Effects of Heat Stress on Reproductive Parameters, Milk Quality, and Cow Activity in Lactating Holstein and Jersey Dairy Cows

by
Erin Coleman

A thesis proposal to the Honors College of Middle Tennessee State University in partial fulfillment of the University Honors College

Spring 2022

Thesis Committee:
Dr. Jessica Carter, Thesis Director
Dr. Philip E. Phillips, Thesis Committee Chair

Effects of Heat Stress on Reproductive Parameters, Milk Quality, and Cow Activity in Lactating Holstein and Jersey Dairy Cows

by Erin Coleman

APPROVED:

____
Dr. Jessica Carter, Thesis Director
Director, School of Agriculture, Animal Science

____
Dr. Philip E. Phillips, Thesis Committee Chair
Associate Dean, University Honors College

Abstract

Heat stress can negatively affect pregnancy rate, conception rate, and milk quality in dairy cattle. Heat stress is one of the major challenges dairy farms face due to the negative effects heat stress plays on production. The objective of this study was to determine if there is a relationship between heat stress and cow reproductive parameters, cow activity, and milk quality in Holstein and Jersey cows. Two groups of cattle consisting of both Holstein and Jersey cows were evaluated over 2 seasons: summer (July and August) and winter (December and January) for heat stress. Cows were monitored through DHIA data to analyze somatic cell count, milk yield, conductivity, average rest time, average rest bouts, and average activity. Temperature Humidity Index (THI) was also calculated to show if the lactating herd was suffering from heat stress. Cows were under mild to moderate heat stress during the summer months of July and August. During the winter months of December and January, cows did not suffer from heat stress. In the summer, cows had increased restless activity due to heat stress which can have negative effects such as lower milk production and increased chances of lameness.

Table of Contents

List of Tables

List of Figures

Introduction

(Background) The inspiration for this thesis came to me during my time working for the Middle Tennessee State University Dairy Farm and Creamery. At these worksites, I have had hands-on experiences each day with the dairy cows and the milk from the cows that is being processed on campus. I found this type of research very interesting, and I started looking up topics of my own that I could do research about at our dairy campus. I then started talking to Dr. Carter about possible research topics that I could do at our MTSU Dairy farm. We had a few meetings to discuss topics and came up with focusing on dairy cows in early gestation and how heat stress affects them and their milk quality.

Heat stress is defined as the sum of external forces acting on an animal that causes an increase in body temperature and evokes a physiological response (Dikmen and Hansen, 2009). Heat stress occurs when the body cannot cool itself and maintain a healthy temperature. In dairy cattle, this can have many negative effects such as decreased milk production, increased somatic cell count, and can increased respiratory rates. Heat stress can also play a role in cow activity. The amount of time that dairy cows are lying or feeding can affect their milk production levels (Tullo et. al., 2016). The southeastern United States, where the Middle Tennessee State University dairy farm is located, is prone to having high humidity and temperature, which can easily lead to heat stress in dairy cattle. This occurs because the cow's body is spending more time thermoregulating instead of producing milk. Cows that are not comfortable in their environment do not eat as much and therefore do not produce as much milk. This region of the United States is characterized as humid subtropical (West, 2003). Temperature humidity index is calculated as follows:

$$THI = [0.8 \times \text{ambient temperature } (°C)] + [(\% \text{ relative humidity}/100) \times (\text{ambient temperature } -14.4)] + 46.4$$

Milk quality is measured by the somatic cell count (**SCC**), bulk tank somatic cell count (**BTSCC**), standard plate count (**SPC**), preliminary incubation count (**PIC**), coliform count (**CC**), and laboratory pasteurization count (**LPC**). Milk conductivity (**EC)** is how well milk conducts electricity. This is another way to determine if a cow has mastitis. The typical milk conductivity is 4.0 to 5.5 mS cm^{-1} at 20°C (Henningsson et. al., 2005). The somatic cell count is the total number of cells per ml of milk. The legal limit in the United States for grade A pasteurized milk is less than 750,000 cells per ml. Milk with a SCC higher than 200,000 cells per ml indicates that a cow has a mammary gland infection, known as mastitis (Dufour et al., 2019). Typically, SCC is higher in the summer and lower in the winter months. Bacteria growth happens more in the summer because of higher environmental temperature and humidity, which is favorable for bacterial growth (Jones et al., 2009).

Mastitis can either be contagious, transferred from one cow to another during the milking process, or it can be an environmental infection caused by bacteria found in the cow's habitat. Frequent symptoms found in clinical mastitis include redness, swelling, and inflammation of the mammary gland, as well as physical changes such clots in the milk and loss of appetite, being more apparent to caretakers (Jones et al., 2009). The most common types of bacteria found in mastitis are *Escherichia coli, Streptococcus uberis, Streptococcus dysgalactiae* (Dufour et al., 2019).

Artificial insemination (**AI**) is a modern breeding technique used to obtain desired genetics without having to have a bull present and to increase the chance of pregnancy through direct placement of the semen in the uterus. It is the process where semen is collected from the bulls and inserted directly into the female reproductive tract. Artificial insemination is used in the dairy industry to maintain genetic oversight in the herd, protect cows from being injured by large bulls, reduce stress, and reduce the chances of sexually transmitted diseases within cattle. The use of AI can increase the inclusion of superior genetics in the industry (Webb, 2003). The dairy cow must be in heat in order to be impregnated via AI. Estrus (or heat) is most commonly detected when a cow stands to be mounted by another cow (standing heat). Reproductive parameters such as heat detection rate (**HDR**), conception rate (**CR**), and pregnancy rate (**PR**) are important reproductive success measurements in the dairy herd. These measurements can be influenced by the environment, handing of frozen semen during artificial insemination, cow comfort, and heat detection (DeJarnette et. al., 2004). Environmental factors such as slippery floors can affect CR, as cows will not try to mount for fear of injury, which will decrease reproductive success within the herd. Heat detection rate is determined as follows:

HDR (%) = (No. of cows bred / no. of cows eligible to be bred) × 100%

Conception rate is a measure of a cow's fertility at service. Conception rate can help determine a cow's reproductive performance and is calculated as follows:

CR (%) = (No. of Pregnant Cows / Total Services) × 100%

Pregnancy rate is measured by time intervals based on frequency in which cows come into estrus. In dairy cattle it is measured every 21 days. Body condition score, heat stress, environmental factors, and parity all have an effect on pregnancy rate. Pregnancy rate is determined as follows:

Pregnancy Rate = Heat Detection Rate x Conception Rate

Literature Review

Effects of heat stress on reproduction

Lactating dairy cattle that are affected by heat stress have many negative reproductive effects. Heat stress has been shown to alter reproductive parameters such as the duration of estrus, colostrum quality, conception rate, uterine function, fetal growth, and follicular development. Jordan (2003) found that providing shade in the lounging area, holding pen, or dry cow areas and fans in the lounging area improved chances for summer pregnancy, whereas fans in the dry cow area decreased the chances of summer pregnancy. Jordan also found embryo transfer can be used to increase CR of cattle affected by heat stress. There are ways to combat heat stress by keeping dairy cattle cool with shade and cooling measures. Sprinklers and fan cooling in housing barns had key effects to lowing heat stress. Polsky et. al. (2017) found the decrease in conception rates during summer seasons can range between 20 and 30%, with evident seasonal patterns of estrus detection. Heat stress can affect how dairy cattle show physical signs of estrus such as decreasing activity and decreased mounting behaviors. Polsky et. al. (2017) also found a reduction in estrous behavior has been argued to be the result of reduced DMI and the subsequent effects on hormone production.

Effects of heat stress on dairy cattle welfare

Polsky et. al. (2017) found that heat stress results in total annual economic losses to the US livestock production industry ranging from $1.69 to 2.36 billion, of which $900 million is specific to the US dairy industry, stemming from decreased milk production, compromised reproduction, and increased culling. Dairy cattle in the southwestern United States have the highest possibility of suffering from heat stress. However, dairy cattle in the northern United States can also suffer effects of heat stress. It is important for dairy farms to monitor heat stress in their lactating herd closely as heat stress is becoming more common in cows due to increased milk production which raises metabolic activity. Polsky et. al. (2017) found cattle that are affected by heat stress will cope by having an increased respiration rate, panting, sweating, reduced milk yield, poor reproductive performance, modify drinking and feed intake, and seek shade more frequently.

This article explains how concerns for dairy cattle welfare and heat stress overlap. Polsky et. al. (2017) explains that a lactating cow unable to seek shade on a hot day (natural living) will likely feel uncomfortably hot (affective state) and will experience reduced milk production. Cattle experiencing heat stress spend more time standing rather than lying down to increase the surface area for cooling by air movement and water loss. Increased standing time can increase the risk of lameness. Researchers have shown that lameness has been associated with pain in dairy cattle (Polsky et. al., 2017). Heat stress has also been found to increase frustration and aggression in dairy cattle.

Economic effects of heat stress

Heat stress in dairy cattle has been studied in the past and the consensus has been proven again and again. Problems with DMI, digestibility, and fertility have strenuous effect on the cattle and their productivity. Loss of productivity or delay of productivity can be directly related to a dollar amount. These amounts can be from production decrease, sickness, or even death from heat stress.

Varying from state to state, the national average was over 7,000 units per year in dairy cows, while replacement heifers was lower at 1010 (St-Pierre et. al., 2003). This shows how heat stress has a more intense effect on the lactating cow than a heifer that has yet to be in production. Any drop of production adversely causes a drop in revenue, to maintain a productive herd and considerable revenues farmers must do everything they can to minimize heat stress. Although heat stress occurs in other animals, the effects do not seem to be as drastic when compared to the dairy industry. Over 1.7 billion dollars in monetary losses across pork, beef cattle, poultry, and dairy cattle, the dairy industry leads the way in losses at 897-15000 million (St-Pierre et. al., 2003). This shows the vital role heat stress reduction plays in the industry, herds that can stay cooler longer will provide more revenue by reducing losses.

Objective

The objective of this study was to determine if there is a relationship between heat stress and cow reproductive parameters, cow activity, and milk quality in Holstein and Jersey cows. Heat stress can have negative effects on dairy cattle, such as lower milk production, conception rate, and pregnancy rate. This potential link could improve cow management and cow productivity, particularly in the summer months when cows experience heat stress. This could benefit producers by increasing milk production, improving milk quality, and improving reproductive parameters, which in turn can help increase profits.

Methodology

Dairy cows from the Middle Tennessee State University farm laboratory were used for this research project. Two groups of cattle consisting of both Holstein and Jersey cows were evaluated over 2 seasons: summer (July and August) and winter (December and January) for heat stress. Throughout the months of July and August (heat stress), and December and January (no heat stress), conception rate and pregnancy rates were monitored for all the cows that were bred during these months. Somatic Cell Count (SCC) data were collected from Dairy Herd Improvement Association (DHIA) records each month. SCC data were transformed to Somatic Cell Score (SCS) using the following formula: SCS=log2(SCC/100)+3. Production and activity data were collected from each cow using Afimilk parlor system including milk conductivity, daily milk yield, activity (steps/hr), rest time, and rest bouts. Data were compiled and analyzed using a mixed model with repeated measures using season as the main effect, and analyzed using SAS software (v9.4, SAS Institute Inc., Cary, NC). Production measures were reported as least squares means including standard error with significant differences noted at $P < 0.05$. The THI of each period was categorized as control (THI below 72), mild (THI between 72 and 78), moderate (THI between 78 and 88), or high (THI greater than 88) depending on the measurement at the time of the period (Armstrong, 1994). Guidance by the US government sets thresholds of THI for heat stress levels at 72-78 for mild heat stress, 78-89 for severe stress and 89-99 for very severe stress (Dunn et al., 2014).

Results

Production data by season

Milk yield and SCS were not statistically different between summer and winter months (**Table 1**). Conductivity was higher in summer months at 10 (mS/cm) whereas in winter months it was 9.3 (mS/cm) ($P < 0.0001$; **Figure 1**). The average activity of the lactating herd in the summer months was higher at 126.6 steps/hr, whereas in the winter they had lower activity at 114 steps/hr ($P < 0.0001$; **Figure 2**). Average rest bouts were also higher in summer months at 7.6 times/d whereas in the winter it was 6.3 times/d ($P < 0.0001$; **Figure 3**). Average rest time was higher in the winter months at 298.2 minutes, whereas in the summer it was 253 minutes ($P < 0.0001$; **Figure 4**).

Production data by breed

SCS, average rest bouts, and average rest time were not statistically different between Holstein and Jersey cows (**Table 2**). Unsurprisingly, milk yield was higher in Holstein cows at 62.5 kg/d, whereas Jersey cows had lower milk yield at 38.2 kg/d ($P < 0.0001$; **Figure 5**). Conductivity was also higher in Holstein cows at 9.9 while Jersey cows had conductivity of 9.4 ($P = 0.0006$; **Figure 6**). Holstein cows had higher activity rates measured by steps per hour at 115.6 steps/hr compared to Jersey cows with an average activity of 114.0 steps/hr ($P = 0.0003$; **Figure 7**).

Production data by season by breed

SCS, conductivity, and average rest time were not statistically different between season by breed (**Table 3**). Milk yield was higher during the winter months for Holstein at 29.4 kg/d whereas in the summer months Holstein milk yield was at 27.3 kg/d. ($P < 0.0001$; **Figure 8**). Average activity was lower in the winter months for both Holstein at 108.2 steps/hr and Jersey cows at 119.9 steps/hr ($P < 0.0001$; **Figure 9)**. In the summer months, average rest bouts were higher for both Holsteins 8.0 times/day and Jerseys 7.2 times/day ($P < 0.0001$; **Figure 10**). Rest bouts were lower in the winter months at 6.3 times/day for Holsteins and 6.4 times/day for Jerseys.

Temperature data

The average temperature was 79.8°F in July and 79.3°F in August with the average high being 89°F in July and 88°F in August (**Table 4**). In December, the average temperature was 52°F. In January, the average temperature was 36°F with the average high being 48°F. The average humidity was 69.9% in August and 68.4% in July, respectively. The humidity in December was 66.1%. The THI was 74.86 in July and 75.52 in August. The THI in December was 52.62 and 43.90 in January. In the summer months, THI levels were in the range of mild to moderate heat stress (72-78). THI levels were much lower in December and January (under 68 – no heat stress). Therefore, cows did not suffer from heat stress during winter months.

Discussion

Heat stress plays a role in the overall production levels of lactating dairy cattle. In this study, Holsteins were more productive in the summer months than winter months. The type of breed also plays a role in productivity. Holstein cows were shown to be more productive than Jersey cows in both summer and winter months. The time of year influences cow activity such as steps per day, rest bouts per day, and overall rest time during the day. It was shown cows have more activity in the summer than in the winter months. Lactating cows are more active in the summer because they are restless due to heat stress. In July and August, while cows were heat stressed, they had increased restless activity which has negative effects such as lower milk production and can increase chances of lameness. Dairy cows will increase their standing time to try to cool off by dry panting which reduces the amount of dry matter intake (**DMI**) they consume. When lactating cows consume less DMI, this reduced the amount of blood flow to the mammary gland which reduces the amount of milk being produced by the cow. These results confirmed what had been previously found on research done on heat stress in the past.

Conclusion

Keeping cows from heat stress plays an important role in overall production of dairy cattle. When cows suffer from heat stress it can have negative effects on milk production, milk quality, and reproductive performance. Heat stress is a major challenge for dairy producers because of its negative impact on milk production and reproductive performance, which results in economic losses. In the present study, there were many differences in cow behavior between summer and winter months due to heat stress. Improved ways to keep cows from heat stress need to be further investigated, such as sprinklers and misters, proper ventilation, and providing clean drinking water. These methods of keeping cows from heat stress should be researched to see if there are improvements such as improved milk quality, reproductive rates, and decreased restless activity among herds suffering from heat stress.

List of Terms

- Artificial insemination (**AI**): A modern breeding technique used to obtain desired genetics without having to have a bull present, while also increasing the chance of pregnancy through direct placement of the semen in the uterus.
- Conception rate: A measure of a cow's fertility at service
- Estrus (or heat): Reoccurring state of sexual receptivity that is induced by reproductive hormones
- Heat stress: When the body cannot cool itself and maintain a healthy temperature
- Mammary gland: A gland found in mammals that produces milk to feed offspring
- Mastitis: Inflammation of the udder that is a result of bacterial infection
- Milk conductivity (**EC)**: How well milk conducts electricity
- Pregnancy rate: Measured by time intervals based on frequency in which cows come into estrus.
- Somatic Cell Count (**SCC**): The number of white blood cells per milliliter in milk.
- Thermoregulating: A natural process that allows the body to maintain a constant temperature

References

Cook, N. B., Mentink, R. L., Bennett, T. B,, Burgi, K. 2006. The Effect of Heat Stress and Lameness on Time Budgets of Lactating Dairy Cows. J. Dairy Sci. 90:1674–1682.

DeJarnette, J.M., Marshall, C. E., Lenz, R. W., Monke, D. R., Ayars, W. H., Sattler, C. G. 2004. Sustaining the Fertility of Artificially Inseminated Dairy Cattle: The Role of the Artificial Insemination Industry. J. Dairy Sci. 87:(E. Suppl.): E93–E104.

Dufour, S. Labrie, J. Jacques, M. 2019. The Mastitis Pathogens Culture Collection. Microbiol Resour Announc. 8:e00133-19.

Henningsson, M., Östergren, K., Dejmek, P. 2005. The Electrical Conductivity of Milk: The Effect of Dilution and Temperature, International Journal of Food Properties. 8:1, 15-22.

Jones, G.M., Bailey, T. L. Jr. 2009. Understanding the Basics of Mastitis. Virginia Cooperative Extension. 404-223.

Jordan, E. R. 2003. Effects of Heat Stress on Reproduction. J. Dairy Sci. 86:(E. Suppl.):E104–E114.

Polsky, L., Keyserlingk, M. A. G., 2017. Invited Review: Effects of Heat Stress on Dairy Cattle Welfare. J. Dairy Sci. 100:8645–8657.

St-Pierre, N. R., Cobanov, B., Schnitkey, G. 2003. Economic Losses from Heat Stress by US Livestock Industries. J. Dairy Sci. 86:(E. Suppl.):E52–E77.

Tullo, E., Fontana, I., Gottardo, D., Sloth, K. H., Guarino, M. 2016. Technical note: Validation of a commercial system for the continuous and automated monitoring of dairy cow activity. J. Dairy Sci. 99:7489–7494.

Webb, D. W. 2003. Artificial Insemination in Dairy Cattle. University of Florida. DS58.

West, J. W. 2003. Effects of Heat-Stress on Production in Dairy Cattle. J. Dairy Sci. 86:2131–2144.

APPENDIX

Table 1. Least square means for production measures by season.

Measure	**Summer**	**Winter**	**SEM**	***P-Value***
No. of Cows	45	56		
DIM	175	169		
Milk Yield, kg/d	22.9	22.7	1.4	0.3830
Somatic cell score [a]	10.2	10.5	2.6	0.2369
Conductivity	10.0	9.3	0.1	<.0001*
Avg. Activity, steps/hr	126.6	114.0	4.36	<.0001*
Avg. Rest Bouts, times/d	7.6	6.3	0.2	<.0001*
Avg. Rest Time	253.0	298.2	7.3	<.0001*

[a] Somatic cell count data was logarithmically transformed using the formula:SCS=log2(SCC/100)+3.

*Significant difference determined at $p < 0.05$.

Table 2. Least square means for production measures by breed.

Measure	**Holstein**	**Jersey**	**SEM**	***P-Value***
No. of Cows	40	38		
DIM	175	169		
Milk Yield, kg/d	28.3	17.3	1.7	<.0001*
Somatic cell score [a]	10.0	10.6	0.31	0.1430
Conductivity	9.9	9.4	0.1	0.0006*
Avg. Activity, steps/hr	115.6	114.0	4.36	0.0003*
Avg. Rest Bouts, times/d	7.1	6.8	0.3	0.3037
Avg. Rest Time	283.9	267.3	7.3	0.1089

[a] Somatic cell count data was logarithmically transformed using the formula SCS=log2(SCC/100)+3

*Significant difference determined at $p < 0.05$.

Table 3. Least square means for production measures for season by breed interactions.

Season	***Summer***		***Winter***			
Measure	**Holstein**	**Jersey**	**Holstein**	**Jersey**	**SEM**	**P-Value**
No. of Cows						
Milk Yield, kg/d	27.3	18.5	29.4	16.1	1.7	<.0001*
Somatic cell score [a]	9.7	10.3	10.6	10.7	0.37	0.3047
Conductivity	10.3	9.8	9.5	9.0	0.1	0.9289
Avg. Activity, steps/hr	123.1	130.2	108.2	119.9	4.5	<.0001*
Avg. Rest Bouts, times/d	8.0	7.2	6.3	6.4	0.2	<.0001*
Avg. Rest Time, min	262.8	243.1	305.0	291.5	7.3	0.2276

[a] Somatic cell count data was logarithmically transformed using the formula SCS=log2(SCC/100)+3.

*Significant difference determined at $p < 0.05$.

Table 4: Environmental averages for each season.

	July	**August**	**December**	**January**
Temperature, °C	26	26.3	11	5.2
Relative Humidity, %	66.6	67.9	76	72.4
THI	74.9	75.5	52.6	43.9

Table 5: Pregnancy Rate by season.

	Summer	Winter
Number of cows	11	15
Pregnant	8	10
Open	3	5
Pregnancy Rate	72.70%	66.7%
Avg. Number of Breedings/cow	4.8	2.9

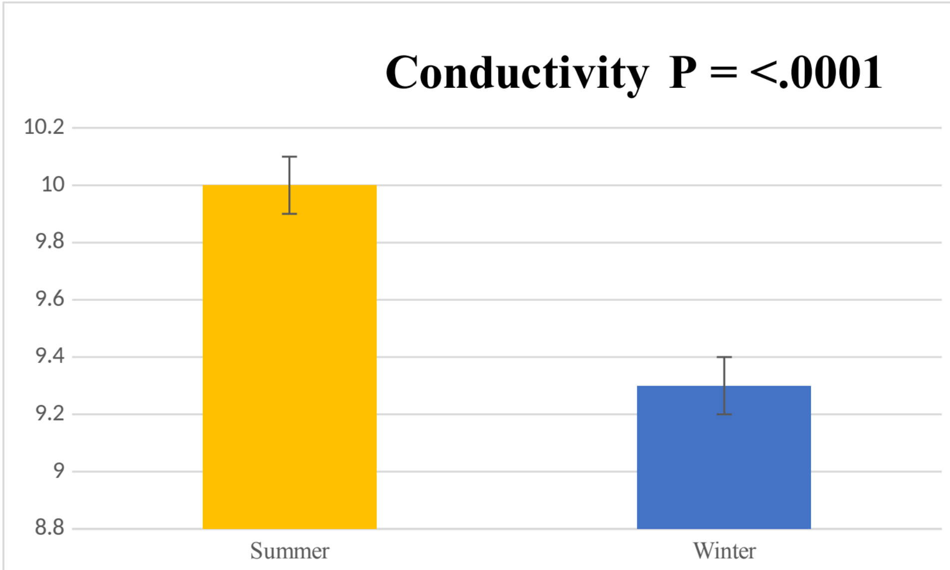

Figure 1. The average conductivity (mS/cm) for cows over the summer and winter months during the study.

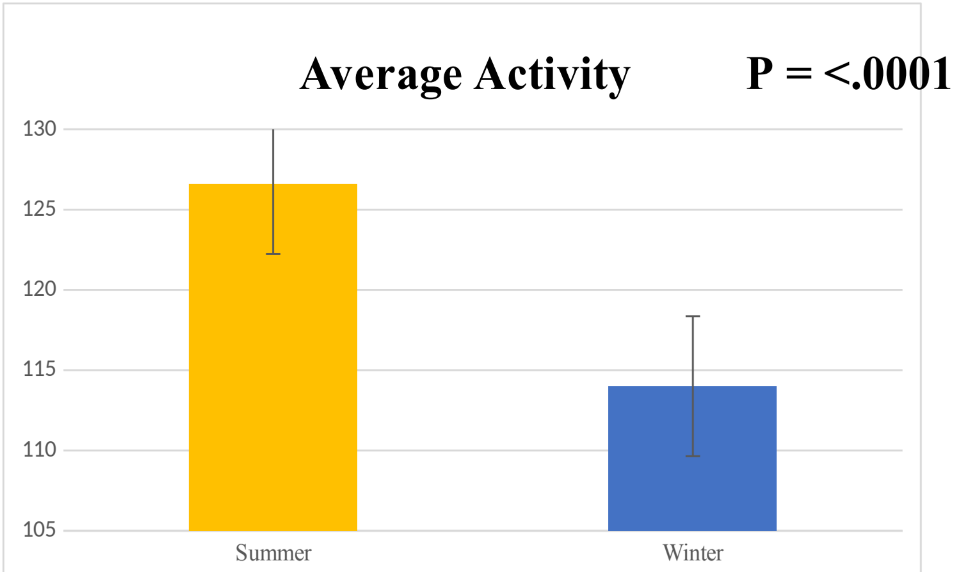

Figure 2. The average activity (steps/hr) for cows over the summer and winter months during the study. The average activity of cows during winter months was lower at 114 steps per hour.

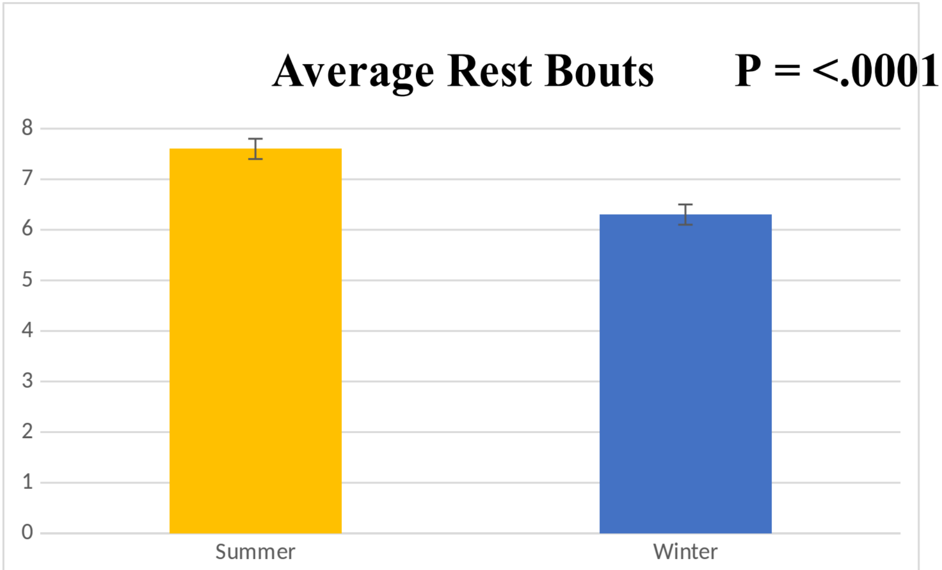

Figure 3. The average rest bouts (time/d) for cows over the summer and winter months during the study. Average rest bouts were lower in winter months at 6.3 rest bouts per day.

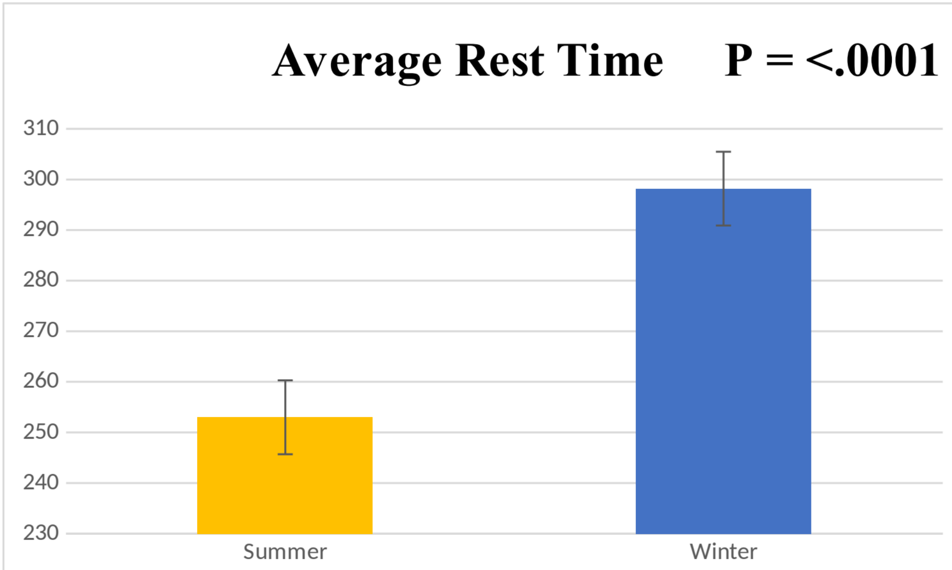

Figure 4. The average rest time (min) for cows over the summer and winter months during the study. Average rest time was greater in the winter at 298.2 min whereas in the summer the average rest time was 253 min.

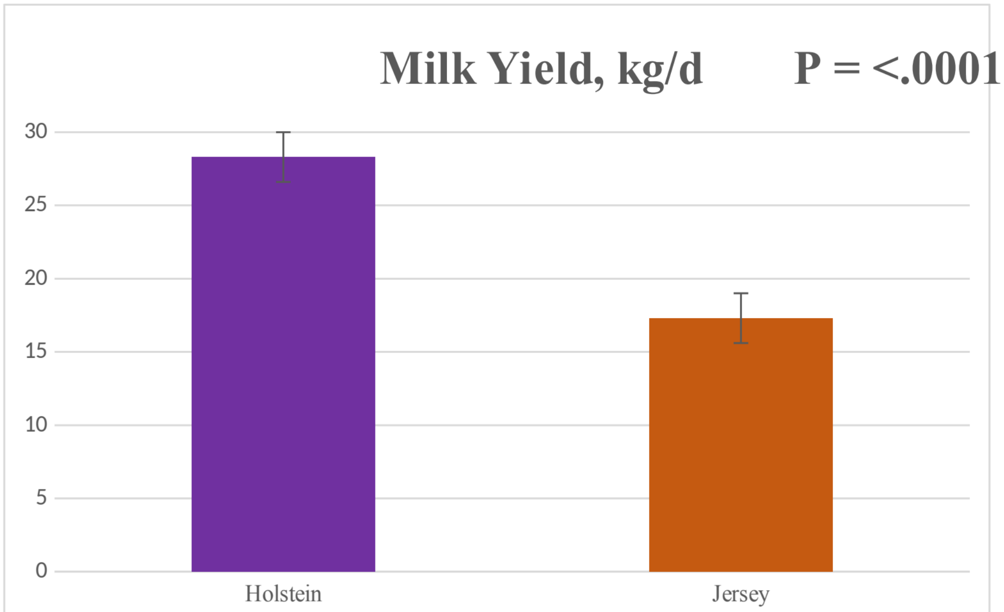

Figure 5. The average milk yield (kg/d) for Holstein and Jersey cows during the period of the study.

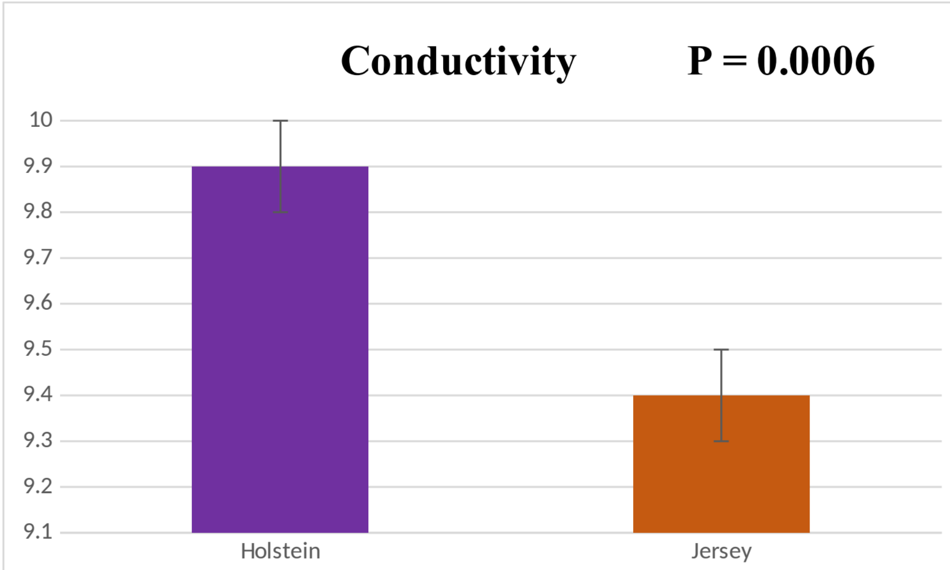

Figure 6. The average conductivity (mS/cm) for Holstein and Jersey cows during the period of the study.

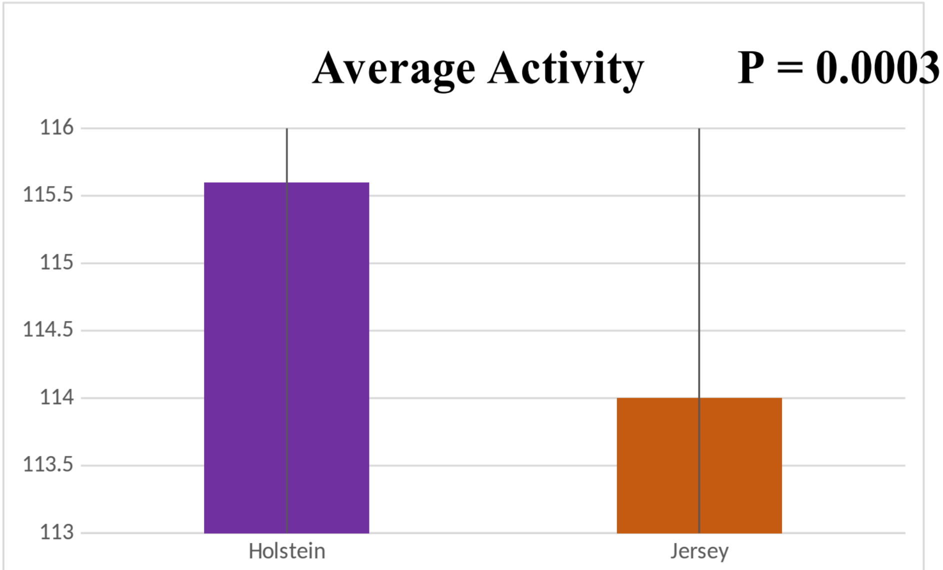

Figure 7. The average activity (steps/d) for Holstein and Jersey cows during the period of the study.

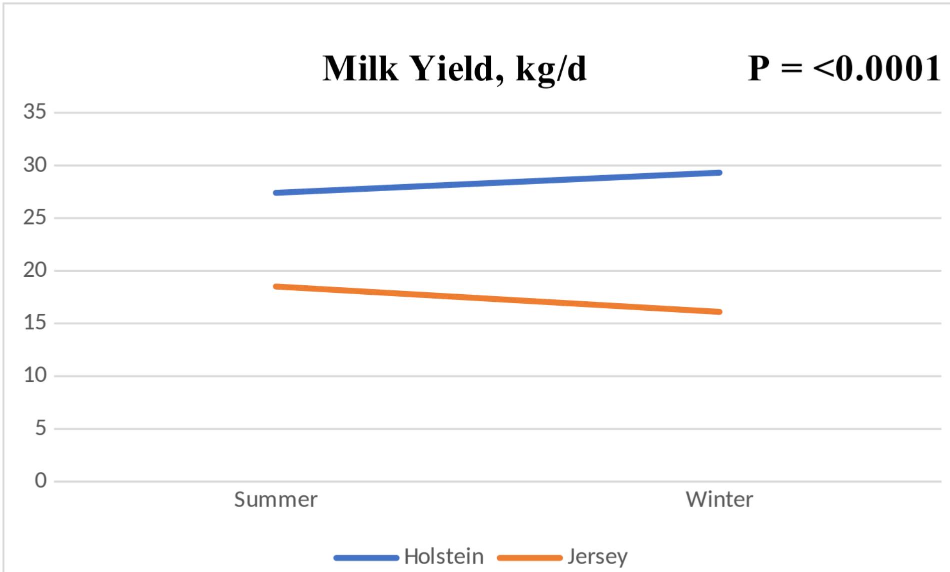

Figure 8. The average milk yield (kg/d) for Holstein and Jersey cows during the period of the study.

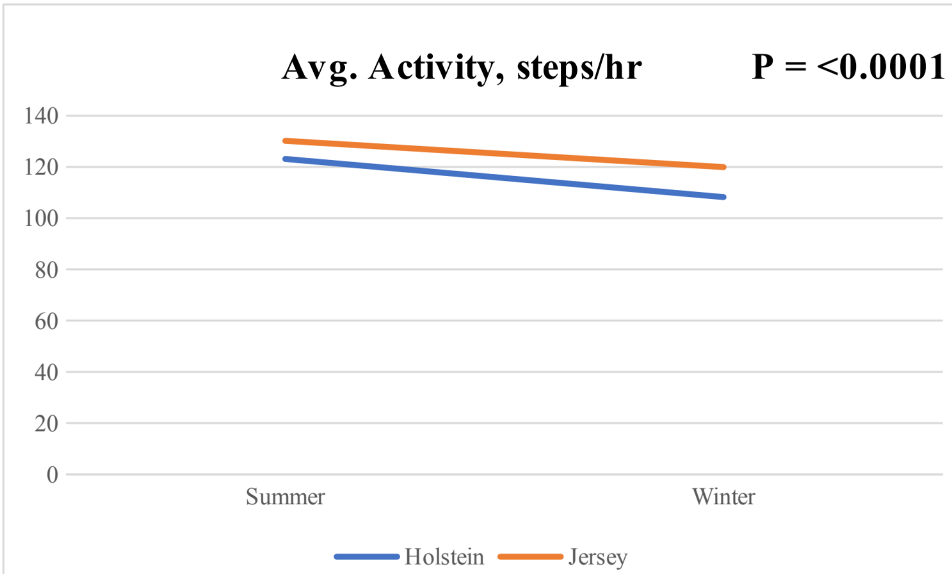

Figure 9. The average activity (steps/hr) for Holstein and Jersey cows during the period of the study.

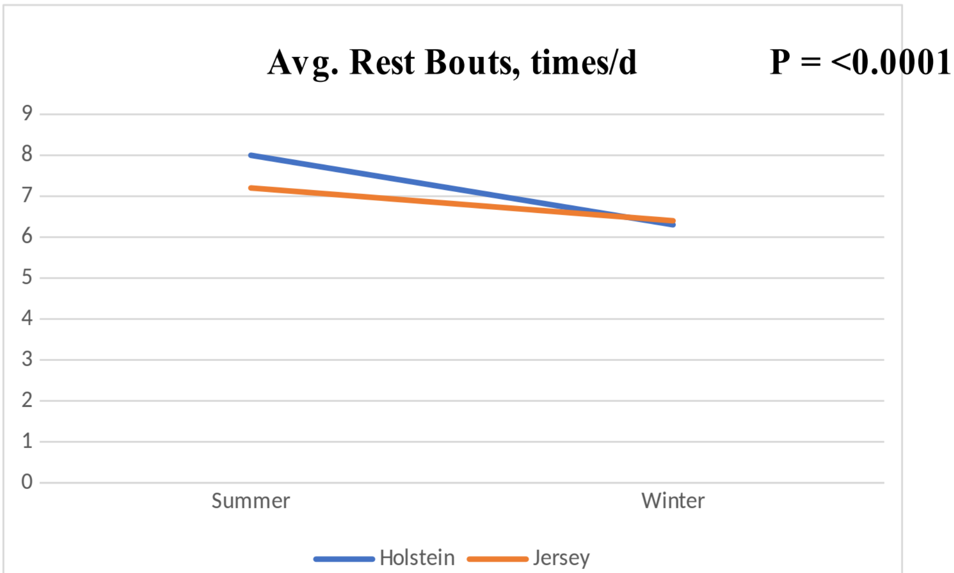

Figure 10. The average rest bouts (times/d) for Holstein and Jersey cows during the period of the study.