast had the highest S:W ratio for protein % (0.96 vs. 0.97 ± 0.001; Table 2.2).

Studies have shown inconsistency in the effects of heat stress on milk component changes for fat and protein %, such that milk fat was lower in summer compared to winter (Bernabucci et al., 2015) whereas others found no difference between seasons (Hammami et al., 2015) or higher concentrations of milk fat in summer compared to cooler weather (Smith et al., 2013). In the current study, milk fat and protein were lowest in the temperate climate of the Northern Plains with a mean THI of 64.7 in the summer. Comparable to the current study, McDowell et al. (1976) reported decreases in milk fat, non-fat solids, and protein % decreases by 39.7, 18.9, and 16.9, respectively when ambient temperature increased from 18 to 30°C. Fat yield decreases could be explained by a decrease in forage intake with low fiber levels, and protein decreases could be attributed to reduced DMI and energy intake when the animal is under heat stress, although DMI was not quantified in this study. Opposing results from Nasr and El-Tarabany (2017) reported an inverse relationship between milk components and THI. Fat % decreased in the high THI group at 3.74% and at 3.91% in the low THI group. Milk protein yield decreased 18 kg and fat yield decreased 19 kg from low to high THI (Nasr and El-Tarabany, 2017).

Reproductive Performance

Descriptive Findings

Reproduction showed the greatest negative effects during the summer. Overall mean conception rate was 45.9 ± 19.4% for all regions combined (Table 2.1).

Conception Rate S:W Ratio Model

The mean S:W ratio for conception rate combined for all regions was 0.92 ± 0.001. Differences for conception rate S:W ratio were present among regions ($P < 0.001$). Summer to Winter ratios for conception rate were lowest for the Southeast and Southern Plains, and highest for the Northeast, Midwest, and Northern Plains (0.87 ± 0.004 and 0.87 ± 0.008 vs. 0.92 ± 0.001, 0.92 ± 0.002 and 0.91 ± 0.008; Table 2.2). The conception rate in the Southern Plains and Southeast decreased by an average of 11% in summer compared to winter, with the Northeast, Midwest, and Northern Plains decreasing 8% from Summer to Winter. A preliminary study by Robertson (2012) found similar results for conception rate with the north having higher conception rate than the south (34.3 vs. 21.2%) and found the same for S:W ratio for conception rate (0.90 vs. 0.58 ± 0.02).

Descriptive Findings

Heat detection rate was different for the herds analyzed with the overall mean HDR being 45.0 ± 16.8% for all regions combined (Table 2.1).

Heat Detection Rate S:W Ratio Model

The mean S:W ratio for HDR combined for all regions was 0.97 ± 0.001, and were different among regions ($P < 0.001$). The lowest S:W for HDR was in the Southern Plains and the highest in the Northeast (0.88 ± 0.008 vs. 0.98 ± 0.001; Table 2.2). These results agree with other studies, as heat stress has a known detrimental effect on detecting estrus in dairy cattle (Thatcher and Collier, 1986, Hansen and Arechiga, 1999, Schüller et al., 2016) likely because of lowered estradiol concentrations (Roth et al., 2001). Up to 80% of estrus behaviors are not detected because of the effects of heat stress (Thatcher and Collier, 1986). Hot weather causes a reduction in activity, (Hansen and Arechiga, 1999) due to physical lethargy. According to De Rensis and Scaramuzzi (2003), heat stress leads to infertility by two independent pathways (Figure 1.2); the direct effect of hyperthermia on the reproductive axis, and the indirect effect associated with reductions in appetite and DMI, relating to negative energy balance. Although timed artificial insemination (TAI) protocols were developed to reduce the need for visual detection of estrus with the goal of increasing pregnancy rate (Collier et al., 2006), and have shown positive effects (Edwards and Hansen, 1997) and are widely used on dairy farms in the US (USDA-APHIS, 2007). The S:W ratios for heat detection rate in this study are supported by previous literature.

Descriptive Findings

Pregnancy rate was different for the herds analyzed with the overall mean pregnancy rate being 17.11 ± 0.009% for all regions combined (Table 2.1).

Pregnancy Rate S:W Ratio Model

The S:W ratio for pregnancy rate combined for all regions was on average 0.86 ± 0.001. Differences among regions were present ($P < 0.001$). The Southern Plains region had the lowest and the Northeast had the highest S:W ratio for pregnancy rate (0.66 ± 0.011 vs. 0.89 ± 0.002; Table 2.2), giving the largest difference in all performance variables. Similar to previous literature, pregnancy rate decreased continuously once THI reached 51 until a THI of 74 (Schüller et al., 2016). Summer pregnancy rate is lower than winter pregnancy rate in all regions.

Study Limitations

Although the S:W ratio has an important role as a key performance indicator on farm, limitations exist. In this study, seasonal herds could affect the results by the number of cows in milk during the summer period being less for seasonal herds, which in turn would increase the S:W ratio. However, to account for this in the best way possible, DIM was included in all models as a covariate. Additionally, housing and herd management practices, such as access to pasture, and heat abatement strategies could not be accounted for as this data was not available in the dataset. Therefore, some heat stress effects were likely alleviated. Further studies should investigate the use of S:W ratio in relation to on farm management practices.

Another limitation includes how management changes between seasons could not be accounted for, such as changes in rations or changes in reproductive management. Future research should investigate how nutritional and managerial factors might affect performance during the summer months and compare with the effects caused by heat stress alone.

Temperatures may vary for the summer season among states. For instance, Florida may experience higher temperatures in earlier months compared to other states, however summer was defined by astronomical dates for every state. This would exclude periods of heat stress in the spring and carry over into the fall. Limitations exist, but it is important to understand that all key performance indicators have flaws but are still useful in making management changes to improve cow comfort and performance.

CONCLUSIONS

The results from this study identified a major effect of summer in dairy farms performance, which can be attributed for heat stress. There is a need for improvement in heat abatement in the US, specifically in the southern US based on the information collected. For all performance variables evaluated in this study, negative effects were primarily seen in the Southeast and Southern Plains coupled with a higher THI, indicating exposure to summer heat stress, and potential lack of heat abatement strategies during heat stress periods. The results of this study demonstrate the use of the S:W ratio in having potential to benefit producers and consultants as a tool to assess heat stress in specific herds or regions, with the goal of encouraging improvement of on-farm heat abatement. Quantifying heat stress for the producer in terms of performance could assist in understanding economic losses and drive them to improve their heat stress management strategies by adopting mechanical means for cooling. As climate change continues to increase temperatures worldwide, the importance of controlling heat stress in dairy cattle is imperative.

ACKNOWLEDGEMENTS

The Southeast Quality Milk Initiative is supported by the National Institute of Food and Agriculture, US. Department of Agriculture, under award number 2013-68004-20424. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US Department of Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US Department of Agriculture. The authors would like to thank the researchers leading the Southeast Quality Milk Initiative projects, who have contributed to this paper, including Derek Nolan, Peter Krawczel, Christina Petersson-Wolfe, Gina Pighetti, Amanda Stone, Stephanie Ward, and Jeffrey Bewley.

Table 2.1. Summary of results for production, milk quality, and reproductive performance data from 2007 to 2016 by season and US region, to identify variance among regions (n represents number of herds per region). Variable means by region and season, and total mean are also included.

Performance Variables	Northeast (n = 7,955)	Midwest (n = 6,555)	Northern Plains (n = 305)	Southeast (n = 1,370)	Southern Plains (n = 388)	Total Mean
Energy corrected milk (kg)						30.89 ± 0.004
Spring	31.68 ± 0.012	31.43 ± 0.015	30.15 ± 0.065	29.77 ± 0.033	29.89 ± 0.062	
Summer	30.20 ± 0.012	30.17 ± 0.015	28.75 ± 0.067	27.63 ± 0.034	27.38 ± 0.062	
Fall	30.87 ± 0.012	30.86 ± 0.015	29.82 ± 0.066	29.15 ± 0.033	29.30 ± 0.063	
Winter	31.80 ± 0.012	31.61 ± 0.148	30.60 ± 0.066	30.70 ± 0.032	30.96 ± 0.061	
Somatic cell score						2.69 ± 0.001
Spring	2.56 ± 0.002	2.65 ± 0.002	2.86 ± 0.001	2.88 ± 0.004	2.76 ± 0.009	
Summer	2.71 ± 0.002	2.79 ± 0.002	2.93 ± 0.010	3.11 ± 0.005	3.02 ± 0.009	
Fall	2.64 ± 0.001	2.70 ± 0.002	2.91 ± 0.009	3.08 ± 0.004	2.91 ± 0.008	
Winter	2.56 ± 0.002	2.68 ± 0.002	2.93 ± 0.009	2.95 ± 0.004	2.81 ± 0.009	
Fat (%)						3.74 ± 0.001
Spring	3.70 ± 0.001	3.71 ± 0.001	3.65 ± 0.004	3.57 ± 0.002	3.62 ± 0.004	
Summer	3.61 ± 0.001	3.64 ± 0.001	3.56 ± 0.004	3.57 ± 0.002	3.59 ± 0.004	
Fall	3.82 ± 0.001	3.85 ± 0.001	3.82 ± 0.005	3.75 ± 0.002	3.76 ± 0.004	
Winter	3.83 ± 0.001	3.84 ± 0.001	3.81 ± 0.005	3.75 ± 0.002	3.77 ± 0.004	
Protein (%)						3.06 ± 0.001
Spring	3.01 ± 0.001	3.04 ± 0.001	3.06 ± 0.002	2.99 ± 0.001	3.06 ± 0.002	
Summer	2.97 ± 0.001	2.99 ± 0.001	3.00 ± 0.002	2.99 ± 0.001	3.04 ± 0.002	
Fall	3.11 ± 0.001	3.15 ± 0.001	3.19 ± 0.002	3.13 ± 0.001	3.19 ± 0.002	
Winter	3.08 ± 0.001	3.12 ± 0.001	3.15 ± 0.002	3.07 ± 0.001	3.14 ± 0.002	
Conception Rate[1]						45.41 ± 0.022
Spring	45.12 ± 0.056	46.28 ± 0.074	49.28 ± 0.391	49.39 ± 0.182	47.12 ± 0.348	

Table 2.1 (continued)

Summer	42.39 ± 0.060	43.15 ± 0.077	46.25 ± 0.423	45.57 ± 0.224	43.01 ± 0.436	
Fall	45.60 ± 0.056	46.51 ± 0.071	49.50 ± 0.379	48.85 ± 0.193	45.79 ± 0.367	
Winter	45.58 ± 0.054	46.73 ± 0.070	49.95 ± 0.380	49.69 ± 0.167	47.55 ± 0.310	
Heat Detection Rate[2]						45.74 ± 0.019
Spring	46.98 ± 0.051	45.07 ± 0.064	39.88 ± 0.318	43.48 ± 0.147	42.34 ± 0.283	
Summer	45.95 ± 0.051	43.19 ± 0.065	37.21 ± 0.321	39.50 ± 0.164	36.50 ± 0.306	
Fall	47.72 ± 0.051	45.75 ± 0.065	40.85 ± 0.319	42.80 ± 0.165	40.25 ± 0.315	
Winter	47.31 ± 0.050	45.63 ± 0.062	39.30 ± 0.305	44.51 ± 0.142	43.61 ± 0.273	
Pregnancy Rate[3]						17.11 ± 0.009
Spring	17.99 ± 0.025	16.99 ± 0.029	14.86 ± 0.125	15.73 ± 0.058	15.00 ± 0.108	
Summer	16.01 ± 0.024	14.67 ± 0.027	12.17 ± 0.116	10.90 ± 0.055	9.58 ± 0.098	
Fall	18.63 ± 0.025	17.73 ± 0.029	15.52 ± 0.124	15.28 ± 0.063	13.92 ± 0.118	
Winter	18.52 ± 0.025	17.73 ± 0.029	15.19 ± 0.124	17.74 ± 0.059	17.43 ± 0.115	

[1]Conception rate was calculates as the number of successful services in each test period divided by the total number of services for that test period.
[2]Heat detection rate was calculates as the percent of the possible heats that are detected, calculated as % Heats Obs. = [number of services and heats reported in the test period for eligible cows / (estrous cycle days in test period for eligible cows / 21)] X 100.
[3]Pregnancy rate was calculates as the percentage of cows eligible to become pregnant that are reported pregnant within a specific period of time.

Table 2.2. Descriptive data displaying summer and winter means (± SE) for each performance variable used to calculate Summer to Winter ratios for US regions.

Performance Variables	Northeast (n = 7,955)	Midwest (n = 6,555)	Northern Plains (n = 305)	Southeast (n = 1,370)	Southern Plains (n = 388)
Energy Corrected Milk (kg)					
Summer	30.54 ± 0.04[a]	31.75 ± 0.04[b]	29.89 ± 0.19[c]	28.80 ± 0.09[d]	28.66 ± 0.18[d]
Winter	32.02 ± 0.03[c]	32.04 ± 0.04[c]	31.81 ± 0.16[bc]	32.22 ± 0.08[b]	32.78 ± 0.15[a]
Somatic cell score					
Summer	2.72 ± 0.01[d]	2.82 ± 0.01[c]	2.88 ± 0.03[c]	3.12 ± 0.01[a]	3.00 ± 0.03[b]
Winter	2.56 ± 0.01[d]	2.71 ± 0.01[c]	2.86 ± 0.03[ab]	2.93 ± 0.01[a]	2.77 ± 0.03[bc]
Fat (%)					
Summer	3.61 ± 0.01[b]	3.64 ± 0.01[a]	3.53 ± 0.01[c]	3.54 ± 0.01[c]	3.54 ± 0.01[c]
Winter	3.84 ± 0.01[b]	3.85 ± 0.01[a]	3.80 ± 0.01[c]	3.70 ± 0.01[d]	3.73 ± 0.01[d]
Protein (%)					
Summer	2.98 ± 0.01[c]	2.99 ± 0.01[b]	3.00 ± 0.01[b]	2.98 ± 0.01[c]	3.03 ± 0.01[a]
Winter	3.09 ± 0.01[c]	3.12 ± 0.01[b]	3.14 ± 0.01[a]	3.07 ± 0.01[d]	3.12 ± 0.01[ab]
Conception Rate[1]					
Summer	43.36 ± 0.20[c]	45.83 ± 0.23[b]	49.19 ± 1.08[a]	49.38 ± 0.52[a]	46.66 ± 0.98[ab]
Winter	46.01 ± 0.17[c]	48.92 ± 0.20[b]	50.93 ± 0.91[ab]	51.10 ± 0.43[a]	49.13 ± 0.81[ab]
Heat Detection Rate[2]					
Summer	44.72 ± 0.15[a]	40.96 ± 0.17[b]	36.78 ± 0.80[c]	37.88 ± 0.39[c]	37.00 ± 0.72[c]
Winter	46.23 ± 0.15[a]	43.29 ± 0.17[b]	38.93 ± 0.79[c]	43.10 ± 0.38[b]	43.26 ± 0.70[b]
Pregnancy Rate[3]					
Summer	15.96 ± 0.05[a]	14.41 ± 0.06[b]	12.18 ± 0.26[c]	10.92 ± 0.13[d]	10.20 ± 0.24[d]
Winter	18.25 ± 0.05[a]	17.40 ± 0.06[b]	15.31 ± 0.28[c]	17.59 ± 0.13[b]	17.71 ± 0.55[ab]

[1]Conception rate was calculates as the number of successful services in each test period divided by the total number of services for that test period.
[2]Heat detection rate was calculates as the percent of the possible heats that are detected, calculated as % Heats Obs. = [number of services and heats reported in the test period for eligible cows / (estrous cycle days in test period for eligible cows / 21)] X 100.
[3]Pregnancy rate was calculates as the percentage of cows eligible to become pregnant that are reported pregnant within a specific period of time.
[a-b]Least squares means with different superscripts denoting differences within columns for each question ($P < 0.05$).

Table 2.3. Least squares means (± SE) of Summer to Winter performance ratios for energy-corrected milk, SCS, milk fat %, milk protein %, conception rate, heat detection rate, and pregnancy rate compared among US Regions.

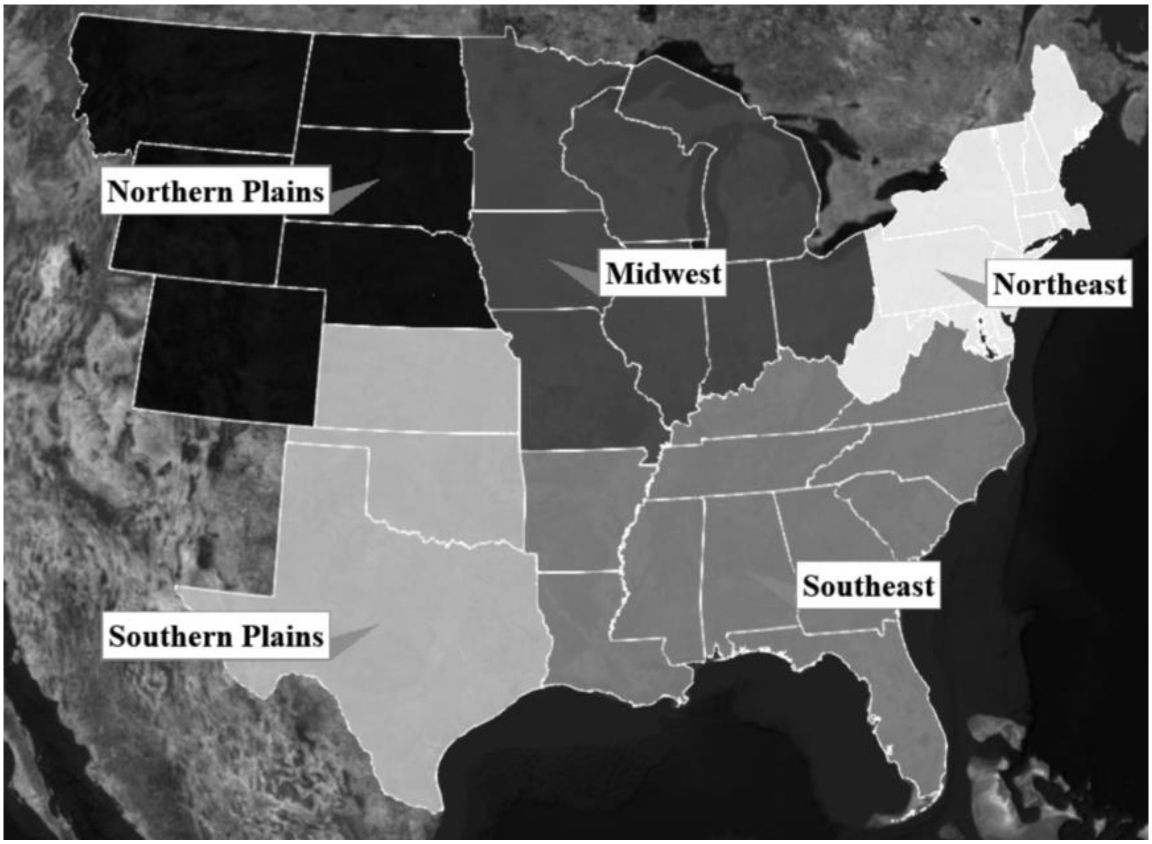
S:W Ratio	Mean	Northeast (n =7,959)	Midwest (n = 6,568)	Northern Plains (n = 303)	Southeast (n = 1,371)	Southern Plains (n = 388)	Region P-value	150-Day Milk *P*-value
Energy corrected milk	0.93 ± 0.001	0.94 ± 0.001^{a}	0.94 ± 0.001^{a}	0.93 ± 0.003^{b}	0.89 ± 0.002^{c}	0.88 ± 0.003^{d}	< 0.001	-
Somatic cell score	1.06 ± 0.001	1.07 ± 0.001^{b}	1.05 ± 0.001^{c}	1.01 ± 0.005^{d}	1.06 ± 0.002^{b}	1.08 ± 0.005^{a}	< 0.001	< 0.001
Fat %	0.94 ± 0.001	0.94 ± 0.001^{c}	0.95 ± 0.001^{b}	0.93 ± 0.002^{d}	0.95 ± 0.001^{a}	0.95 ± 0.002^{a}	< 0.001	< 0.001
Protein %	0.96 ± 0.001	0.97 ± 0.000^{c}	0.96 ± 0.000^{d}	0.96 ± 0.001^{e}	0.97 ± 0.001^{a}	0.97 ± 0.001^{b}	< 0.001	< 0.001
Conception rate	0.92 ± 0.001	0.92 ± 0.001^{a}	0.92 ± 0.002^{a}	0.91 ± 0.008^{a}	0.87 ± 0.004^{b}	0.87 ± 0.008^{b}	< 0.001	< 0.001
Heat detection rate	0.97 ± 0.001	0.98 ± 0.001^{a}	0.96 ± 0.002^{b}	0.96 ± 0.008^{ab}	0.92 ± 0.004^{c}	0.88 ± 0.008^{d}	< 0.001	< 0.001
Pregnancy rate	0.86 ± 0.001	0.89 ± 0.002^{a}	0.86 ± 0.002^{b}	0.84 ± 0.011^{b}	0.70 ± 0.006^{c}	0.66 ± 0.011^{d}	< 0.001	< 0.001

$^{a-b}$Least squares means with different superscripts denoting differences within columns for each question ($P < 0.05$).

Table 2.4. Temperature-humidity index data averaged by season, year, and region. Averages by region and season for all regions combined (± SE).

Year	Northeast (n = 7,955)	Midwest (n = 6,555)	Northern Plains (n = 305)	Southeast (n = 1,370)	Southern Plains (n = 388)
2007					
Summer	66.8 ± 0.6	67.7 ± 1.7	65.5 ± 1.6	73.3 ± 0.6	74.0 ± 1.0
Winter	37.1 ± 1.4	33.1 ± 1.6	32.6 ± 0.7	48.6 ± 1.4	44.0 ± 3.1
2008					
Summer	67.2 ± 0.5	66.8 ± 0.9	64.3 ± 1.5	72.9 ± 0.6	72.5 ± 1.4
Winter	37.2 ± 1.0	32.8 ± 1.6	31.7 ± 0.9	49.4 ± 1.3	44.5 ± 3.7
2009					
Summer	66.3 ± 0.7	65.7 ± 1.1	63.8 ± 1.5	73.3 ± 0.6	72.7 ± 1.6
Winter	35.2 ± 1.00	33.4 ± 1.9	33.5 ± 1.4	48.0 ± 1.5	46.4 ± 3.3
2010					
Summer	68.4 ± 0.6	68.8 ± 1.1	64.7 ± 2.4	74.5 ± 0.5	74.8 ± 1.1
Winter	36.5 ± 0.7	29.5 ± 2.6	30.5 ± 0.8	45.2 ± 1.2	42.6 ± 3.7
2011					
Summer	68.3 ± 0.6	68.1 ± 0.8	65.2 ± 1.4	73.4 ± 0.5	73.4 ± 1.1
Winter	37.2 ± 1.7	32 ± 1.9	33.7 ± 0.9	49.3 ± 1.3	44.4 ± 3.0
2012					
Summer	68.4 ± 0.5	67.7 ± 0.7	64.7 ± 1.3	73.3 ± 0.5	72.9 ± 1.2
Winter	39.8 ± 1.0	34.5 ± 2.4	35.9 ± 0.5	51.7 ± 1.3	48.1 ± 2.8
2013					
Summer	67.9 ± 0.5	68.4 ± 0.8	65.9 ± 1.2	73.3 ± 0.6	73.9 ± 1.5
Winter	36.8 ± 0.8	32.4 ± 1.5	32.8 ± 1.2	47.7 ± 1.9	44.7 ± 3.4
2014					
Summer	67.1 ± 0.6	66.4 ± 1.0	63.8 ± 1.2	73.0 ± 0.6	73.2 ± 1.5
Winter	34.8 ± 0.7	30.1 ± 1.6	34.2 ± 0.9	46.0 ± 1.5	42.8 ± 3.0
2015					
Summer	68.7 ± 0.6	67.6 ± 1.0	65.1 ± 1.7	73.4 ± 0.4	74.0 ± 1.1
Winter	34.8 ± 0.9	32.5 ± 1.2	35.8 ± 0.9	48.3 ± 1.7	44.2 ± 2.9
2016					
Summer	70.2 ± 0.8	69.6 ± 1.1	64.6 ± 1.7	74.9 ± 0.3	74.9 ± 1.0
Winter	39.3 ± 0.8	35.3 ± 2.0	35.4 ± 0.6	49.9 ± 1.4	48.5 ± 3.0
Mean					
Summer	67.9 ± 0.2	67.7 ± 0.3	64.7 ± 0.5	73.5 ± 0.2	73.6 ± 0.4
Winter	36.8 ± 0.4	32.6 ± 0.6	33.6 ± 0.4	48.4 ± 0.5	45.0 ± 0.9

Figure 2.1. States were grouped into regions based on climate zone classification described by USDA (2018b) as Northeast, Southeast, Midwest, Northern Plains, and Southern Plains. Pacific Northwest, and Southwest regions were excluded from the dataset.



CHAPTER THREE

Comparing dairy farm performance and heat abatement management practices among the Southeast United States using Summer to Winter ratios

INTRODUCTION

The climate of the southeastern US is classified as humid subtropical having warm temperatures and full humidity (Kottek et al., 2006)., therefore, extended periods of potential heat stress for dairy cattle are possible. In this region, it is likely that dairy cattle are exposed to temperatures above their thermoneutral zone for four to five months of the year (Beede and Collier, 1986a). Exceeding the thermoneutral zone (5°C to 25°C) of the lactating dairy cow causes significant declines in performance, leading researchers to determine the best way to manage the environment and reduce heat stress. Historically, the Southeast US has struggled with keeping up with milk production and milk quality of the rest of the US. Although milk quality is improving because of many improvements, managing the negative effects of heat stress in a harsh climate is fundamental.

Recommended management practices such as cooling systems are recognized to ameliorate the effects of heat stress on the lactating dairy cow. Implementation of cow cooling strategies to protect from the economic pitfalls caused by heat stress is a recommended practice in the US. Shade, fans, natural ventilation, and water cooling systems (misters and sprinklers) are among the most used and practical (Mukherjee et al., 2013). Of all US dairies in 2007, 94% use at least one of these systems for heat abatement (USDA, 2010). Mukherjee et al. (2013) reported that the average estimated gain in gross revenue based on data from farms in Florida and Georgia using fans and sprinklers combined was $106,830 per year, illustrating the need for evaporative cooling strategies on farm.

To effectively dissipate heat from the cow, it is essential to consider the ambient temperature, relative humidity and solar radiation (West, 2003). (Flamenbaum and Galon, 2010). Evaporative cooling applied in a confinement setting works by wetting the animal's skin surface, and then using the forced ventilation of fans to increase air velocity around the animal. Original work by Seath and Miller (1948) compared the effects of cow cooling by using fans or sprinklers, or the combination of both. Cows in the no cooling treatment showed the least decrease in rectal temperature, followed by cows cooled with either fans or sprinklers, and using a combination of fans and sprinklers had the greatest effect on rectal temperature, thus representing the best cooling technique. Further research demonstrated the combination of shade and sprinklers yielded a respiration rate of 24 breaths/min compared to sprinklers alone at a rate of 30 breaths/min (Kendall et al., 2007). Respiration rates were reduced by 60 and 67% for sprinklers and sprinklers and shade combined, respectively, compared to controls with no heat abatement. Temperature-humidity indices (THI) for control cows, shade alone, sprinklers alone, and shade and sprinklers were 68.8, 68.5, 67.1, and 65.9, respectively (Kendall et al., 2007).

Heat stress in dairy cattle is characterized by a change in behavior, physiologic mechanisms, metabolism, immune system, and in turn negatively affects productivity, fertility, and milk quality, reducing profitability of the farm. Controlling heat stress is a challenge for most producers, especially in the southeastern US (Beede and Collier, 1986a). For this reason, there is an increasing need for methods to quantify heat stress because it can be a challenge. A common approach for determining if cattle are experiencing heat stress, is utilizing the THI equation which accounts for ambient temperature and relative humidity of the surrounding environment (Hammami et al., 2013). Obtaining the THI from a local weather station may not accurately depict the microclimate in the cow's housing environment (Collier et al., 2006) because THI can be higher at the cow level than the station level (Scanavez et al., 2016). However, identifying heat stress at the cow level could be time intensive, subjective from cow to cow and ultimately not realistic to be frequently observed on farm. This may be because of time constraints or lack of heat stress symptoms until performance already begins to decline.

Dairy cattle begin experiencing heat stress well before the temperature is hot for humans. Additionally, the industry is lacking a simple, non-invasive measure for quantifying the effects of heat stress on performance. Producers can quantify various measures of performance and health, such as using a body condition scoring system to identify issues with disease or feeding management, locomotion scoring to detect issues with cow comfort and housing management and obtaining SCC data and other variables to determine the level of mastitis and diagnose milk quality issues. This data is easily accessible through monthly records and can benefit the producer by presenting opportunities for improvement with the goal of increasing profitability. Heat stress identification in the US is not currently being identified in a way that a producer can realize performance declines from Summer to Winter, quantifying the effects of heat stress on the herd. A tool that could be a solution to this issue and provide producers with heat stress data is the S:W ratio (Flamenbaum and Ezra, 2007a). As demonstrated in the sub-tropical climate of Israel, intensively cooling cows during summer months can lead to 50% reductions in the seasonal variation of milk production and conception rates (Flamenbaum and Galon, 2010), thus motivating farmers to implement heat abatement strategies is fundamental. The purpose of the S:W ratio is to quantify the negative effects of heat stress on performance and to determine how well dairy producers are cooling their cows in the summer months. The closer the ratio is to one, the less seasonality of performance variables (Flamenbaum and Ezra, 2007a). The current study presents the use of the S:W ratio as a tool to quantify the effects of heat stress on cow performance in the southeastern US, and to identify farms in this region that may exhibit opportunities for improving heat abatement strategies. The objectives were to (1) compare S:W performance ratios for milk and reproduction variables among southeastern US states and (2) utilize survey responses from farms in three Southeast states, to compare S:W ratios associated with specific heat abatement strategies. We hypothesized that (1) herds in the northern most states would have ratios closer to one because of milder temperatures with less humidity, combined with the use of heat abatement strategies and (2) producers implementing intensive heat abatement strategies will have S:W ratios closest to one, because cooling cows effectively would reduce the seasonality of performance variables.

MATERIALS AND METHODS

Monthly performance data obtained by the Dairy Herd Information Association (DHIA) from 2007 to 2016 were recorded for all US DHIA herds processing records through DRMS (Dairy Records Management Systems, Raleigh, NC). The study was approved under the University of Tennessee- Knoxville IRB protocol # 14-09538 B-XP and IACUC protocol # 2130.

Only Holstein breed herds were included in the dataset. Additional requirements included herds with more than six test dates per year and excluded herds with > 13 test dates per year. Further, herds were required to have at least two test dates per season and herds with more than four per season were excluded To obtain S:W ratios, test day performance data was averaged by herd, season, and year, excluding spring and fall. Summer means were divided by winter means for each performance variable, resulting in one S:W ratio for each variable by year for each herd. Performance variables incorporated in the analysis were energy-corrected milk (ECM), milk fat %, milk protein %, somatic cell score (SCS), conception rate, pregnancy rate, and heat detection rate (HDR). Season dates were based on the astronomical definition of the northern hemisphere with summer as June 21 to September 21 and winter as December 21 to March 19 (NOAA, 2017). December was adjusted to equal the same experimental year as the following January to account for crop season.

Performance records included a total of 1,084 herds including the SE states of FL, (n = 59), GA (n = 162), KY (n = 304), VA (n = 401), MS (n = 29), and TN (n = 129), making up the Southeast region. We chose to include only Southeast states participating in the Southeast Quality Milk Initiative. The Southeast region was classified by state, based on climate zone classification (USDA, 2018b) and was considered humid, subtropical (ISC-Audubon, 2018). Mean, maximum, and minimum herd size was 191, 1,487, and 22 cows respectively for the total dataset.

Weather data was retrieved through the cli-MATE application from the Midwestern Regional Climate Center (Champaign, IL). Data obtained included hourly temperature and relative humidity from one weather station per state. Each weather station was chosen based on the county with the highest milk cow inventory in 2012 (USDA, 2018a). If no weather station was available for that county, the closest county with suitable weather data from a reliable weather station was chosen. The daily THI was calculated and averaged by state for the summer and winter seasons of each year. The THI equation used in this study is shown as: THI = (1.8 x T°C + 32) – (0.55 – 0.0055 x RH%) x (1.8 x T°C – 26), where T = hourly ambient temperature in °C and RH% = hourly relative humidity as a percentage (NRC, 1971). Data greater than the 99^{th} percentile, and less than the 1^{st} percentile were excluded to eliminate outliers.

Survey Data

Research personnel of the Southeast Quality Milk Initiative (SQMI) from universities in each participating state (Virginia, Kentucky, Mississippi and Tennessee) contacted producers to take part in the study and were chosen based on the 2013 rolling herd mean BTSCC provided by DHIA. Bulk tank SCC from all farms were divided into three categories: low (< 220,000 cells/mL), moderate (220,000 to 340,000 cells/mL) and high (> 340,000 cells/mL), with the purpose of including an equal distribution representing each category. Additionally, each herd was required to have a minimum of 25 cows in the herd. Producers were contacted directly by a member of the research team by telephone or email who described the project goals and assured that their information would be kept confidential. To follow, farm visits were conducted by trained researchers from the four universities, from 2014 to 2015. A total of 126 herds were included in the final dataset including herds in Kentucky (n = 40), Virginia, (n = 63), Mississippi (n =4) and Tennessee (n = 19). A single on-farm assessment was conducted for each farm where research personnel recorded housing information and conducted a survey with questions related to heat abatement strategies.

The survey was given in an interview style between the herd manager or farm owner and the research member. Questions included primarily multiple-choice options to collect information related to management practices that might affect milk quality including housing type and management, heat abatement strategies, location of cooling systems, and at what point they turn cooling systems on, among others that will not be discussed in this study. Producers had the opportunity to clarify and discuss responses and withhold information if they chose.

An inspection of the cows' environment was conducted using a housing survey. This included observations of housing type (i.e. freestall, tiestall, compost bedded pack etc.), and housing structure characteristics (i.e. type of ridge vent and natural ventilation) further identifying where fans, and sprinklers are placed throughout the structure (i.e. feed bunks, freestall rows, and parlor).

Statistical Analysis

All procedures were performed using SAS 9.3 (SAS Institute, Inc., Cary, NC). Descriptive statistics were performed for all variables. Experiment 1, comparing S:W ratios among Southeast states, milk and reproductive performance data were edited by removing variables equal to 0, indicating inaccurate data. Additionally, we identified outliers, and values less than the 1st percentile or greater than the 99th percentile for the entire data set, these data points were removed for performance variables, mean herd size, and mean DIM. Furthermore, summer and winter mean DIM, herd size, and mean 150-day milk were averaged by herd and year to be included in the model. After calculating the S:W ratio for each performance variable (summer as the denominator and winter as the numerator), the 1st and 99th percentiles were removed for each variable to exclude outliers potentially caused by inaccurate records.

The GLM procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC) was used to compare test day ECM SCS, fat %, protein %, conception rate, pregnancy rate, and HDR S:W ratios for herds within each Southeastern state (n=7) from 2007 to 2016. Herd test day performance variables in summer and winter were used to calculate S:W ratios for each state and were analyzed using PROC GLM. The effects of year, mean DIM, mean 150-day milk, mean herd size, and number of milking's, were included as covariates in the multivariate model and stepwise backward elimination was performed for each variable to exclude variables that were not contributing significantly to the model ($P > 0.3$). All covariates other than number of milking's were included in all models because of biological significance. Significant differences in the model were considered at $P < 0.05$. A GLM model using the LSMEANS statement was used to generate least squares means separations between summer and winter for each parameter.

Experiment 2, focusing on survey data analysis, included a total 122 herds from VA (n = 63), KY (n = 40), TN (n = 19) in the final data set. Mississippi was excluded due to small sample size. Test day data one year prior to the date of each farm visit was used in the analysis to eliminate the chance of changes in management, which would affect responses to survey questions. The GLM procedure of SAS was again used in this analysis, with the same data set restrictions and model described above.

RESULTS AND DISCUSSION

Southeast States

Descriptive data of summer and winter state means for each performance variable is reported in Table 3.2. Mean DIM, mean herd size, and mean 150-day milk are 191 ± 30.21, 191 ± 195.06 cows, and 70 ± 4.84 kg, for the entire dataset, respectively. An effect of state as a covariate on S:W ratios for all performance variables ($P \leq 0.01$) was evident. An effect of 150-day milk production on S:W ratios for all performance variables other than heat detection rate was revealed ($P < 0.001$; Table 3.1). Table 3.3 presented mean THI data between summer and winter for each state, as descriptive data. Florida THI values were numerically highest and Virginia THI values were lowest, for summer and winter.

The results from this study recognize that states in the Southeast experience summer heat stress based on the decline in performance from winter to summer. For all performance variables, lower S:W ratios were primarily seen in MS and FL with higher S:W ratios in VA and GA, indicating a potential combination of factors, such as the more extreme heat and humidity in the summer, housing environment or lack of heat abatement strategies during heat stress periods for the southernmost states.

Milk Production

The mean S:W ratio among all herds for ECM was 0.89 ± 0.0001 (Table 3.1). The S:W ratio for ECM varied between states ($P < 0.001$), indicating that some states might have been experiencing higher levels of heat stress, possibly from climate difference, and improper and insufficient heat abatement strategies. The highest S:W ratio for ECM found in this study was in VA and the lowest in MS (0.92 ± 0.003 vs. 0.84 ± 0.012).

Virginia experienced a 7% drop in summer ECM production compared to winter and MS a 17% drop (Table 3.2). Interestingly, MS ECM production in winter was not different than VA (31.21 ± 0.69 vs. 30.98 ± 0.17), illustrating the assumption that a higher level of heat stress on milk production may be occurring in MS, heat abatement strategies may not be adequate, or most likely a combination. Based on the evidence of cows in subtropical climates experiencing heat stress and a higher S:W ratio for VA, one explanation that should be further investigated is that farms in VA may be cooling their cows more efficiently than farms in FL or MS. Based on these results, the S:W ratio demonstrates sensitivity in identifying seasonality of performance between states with a similar climate. Other factors may exist, but because winter ECM is similar throughout the states, we concluded that because of the effects of summer heat stress, ECM is reduced. Especially, herds in the FL or MS have a greater need to improve heat abatement strategies to counteract the negative effect, as local climate is unchangeable.

All Southeast states have a climate considered as subtropical, and evidence suggests that dairy cattle in this environment are affected by heat stress most of the year. However, variations in THI are still seen between each state most likely affecting cattle in the northern most states differently than the southernmost. Evidence of heat stress causing milk loss is explained by direct and indirect factors. The additional heat load put on the animal during summer causes a reduction in DMI indirectly affecting milk production. In addition, there is evidence that heat stress has a direct effect on milk production. Johnson and Vanjonack (1976) reported that 3-10% of the change in milk production was caused by climate factors. In another study on mid-lactation heat stressed cows, DMI accounted for only 50% of the drop in milk production, proposing that other factors influenced the remaining reduction (Wheelock et al., 2010).

Milk Quality

Milk quality results are represented by SCS, milk fat and protein %. The mean S:W ratio for SCS among all herds was 1.05 ± 0.002 (Table 3.1). The highest SCS S:W ratio was in FL (1.15 ± 0.019), compared to all other states. Summer to Winter ratios for SCS were differences among states ($P < 0.001$). Once more, S:W ratios above one for SCS indicate a higher SCS in the summer, which is reverse when considering S:W ratios for other variables. For KY, a S:W ratio of 1.04 indicates less seasonality of SCS, whereas FL SCS increases from 2.92 in winter to 3.39 in summer. Somatic cell counts typically rise during hot summer months, as the S:W ratios in this study showed for all states. Nasr and El-Tarabany (2017) reported that from low to high THI, SCC increased by 36%. For year-round calving herds, BTSCC was the highest from July to October, showing a seasonal pattern (Schukken et al., 1993, Sargeant et al., 1998), with individual cow SCC being highest in July and August (Bodoh et al., 1976, Salsberg et al., 1984). This likely happens because of the increased bacterial load in the cows' environment especially in humid areas where bacteria can thrive and are more available to enter the mammary gland. The stress undergone because of the heat might suppress the immune system of the cow enabling a mastitis infection to occur. The difference among states most likely stems from management practices to control heat stress. Many factors can affect clinical and subclinical mastitis, resulting in increases in herd SCC, such as parity, stage of lactation, type of housing, pasture access, management, and environmental factors such as temperature, humidity, and season (Hogan and Smith, 1997). Each state may experience differences in environment, affecting cows differently.

Milk Components

The mean fat % for all states combined was 3.66 ± 0.29. The mean S:W ratio for fat % among all herds was 0.95 ± 0.001, with the highest S:W ratio for fat % in FL and lowest for KY, TN and VA (1.00 ± 0.006 vs. 0.94 ± 0.002, 0.95 ± 0.003 and 0.94 ± 0.002 ; Table 3.1). The mean S:W ratio for protein % was 0.97 ± 0.001 for all herds combined, and was highest for FL and lowest for VA (1.00 ± 0.003 vs. 0.96 ± 0.001).

Studies have shown varying results on milk component changes during a state of heat stress. Comparable to the current study, McDowell et al. (1976) reported no changes in milk fat, during the summer season. Other studies have found that milk fat is reduced during the summer (Heck et al., 2009, Bernabucci et al., 2015). Protein % in the current study also showed no seasonality among states. Some studies showed a decrease in protein % during heat stress (Sharma et al., 1983, Bouraoui et al., 2002) but some showed no difference (Wheelock et al., 2010). Causes in in milk protein synthesis reductions during periods of heat stress is unknown, but likely caused by multiple biological systems. Gao et al. (2017), found that heat stress reduced milk yield by 17%, milk protein by 4.1%, milk protein yield by 19%, 4% fat corrected milk by 23% and overall milk yield by 19% compared to pair-fed cows in a thermoneutral zone.

Reproductive Performance

Reproduction showed the most negative effects of all variables in the summer for all states. The mean S:W ratio for conception rate was 0.87 ± 0.004 for all herds combined (Table 3.1). The lowest S:W ratio for conception rate was for VA and highest for KY and GA (0.85 ± 0.008 vs. 0.89 ± 0.012 and 0.90 ± 0.015). The mean S:W ratio for HDR was 0.93 ± 0.004 for all herds combined (Table 3.1). The highest S:W ratio for HDR was in VA and lowest for MS (0.95 ± 0.007 vs. 0.83 ± 0.035), with differences among states ($P < 0.0001$). The mean S:W ratio for pregnancy rate was 0.71 ± 0.005 for all herds combined (Table 3.1). The highest S:W ratio for pregnancy rate was in VA (0.76 ± 0.009) compared to all other states. Pregnancy rate S:W ratios were different among states ($P < 0.001$). Similar results were seen by Flamenbaum and Galon (2010) and Robertson (2012) who also explored the use of S:W ratios in Israel and the US, respectively. Results from the study by Flamenbaum and Galon (2010) showed that high S:W ratio grouped farms had higher summer conception rates compared to low S:W ratio farms (27 vs. 19%). Additionally in winter, high ratio farms had conception rates comparable in the high and low groups (40 vs. 36%). Robertson (2012) saw similar results for conception rates with the north having higher conception rates than the south (34.25 vs. 21.24) and saw the same for conception rate S:W ratio (0.90 vs. 0.58 ± 0.02). In addition, heat stress affects reproduction in the lactating dairy cow through lack of expressing heat appropriately, an increased number of days open, reduced conception rates, an increase in anestrus including anovulatory follicles, changes in follicle growth, reduced oocyte quality, reduced life of the embryo, and altering the uterine environment (Hansen and Arechiga, 1999, Wolfenson et al., 2000, Kadzere et al., 2002), leading to lower conception rate, pregnancy rate, and HDR.

Survey Data

Survey results include the Southeast states of KY (n=40), TN (n=19), and VA (n=63). Comparing S:W ratios based on heat abatement management practices, showed varying results for the various performance variables. Results are shown in Table 3.3 for milk production and quality variables and Table 3.4 for reproduction variables. The first survey response analyzed pertained to what temperature producers turned on their fan cooling systems. Responses were grouped into > 70°F or < 70°F. Summer to Winter ratios showed significant differences in ECM when turning fans on at temperatures > 70°F or < 70°F (0.93 ± 0.008 vs. 0.88 ± 0.02; *P* = 0.017) but showed no differences for other variables. Similarly, Flamenbaum and Galon (2010) found that S:W ratios for milk production were 0.91, 0.96, and 0.99 for farms that had no cooling, cooling in holding pen, and cooling in holding pen and feed bunk, respectively.

When asked if producers used water to keep cows cool, no differences were seen in S:W ratios for any variables between yes and no answers (Table 3.3 and 3.4). This might be because different farms may have different cooling systems, with varying droplet sizes, or different durations of them being on throughout the day, affecting the cooling effects. However, ECM, fat %, protein %, and reproduction variables numerically had S:W ratios closer to one. Somatic cell score was numerically higher for farms that used water systems for cooling, which would in theory indicate that the water could increase bacteria load in the environment, increasing the risk of mastitis causing pathogens, however, no significant differences were observed.

The remaining survey questions were reported by researchers who observed the housing facilities. Having fans vs. no fans in the holding pen, or sprinklers vs. no sprinklers in the holding pen showed no effects on the S:W ratio for all variables other than the SCS S:W ratio. Somatic cell score S:W ratios were higher for farms that did not have fans in the holding pen compared to farms that did have fans in the holding pen

(1.11 ± 0.03 vs. 1.04 ± 0.01 P = 0.04). The opposite effect was seen for SCS S:W ratios for using sprinklers in the holding pen with a higher SCS S:W ratio for farms that used sprinklers in the holding pen (1.09 ± 0.02 vs. 1.03 ± 0.01; P = 0.03). One speculation made was that this may be from crowding in the holding pen limiting the evaporation of water from the cows skin surface, causing excess water to run down their body, with potential of reaching teat ends.

Responses were grouped into the categories of using fans and sprinklers combined or no cooling systems at all in the holding pen. Summer to Winter ratios were statistically higher ratios for farms using both in the holding pen compared to none (0.87 ± 0.04 vs. 0.67 ± 0.06 P = 0.02) and (0.94 ± 0.03 vs. 0.80 ± 0.05 P = 0.04) for conception rate and HDR S:W ratios, respectively. For some farms this could be in addition to cooling their cows at the feedbunk, or in the housing environment, or it could be the only place they are cooled. The additional cooling in the holding pen seems to have positive effects on reproduction variables compared to not cooling in the holding pen. Similar results were seen by (Flamenbaum and Galon, 2010), in that intensively cooled cows producing 30 kg/day showed little difference in conception rates when comparing summer conception rate to winter conception rate.

Unexpectedly, effects of using fans or sprinklers over the feedbunk or freestall rows showed no effects on performance variables.

Results for using fans over a bedded pack housing environment or using fans for dry cows showed no effects. Evidence of cooling dry cows to improve milk production in subsequent lactations, and for growth and health of the calf has been found (Tao et al., 2012). Summer to Winter ratios tend to be numerically higher for farms using fans over bedded packs and for their dry cows, although no differences were detected.

Producers that had ridge vents in their facilities had higher S:W ratios for conception rate than facilities that did not have ridge vents (0.83 ± 0.03 vs. 0.69 ± 0.06; $P = 0.04$). With these results, there is evidence of a relationship between the S:W ratio and management practices.

Herds that used fans and sprinklers combined vs. no cooling in all areas of the farm (holding pen, feedbunk, freestall rows) were compared. Summer to Winter ratios for fat % were higher on farms with cooling systems than farms with none (0.97 vs. 0.92 ± 0.01; $P = 0.03$). Milk fat has shown inconsistent changes between summer and winter among studies. This may suggest that unrelated or indirect effects of heat stress are causing changes in fat %, such as feed composition, stage of lactation, cooling systems, etc. (Tao et al., 2018). In addition, the same effects were seen for HDR S:W ratios (0.95 ± 0.03 vs. 0.83 ± 0.04).

In summary, evaporative cooling using the combination of wetting the cow's skin and forced ventilation has been an effective way to cool cows and reduce the effects of heat stress (Flamenbaum et al., 1986). Positive effects of cooling were seen for some variables, but not for others, depending on the cooling systems compared, as described by S:W ratios. Although not all S:W ratio variables showed positive effects from cooling, most results agree with past and current literature on cooling systems ameliorating the effects of summer heat stress by improving performance. From the results of this study, S:W ratios were sensitive enough to identify differences in management practices on farms in similar climates. For some variables, results showed that as management for heat stress improved, S:W ratios also improved. It appears that there is a positive relationship in cow cooling and the performance ratio, identifying it as a potential measure for heat stress on lactating dairy cows. However, not all performance variables showed significant effects by cooling system.

Study Limitations

Although the S:W ratio has an important role as a key performance indicator on farm, limitations exist. In this study, seasonal herds which could affect the results by the number of cows in milk during the summer period being less for seasonal herds, which in turn would increase the S:W ratio. However, this was somewhat accounted for by including DIM in the model. Also, herds with access to pasture are not accounted for as this data was not available in the dataset, which would show inconsistency in heat abatement practices. Temperatures may vary for the summer season among states. For instance, FL may experience higher temperatures in earlier months compared to other states, however summer was classified the same for every state. This would exclude periods of heat stress in the spring and carry over into the fall. A limitation that could not be accounted for without extensive information from each farm would be feed and management changes that might have occurred during the study period that might affect performance instead of heat stress alone.

Furthermore, surveys can be inconsistent among interviewers and interviewees. Several research students and faculty gave the survey, which could have led to slight misinterpretations of questions, however there is no way to tell if this is the case in this study. It may also be important to address that producer answers regarding questions that require specific answers, may be more of an estimate. Human error is always present, however extensive data from multiple farm visits has proven to be valuable in research.

CONCLUSIONS

Summer to Winter ratios compared among southeast states of the US showed differences mainly between the most northern state compared to the most southern state. In all states, ECM, SCS, PR, CR, and HDR performance in the summer was negatively affected compared to winter. Milk fat and protein % showed little change between summer and winter and among states. Based on the S:W ratio, it is assumed that states with ratios closer to 1.00 are doing more to cool their cows than states with lower ratios.

Results from survey data varied, but in all situations, S:W ratios were better for farms with cooling systems implemented. The S:W ratio has limitations, but it shows potential for benefiting producers in comparing their performance between summer and winter, and motivating heat stress management changes.

By establishing the use of the S:W ratio in this study, an end goal consists of using this on farm to improve heat abatement. Utilizing the S:W to quantify performance losses on farm, producers can visualize economic loss and may be more motivated to make changes in managing heat stress by implement cooling systems, in turn improving performance, profitability and the welfare of their animals.

ACKNOWLEDGEMENTS

The Southeast Quality Milk Initiative is supported by the National Institute of Food and Agriculture, US. Department of Agriculture, under award number 2013-68004-20424. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US.

Department of Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US Department of Agriculture. The authors would like to thank the researchers leading the Southeast Quality Milk Initiative projects, who have contributed to this paper, including Derek Nolan, Peter Krawczel, Christina Petersson-Wolfe, Gina Pighetti, Amanda Stone, Stephanie Ward, and Jeffrey Bewley.

Table 3.1. Least squares means (± SE) of Summer to Winter performance ratios for energy-corrected milk, SCS, milk fat %, milk protein %, conception rate, heat detection rate, and pregnancy rate compared among SE states. The effects of state and 150-day milk production on Summer to Winter performance ratios are also presented.

S:W Ratio	Mean	VA (n=401)	TN (n=129)	KY (n=304)	FL (n=59)	GA (n=162)	MS (n=29)	State *P*-value	150-day milk *P*-value
Energy corrected milk (kg)	0.89 ± 0.001	0.92 ± 0.003^{a}	0.89 ± 0.005^{b}	0.88 ± 0.004^{bc}	0.86 ± 0.009^{cd}	0.85 ± 0.005^{d}	0.84 ± 0.012^{d}	< 0.001	0.012
SCS	1.05 ± 0.002	1.06 ± 0.004^{b}	1.06 ± 0.008^{b}	1.04 ± 0.006^{b}	1.15 ± 0.019^{a}	1.05 ± 0.008^{b}	1.07 ± 0.018^{ab}	< 0.001	< 0.001
Fat %	0.95 ± 0.001	0.94 ± 0.002^{c}	0.95 ± 0.003^{c}	0.94 ± 0.002^{c}	1.00 ± 0.006^{a}	0.97 ± 0.003^{b}	0.98 ± 0.007^{ab}	< 0.001	< 0.001
Protein %	0.97 ± 0.001	0.96 ± 0.001^{e}	0.97 ± 0.002^{c}	0.97 ± 0.001^{d}	1.00 ± 0.003^{a}	0.99 ± 0.002^{b}	0.98 ± 0.004^{bc}	< 0.001	< 0.001
Conception rate	0.87 ± 0.004	0.85 ± 0.008^{b}	0.87 ± 0.017^{ab}	0.89 ± 0.012^{a}	0.93 ± 0.026^{ab}	0.90 ± 0.015^{a}	0.86 ± 0.039^{ab}	0.002	< 0.001
Heat detection rate	0.93 ± 0.004	0.95 ± 0.007^{a}	0.89 ± 0.016^{bc}	0.92 ± 0.011^{abc}	0.95 ± 0.023^{ab}	0.88 ± 0.014^{bc}	0.83 ± 0.035^{c}	< 0.001	0.436
Pregnancy rate	0.71 ± 0.005	0.75 ± 0.009^{a}	0.68 ± 0.020^{b}	0.68 ± 0.014^{b}	0.65 ± 0.031^{b}	0.62 ± 0.017^{b}	0.59 ± 0.050^{b}	< 0.001	0.001

$^{a-e}$Least squares means with different superscripts denoting differences within rows, excluding the mean ($P < 0.05$).

Table 3.2. Descriptive data displaying summer and winter means for each performance variable used to calculate Summer to Winter ratios for Southeast states (n = number of herds; mean ± SE).

Performance Variable	VA (n=401)	TN (n=129)	KY (n=304)	FL (n=59)	GA (n=162)	MS (n=29)
Energy corrected milk (kg)						
Summer	28.88 ± 0.16[a]	27.76 ± 0.30[b]	27.81 ± 0.21[b]	25.85 ± 0.56[c]	26.56 ± 0.28[c]	26.12 ± 0.69[c]
Winter	30.98 ± 0.17[b]	31.22 ± 0.30[ab]	31.44 ± 0.21[a]	29.90 ± 0.57[c]	31.10 ± 0.29[ab]	31.21 ± 0.69[ab]
Somatic cell score						
Summer	3.08 ± 0.08[a]	3.09 ± 0.04[bc]	2.96 ± 0.03[c]	3.39 ± 0.08[a]	3.09 ± 0.04[bc]	3.03 ± 0.09[bc]
Winter	2.93 ± 0.02	2.98 ± 0.04	2.91 ± 0.03	2.92 ± 0.08	3.02 ± 0.04	2.87 ± 0.04
Fat (%)						
Summer	3.56 ± 0.01[ab]	3.61 ± 0.02[a]	3.54 ± 0.01[ab]	3.48 ± 0.04[b]	3.53 ± 0.02[ab]	3.59 ± 0.04[ab]
Winter	3.79 ± 0.01[a]	3.80 ± 0.02[a]	3.77 ± 0.01[a]	3.47 ± 0.04[b]	3.59 ± 0.02[b]	3.61 ± 0.05[b]
Protein (%)						
Summer	2.96 ± 0.01[c]	2.98 ± 0.01[bc]	3.00 ± 0.01[a]	3.00 ± 0.01[abc]	3.00 ± 0.00[ab]	3.01 ± 0.01[ab]
Winter	3.09 ± 0.01[b]	3.06 ± 0.01[c]	3.11 ± 0.01[a]	2.96 ± 0.01[e]	3.02 ± 0.01[d]	3.07 ± 0.02[abcd]
Conception rate						
Summer	42.69 ± 1.17[c]	48.60 ± 2.17[bc]	48.48 ± 1.52[b]	61.23 ± 3.46[a]	53.82 ± 1.92[ab]	39.74 ± 4.90[bc]
Winter	49.26 ± 0.95[bc]	50.47 ± 1.74[bc]	53.10 ± 1.20[ab]	61.83 ± 2.78[a]	52.99 ± 1.54[ab]	38.91 ± 3.77[c]
Heat detection rate						
Summer	41.27 ± 0.72[a]	29.65 ± 1.38[b]	33.30 ± 0.94[b]	44.07 ± 2.28[a]	33.63 ± 1.28[b]	36.73 ± 3.05[ab]
Winter	43.83 ± 0.75[a]	36.77 ± 1.37[c]	38.12 ± 0.95[bc]	44.59 ± 2.20[ab]	42.08 ± 1.25[abc]	49.28 ± 2.95[a]
Pregnancy rate						
Summer	12.45 ± 0.20[a]	9.52 ± 0.38[bc]	10.56 ± 0.27[b]	9.45 ± 0.62[bc]	9.24 ± 0.34[c]	8.72 ± 0.85[bc]
Winter	18.13 ± 0.25[a]	15.29 ± 0.45[b]	17.32 ± 0.32[a]	16.74 ± 0.74[a]	17.23 ± 0.40[a]	19.33 ± 1.02[a]

[a-e]Least squares means with different superscripts denoting differences within rows, excluding the mean ($P < 0.05$).

Table 3.3. Temperature-humidity index data averaged by season and state for 2007-2016 period.

Year	VA (n=401)	TN (n=129)	KY (n=304)	FL (n=59)	GA (n=162)	MS (n=29)
Mean						
Summer	71.0 ± 0.4	74.0 ± 0.3	73.8 ± 1.6	76.4 ± 0.1	73.7 ± 0.3	75.5 ± 0.2
Winter	45.0 ± 0.5	47.9 ± 0.5	48.2 ± 2.2	56.6 ± 0.7	49.2 ± 0.6	52.9 ± 0.7

Table 3.4. Least squares means (±SE) of Summer to Winter performance ratios for milk production and quality variables based on survey question responses.

Survey Question and Response	ECM	Fat %	Protein %	SCS
At what temperature do you turn on fans?				
< 70°F	0.93 ± 0.01[a]	0.95 ± 0.01	0.97 ± 0.01	1.06 ± 0.02
> 70°F	0.88 ± 0.02[b]	0.94 ± 0.02	0.96 ± 0.01	1.05 ± 0.04
Do you use water to keep cows cool?				
Yes	0.93 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.06 ± 0.02
No	0.91 ± 0.01	0.95 ± 0.01	0.96 ± 0.01	1.04 ± 0.02
Are fans in the holding pen?				
Yes	0.93 ± 0.01[a]	0.95 ± 0.01	0.96 ± 0.01	1.04 ± 0.01[b]
No	0.89 ± 0.02[b]	0.94 ± 0.02	0.97 ± 0.01	1.11 ± 0.03[a]
Are sprinklers in the holding pen?				
Yes	0.92 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.09 ± 0.02[a]
No	0.91 ± 0.01	0.95 ± 0.01	0.96 ± 0.01	1.03 ± 0.01[b]
Both or none in the holding pen?				
Both	0.93 ± 0.01	0.96 ± 0.02	0.97 ± 0.01	1.09 ± 0.02
None	0.89 ± 0.02	0.96 ± 0.01	0.97 ± 0.01	1.10 ± 0.03
Are fans over feedbunks?				
Yes	0.92 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.06 ± 0.01
No	0.93 ± 0.01	0.95 ± 0.01	0.96 ± 0.01	1.05 ± 0.02
Are sprinklers over feedbunks?				
Yes	0.93 ± 0.01	0.97 ± 0.01	0.97 ± 0.01	1.07 ± 0.02
No	0.91 ± 0.01	0.94 ± 0.01	0.96 ± 0.01	1.04 ± 0.01
Are fans over each freestall?				
Yes	0.92 ± 0.01	0.94 ± 0.01	0.97 ± 0.01[a]	1.07 ± 0.02
No	0.92 ± 0.01	0.95 ± 0.01	0.95 ± 0.01[b]	1.05 ± 0.02
Are fans over most freestalls?				
Yes	0.92 ± 0.01	0.95 ± 0.01	0.92 ± 0.01	1.06 ± 0.01[a]
No	0.94 ± 0.02	0.94 ± 0.02	0.94 ± 0.01	0.99 ± 0.02[b]
Fans or none in bedded pack?				

Fans	0.92 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.01 ± 0.02
None	0.94 ± 0.02	0.92 ± 0.02	0.97 ± 0.01	1.03 ± 0.04
Are there fans for dry cows?				
Yes	0.92 ± 0.01	0.95 ± 0.01	0.96 ± 0.01	1.05 ± 0.02
No	0.93 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.05 ± 0.02
Describe the approximate height of sidewalls for lactating cow housing				
< 8 ft.	0.91 ± 0.01	0.97 ± 0.01	0.97 ± 0.01	1.07 ± 0.02
8 to 12 ft.	0.91 ± 0.01	0.94 ± 0.01	0.96 ± 0.01	1.05 ± 0.01
> 12 ft.	0.93 ± 0.01	0.95 ± 0.01	0.96 ± 0.01	1.04 ± 0.02
Do you have a ridge vent in primary lactating cow housing				
Yes	0.92 ± 0.01	0.95 ± 0.01	0.97 ± 0.01	1.04 ± 0.01
No	0.91 ± 0.01	0.93 ± 0.01	0.96 ± 0.01	1.08 ± 0.02
Both (fans + sprinklers) or none on entire farm?				
Both	0.93 ± 0.01	0.97 ± 0.01[a]	0.96 ± 0.01	1.07 ± 0.02
None	0.93 ± 0.02	0.92 ± 0.01[b]	0.95 ± 0.01	1.04 ± 0.03
Stocking density level (%)				
Low (< 92)	0.93 ± 0.02	0.93 ± 0.02	0.95 ± 0.01	1.08 ± 0.03
Medium (92 to 119)	0.93 ± 0.01	0.96 ± 0.01	0.97 ± 0.01	1.07 ± 0.02
High (> 119)	0.89 ± 0.02	0.96 ± 0.02	0.96 ± 0.01	1.08 ± 0.03

[a-b]Least squares means with different superscripts denoting differences within columns for each question ($P < 0.05$).

Table 3.5. Least squares means (±SE) of Summer to Winter performance ratios for reproduction variables based on survey question responses.

Survey Question and Response	CR	PR	HDR
At what temperature do you turn on fans?			
< 70°F	0.78 ± 0.03	0.71 ± 0.04	0.93 ± 0.02
> 70°F	0.76 ± 0.08	0.61 ± 0.10	0.86 ± 0.06
Do you use water to keep cows cool?			
Yes	0.80 ± 0.04	0.67 ± 0.04	0.92 ± 0.03
No	0.75 ± 0.04	0.74 ± 0.05	0.93 ± 0.03
Are fans in the holding pen?			
Yes	0.82 ± 0.03	0.74 ± 0.04	0.93 ± 0.02
No	0.68 ± 0.06	0.69 ± 0.07	0.90 ± 0.05
Are sprinklers in the holding pen?			
Yes	0.82 ± 0.05	0.69 ± 0.05	0.95 ± 0.04
No	0.77 ± 0.04	0.75 ± 0.04	0.91 ± 0.03
Both or none in the holding pen?			
Both	0.87 ± 0.04[a]	0.68 ± 0.06	0.94 ± 0.03[a]
None	0.67 ± 0.06[b]	0.66 ± 0.08	0.80 ± 0.05[b]
Are fans over feedbunks?			
Yes	0.79 ± 0.03	0.72 ± 0.04	0.94 ± 0.02
No	0.78 ± 0.06	0.74 ± 0.07	0.88 ± 0.04
Are sprinklers over feedbunks?			
Yes	0.81 ± 0.05	0.69 ± 0.05	0.93 ± 0.03
No	0.78 ± 0.04	0.74 ± 0.04	0.92 ± 0.03
Are fans over each freestall?			
Yes	0.79 ± 0.04	0.67 ± 0.04	0.94 ± 0.03
No	0.76 ± 0.04	0.73 ± 0.05	0.89 ± 0.03
Are fans over most freestalls?			
Yes	0.76 ± 0.04	0.68 ± 0.05	0.95 ± 0.03
No	0.80 ± 0.06	0.78 ± 0.08	0.84 ± 0.05
Fans or none in bedded pack?			
Fans	0.88 ± 0.07	0.80 ± 0.07	0.95 ± 0.03
None	0.80 ± 0.10	0.70 ± 0.12	0.85 ± 0.04
Are there fans for dry cows?			
Yes	0.84 ± 0.05	0.77 ± 0.06	0.96 ± 0.04
No	0.76 ± 0.04	0.70 ± 0.04	0.92 ± 0.02
Describe the approximate height of sidewalls for lactating cow housing			
< 8 ft.	0.78 ± 0.05	0.78 ± 0.06	0.95 ± 0.03

8 to 12 ft.	0.79 ± 0.05	0.68 ± 0.05	0.89 ± 0.03
> 12 ft.	0.79 ± 0.05	0.74 ± 0.06	0.95 ± 0.04
Do you have a ridge vent in primary lactating cow housing			
Yes	0.83 ± 0.03[a]	0.73 ± 0.04	0.93 ± 0.02
No	0.69 ± 0.06[b]	0.68 ± 0.07	0.91 ± 0.04
Both (fans + sprinklers) or none on entire farm?			
Both	0.80 ± 0.05	0.68 ± 0.05[a]	0.95 ± 0.03[a]
None	0.77 ± 0.07	0.81 ± 0.07[b]	0.83 ± 0.04[b]
Stocking density level (%)			
Low (< 92)	0.67 ± 0.06	0.63 ± 0.07	0.92 ± 0.06
Medium (92 to 119)	0.81 ± 0.04	0.70 ± 0.05	0.93 ± 0.03
High (> 119)	0.71 ± 0.06	0.58 ± 0.07	0.88 ± 0.05

[a-b]Least squares means with different superscripts denoting differences within columns for each question ($P < 0.05$).

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VITA

Jenna Guinn grew up in Lexington, Kentucky. She attended the University of Kentucky where she majored in Animal Sciences with a Dairy emphasis and minored in Agricultural Economics. Upon graduating in 2014, Jenna accepted an internship in the poultry research group at Alltech. She then moved to a position in the Quality Assurance department as a laboratory coordinator and then laboratory technician.

Jenna then began her master's degree at the University of Kentucky in January 2016, working with the Southeast Quality Milk Initiative. Her research focused on heat stress and milk quality. During her time there, Jenna became a member and an officer of the Animal and Food Science Graduate Association, and a teaching assistant for two courses. Jenna is a current member of the American Dairy Science Association Graduate Student Division (ADSA-GSD) and the National Mastitis Council.

Peer Reviewed Publications:

Guinn (Klefot), J.M., J.L. Murphy, K.D. Donohue, B.F. O'Hara, M.E. Lhamon, and J.M. Bewley. 2016. Development of a noninvasive system for monitoring dairy cattle sleep. J Dariy Sci 99(10):8477-8485.

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