Environmental temperature effects on milk production and daily activity of dairy cows with respect to different breeds

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Abstract

Heat stress is an animal's response to an increase in thermal environment that causes the animal to inadequately dissipate heat out of the body. This stress occurs at temperatures over 77 °F, when cows are unable to cool themselves down. This increase in heat stress causes a decrease in milk production because more energy is needed to cool down, so there is less energy focused on producing milk. Temperature and relative humidity data, as well as daily milk yield, daily activity, and conductivity, were measured for three 6-week periods during different seasons to determine the effects of environmental temperature on milk production and activity levels. Cows produced more milk during the spring period ($p < 0.0001$) and had a higher conductivity in the summer ($p < 0.0001$). Jerseys were more active through each period than Holsteins ($p < 0.0001$) and mild heat stress occurred in the summer with an average THI index of 76.3. The optimum temperature range for Jerseys occurred during the spring period (18°C average temperature), while the optimum temperature for Holsteins occurred during the winter period (8.5°C average temperature).

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List of Terms

Afimilk® – the system used to track each cow's production and activity levels by a pedometer on each cow's front hoof.

Average activity – the activity level in cows expressed in steps/hr.

Average rest bouts – the average number of times, in times/d, each cow lays down during the day.

Average rest time – the average length of times, in minutes, that a cow lays down in a day.

Conductivity – a measurement used to determine the health of a cow in relation to mastitis. High conductivity tends to indicate a high level of mastitis.

Days in Milk (DIM) – After giving birth, cows begin to lactate. DIM is the number of days of active lactation after giving birth.

Milk yield – the amount of milk each cow produces daily, in kg.

Relative Humidity – The amount of humidity that is present in the air.

THI – Termed the Temperature Humidity Index, it is a temperature rating using the ambient temperature (T), in °C, and the relative humidity (RH), in %. The equation is as follows: **THI =0.8*T + RH*(T-14.4) + 46.4**

TMR – The feeding method used at the MTSU dairy. TMR stands for Total Mixed Ration, which includes corn silage, ground corn, soybean meal, and protein mix.

Introduction

There are two main breeds of dairy cattle that are used in most milking operations in the United State: Holstein and Jersey. The Holstein is the larger of the two breeds and produces more milk per lactation, averaging about 23,791 lb of milk/305-day lactation period. The fat content of milk produced by the Holstein is 3.65%. Jerseys are the smallest of all the dairy breeds and produce less milk than Holsteins at 17,302 lb of milk/305-day lactational period, but Jersey cows have the greatest number of solids in their milk at 4.65% fat (Field, 2020). Over time, these two breeds of dairy cattle have been genetically selected for their respected favored traits based on the milking operation.

Modern dairy cattle have been genetically selected for increased milk production. This increase in milk yield may have resulted in cows experiencing heat stress at a lower temperature considering the positive correlation between feed intake and metabolic heat production (Kadzere et al., 2002). Because milking operations have been selected for increased milk production, each cow requires enough feed daily to produce the desired amount of milk. Dairy cattle are considered the most feed efficient because they only require 1.1 lb of feed to make 1.0 lb of milk. The more feed each cow consumes each day, the more milk that cow can produce. On the other hand, if a cow's daily dry matter intake decreases, then so does the milk production because the cow is not fueling her body enough to produce large quantities of milk on low amounts of feed.

Heat stress is a response of an animal to an increased thermal environment that causes that animal to inadequately dissipate all the heat in the body. Heat stress in dairy cattle can occur during times of extreme heat and humidity, such as in the middle of the summer when ambient temperatures and relative humidity are high. In summer months, the cow's ability to dissipate the needed amount of heat through skin evaporation is limited because of the low surface area to body weight ratio (Liu et al., 2019). The Temperature Humidity Index, also termed THI, is a tool used to combine the ambient temperature with relative humidity (Smith et al., 2013).

High yielding cows require more nutrients to maintain milk production as well as maintenance and reproduction. It has been well established that increased thermal environment can have a negative effect on milk production (Kadzere et al., 2002). As environmental temperatures steadily begin to increase, cows are slowly being pushed out of their comfort temperature zones. Lactating cows prefer ambient temperatures between 41 - 77°F, which is considered the thermoneutral zone (Roenfeldt, 1998). At temperatures above 77°F, cows will reach a point where they can no longer cool down adequately and enter heat stress. With an increase in temperatures over 90°F, milk production can decrease as much as 20% (Keown and Grant, 1993). It is suggested that Jersey cattle have more tolerance in higher temperatures (Smith et al., 2013). During times of heat stress in cattle, the cow requires more energy to cool down, so less energy is being put into milk production (Qi et al., 2015).

Literature Review

West (2003) looked at the effect of climate variables on body temperature, dry matter intake, and milk yield, metabolic heat production, and physiologic effects of heat stress on dairy cows, as well as provided some suggestions to improve production performance in hot and humid conditions. West summed up heat stress as “the sum of heat accumulated from the environment and the failure to dissipate heat associated with metabolic processes” (West, 2003). Beginning with effects of climatic variables on cow body temperature, dry matter intake and milk yield, West writes “in the Southeast one of the major challenges is the combined effects of high relative humidity with high ambient temperature. At a temperature of 29 degrees C [84.2° F] and 40% relative humidity the milk yield of Holstein, Jersey, and Brown Swiss was 97, 93, and 98% of normal, but when relative humidity was increased to 90% yields were 69, 75, and 83% of normal (Bianca, 1965)” (West 2003). This statistic shows that with an increase in temperature and humidity levels, milk yields decreased significantly compared to the normal, average milk yield. Moving onto metabolic heat production, body heat increases as metabolic processes, daily feed intake, and digestive requirements increase due to the increase in milk yield (West, 2003).

Next is the physiological effects of heat stress. West (2003) suggests that physiological changes in the body could either be the result of decreased nutritional levels, due to reduced daily feed intake or the stress the cow is under because of the environmental temperature. These stress factors can cause many problems in the cow’s body, including altering hormone levels, such as declining plasma somatotropin, triiodothyronine, and thyroxine levels when exposed to high ambient temperatures.

Another effect of heat stress is altering the exchange rate of CO_2, which reduces the amount of carbonic acid in the blood and throws off the balance of carbonic acid to bicarbonate that is useful in maintaining correct blood pH. This imbalance of blood concentrates leads to respiratory alkalosis in dairy cows (Benjamin, 2981; West, 2003). While there are obvious repercussions to heat stress such as milk yield, there are also some other issues that occur within the body that we cannot see from the outside. These physiological problems are important to understand, so we as researchers can do the most possible to avoid them. Lastly, West (2003) recommends a few improvements for cow performance under heat stress conditions. The two main improvements that he recommends are plenty of shading and misting to reduce the direct sunlight and to aid in the natural evaporative cooling that each cow exhibits.

West (2003) indicates that the problem for high producing dairy cows is the ability to dissipate heat from metabolic processes. Heat from metabolic processes increases as dairy cows improve their productive capacity. In this study, the researchers exposed dairy cows to moderate and humid weather to determine the effect of increasing summer temperatures and the effect that the THI rating had on daily feed intake and milk production. For this research, they used 24 Holstein and 8 Jersey cows housed in free-stall sheds and each cow averaged 60 days in milk. Their research period ranged from April 28 (to accommodate cooler temperatures) until July 27 (to accommodate hot and humid temperatures). It was shown that there was a significant increase in temperatures around June 2, so that is the cutoff point between the COOL and HOT periods. The average minimum temperature for the COOL period was 64.22°F, and the maximum temperature for the COOL period was 85.1°F. The average minimum temperature for the

HOT period was 72.5°F, while the average maximum temperature was 93.92° F. During the COOL period, both breeds of cows exhibited normal milk temperature at around 100°F, but once in the HOT period, Holsteins exhibited an average milk temperature of 103.28°F, while Jerseys exhibited an average of 102.56°F. Researchers additionally pointed out that the temperature and humidity ratings for the day before the current day might have a greater impact on daily milk yield and feed intake, instead of current day temperatures. It was also concluded that both breeds experienced similar declines in feed intake during hot and humid summer temperatures, and both breeds experienced a similar curvilinear decline in performance when compared to a 2-day lag on the milk temperature. Lastly, this study concluded that environmental conditions should be considered up to two days before determining feed intake or daily milk yield to accurately determine the effects of heat stress (West et al. 2003).

The next study was recorded using data from April 2010 to March 2011 to compare the effect of the temperature-humidity index (THI) on milk yield and somatic cell count scores in lactating dairy cows using five herds ranging from 70 to 200 cows for each of the four housing types: warm loose housing with access to grazing (WG), warm loose housing without access to grazing (WI), cold loose housing with access to grazing (CG), and cold loose housing without access to grazing (CI; Lambertz et al., 2014). The WG and CG groups, cows were able to graze on pasture from May to October. The main difference in the warm and cold groups were the construction types. The warm housing had an insulated roof, while the cold housing did not. In this study, THI was calculated for each hour, while collecting milk production values from 21,546 records of milk yield, fat yield, protein yield, and somatic cell count score data. This study concluded that based on the temperature data, cows could be exposed to heat stress at any point during the year, not only during the summer months. Researchers found that the THI gradually increased from January until July and then slowly decreased to December. Researchers determined that from June to September the monthly averages exceeded a THI of 60. Researchers also noted that there was no difference in the housing systems. Housing system exceeded a THI of 72 between April and September in a non-pasture-based housing, with a pasture-based housing system exceeding a THI of 72 from April to October. (Lambertz et al., 2014). It was observed that the highest THI value was recorded in July. This study concluded that the effects of heat stress included decreased milk yield, decreased fat and protein percentages in the milk, and an increase in somatic cell count. Researchers noted that the effects of heat stress did not vary between housing systems, so researchers could not find a housing system that was preferred in times of heat stress (Lambertz et al., 2014).

In an article published by Dunn et al. (2014), researchers studied effects of heat stress on milk yields in dairy cattle housed in the United Kingdom. This study period included the August 2003 and July 2006 heat waves and included farms in the warmer, southern counties: "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). The warmest days in those heat waves were August 10 and July 19. Based on their data (August 9-11, 2003, and July 18-20, 2006), they concluded that only 4 out of the 17 herds showed a decrease in milk yields. However, the data company they used to compile the data from the different herds did not provide details as to where the farms were located, so it is hard to determine the elevations that each farm was at as compared to the effect each farm experienced due to heat stress. They concluded that at least one herd of the 17 had a decrease of 30% in milk yield due to the high THI during the July 2006 heat wave (Dunn et al., 2014).

Smith et al. (2013) investigated differences among dairy breeds for heat tolerance. This was in an effort to allow dairy producers in climates prone to heat stress to select the most suitable cattle for successful production (Smith et al., 2013). In their study, researchers used over 16,000 records, including milk yield and milk fat and protein percentages from cows dating from 1997 to 2010. There were records for 142 Jerseys with an average DIM of 190 days, and records from 586 Holsteins with an average DIM of 205. They also used daily ambient temperatures to determine the THI. The constants of this study were that cows were housed in 2 free stall barns, which included fans and sprinklers to be turned on when temperatures reached 23.8°C (74.24° F) and fed the same TMR daily. This study concluded that Holstein milk yield decreased from 34.8 kg/d to 32.9 kg/d during moderate heat stress and decreased from 34.8 kg/d to 30.4 kg/d during severe heat stress. Milk yield from Jersey cow's milk yield did not significantly decrease in moderate heat stress but decreased from 25.9 kg/d to 23.8 kg/d during severe heat stress. Other milk characteristics such as fat percentage increased in Holstein cows during heat stress but stayed the same for Jersey cows. Both Jersey and Holstein cows exhibited similar somatic cell scores during heat stress. This study implies that somatic cell count and THI may have a direct relationship. In instances of high THI, there might be a reduced somatic cell count in the herd, but the clinical cases of mastitis may still be present (Smith et al., 2013).

Almoosavi et al. (2020) aimed to identify the effects of heat stress from decreased dry matter intake on reproductive aspects such as colostrum and production in a study conducted in Iran from August to November 2017. Using Holstein cows, the authors created three separate groups including (1) 10 cows in a cooled condition with constant access to feed, (2) 10 cows in a heat stress environment with constant access to feed, and (3) 10 cows in a pair-fed cooled system with a reduced amount of dry matter intake. In the cooled condition, cows were placed in barn systems with shade, sprinklers, and fans, where the heat stress group only had access to shade. Researchers suggested that heat stress, when compared to cooled cows, can have negative effects on dairy production, such as decreased gestation length, low colostrum volume, and low calf birth weights (Almoosavi et al., 2020). To determine the colostrum yield, each cow was milked 2 hours after giving birth. Rectal temperature and respiratory rate are two of the main physiological features that are easiest to measure when determining if heat stress is present.

When cows were in the cooling systems, the rectal temperature and respiratory rate decreased based on the increase amount of evaporative cooling aided by shade, misting, and fans. The higher rectal temperature and respiratory rates seen in the heat stress group were due to the increase in effects of heat stress. Results of standing time differences between cooled and heat stress cows indicated that the cooling groups exhibited shorter standing times. Heat stress cows exhibited longer standing times to "expose more surface area for heat abatement" (Almoosavi et al., 2020). Cows under heat stress at 45d before birth showed heat stress that can have a direct effect on fetal growth to lessen the growth rate in utero. Feed restriction did not have a large effect on fetal growth when compared to the heat stress group. This shows that there is a direct relationship between heat stress and decreases in fetal growth: “in agreement with the current study, Moteiro et al. (2014) observed that calves born to HS cows during the dry period (46 d before the expected calving date) had lower birth BW compared with those born to CL cows (45.0 kg vs 40.2 kg respectively)” (Almoosavi et al., 2020). Thus, cows under heat stress contributed to decreased fetal growth in late gestation as opposed to reduced feed intake or some other factor. It was also suspected that heat stress has more of an effect on fetal growth than on the body weight of the dam, so there is more weight change in the fetus then in the cow.

Qi et al. (2015) studied climatic effects and productivity in Wisconsin dairy farms. Using past data, researchers determined the average temperature for winter (December-March) was -4°C (24.8°F), and the average temperature for the summer (June – September) was 19°C (66.2°F). This study used data from 958 dairies across Wisconsin ranging from 1996 to 2012. Throughout their research, they have determined that the effects of climate change will have an important effect on the future of dairy production (Qi et al., 2015). According to the study, the researchers concluded that higher temperatures in the summer months are harmful to dairy, while warmer temperatures in the winter months could be beneficial (Qi et al., 2015).

If researchers can find and lessen the effects of heat stress for cows, we could eventually see not only milk yield increase during times of heat stress, but also outcomes like maintaining good body condition scores and an overall healthy cow, who is well nourished and maintains a balanced activity level.

Thesis Statement

The objective of this research was to identify the most desirable range of temperature and humidity for dairy cows housed in a compost bedded pack barn that will allow cows to produce the optimum amount of milk/cow/day and have normal activity ranges. Researchers also studied temperature and humidity effects by cow breed. Although climate is unchangeable, farmers can change aspects in their barns, such as adding adequate ventilation, to allow their cows to be comfortable and produce at maximum capability.

Methods

Middle Tennessee State University's dairy herd was used for this research, which consists of two breeds: Holstein and Jersey. The cows were housed in a compost bedded pack barn with constant access to food and water. The dairy herd is milked twice daily at 5:00 am and 4:00 pm. These constant factors allow for a specified look into the daily temperature and relative humidity effects on the lactating dairy cows to determine the temperature range that produces the optimum amount of milk while exhibiting normal activity levels.

This research was conducted over three 6-week periods over in different seasons to receive data from a wide range of temperatures. The first period, February 8 to March 22, 2021, allowed for cold, wintery temperatures, while the second period, April 20 to June 1, allowed for this transition into the warmer, spring temperatures. The last period, July 21 to September 1, allowed for hot and humid summer temperatures.

Milk yield, conductivity, and activity levels of each cow were collected through the Afimilk® system software that is installed at the MTSU Dairy. Each cow was equipped with a pedometer on her front leg and activity and milking data was collected each time the cow walked through the parlor to be milked. Daily milk yield, conductivity, and activity level for each cow were compiled.

Bedded pack temperatures were collected weekly during each 6-week period by placing a thermometer 14 inches deep into the pack at 8 different places around the barn. These 8 temperatures were averaged. A Sensorpush® Wireless Thermometer was mounted the pack barn to measure the air temperature and relative humidity throughout the day. The temperature data was collected every minute and averages were calculated.

Data collection occurred each week to compile the bedded pack and air temperatures. For the Afimilk® system, data collection occurred each week to compile each cow's individual daily milk production and conductivity. Overall data analysis occurred at the end of the project to compare seasonal temperature effects on daily milk yield and activity levels. Each research period focused on a different temperature range, so the temperature that allows for the optimum milk yield could be determined. All cow data and environmental temperature data were analyzed using a mixed model with SAS 2016 – (v9.4, SAS Institute Inc., Cary, NC) to determine the main effects of temperature on breed and season.

Results

For all three seasons (winter, spring, and summer), Holstein cows produced more milk than Jersey cows ($p < 0.0001$). The average milk yield for the Holsteins was 24.4 lb/d, while the average for the Jerseys was 18.5 lb/d **[Table 1]**. Next, all the cows in the study produced more milk in the spring season ($p < 0.0001$). The average milk production per cow in the winter period was 21.2 lb/d, the average for the spring period was 22.1 lb/d, and the average for the summer period was 21.1 lb/d **[Figure 1]**. The breed by season interaction daily averages for Holsteins are 25.1 lb in the winter period, 24.7 lb in the spring period, and 23.4 lb in the summer period **[Table 3]**. The breed by season interaction daily milk production averages for Jerseys are 17.4 lb in the winter period, 19.5 lb in the spring period, and 18.7 lb in the summer period **[Figure 8]**.

There were no significant differences in conductivity between breeds. The average conductivity for Holsteins was 9.8, while the average for Jerseys was 9.5 over all three research periods **[Table 1]**. However, the analysis did show that there was a significance in the effect of season on conductivity values **[Table 4]**. The average conductivity for the winter period was 9.3 mS, the average for the spring period was 9.6 mS, and the average for the summer period was 10.0. mS. There were significant differences between the breed by season interactions ($p < 0.0001$). The average for the Holsteins were 9.4 mS during the winter period, 9.8 mS during the spring period, and 10.1 mS during the summer period. The averages for the Jerseys were 9.2 mS during the winter period, 9.4 mS during the spring period, and 9.9 mS during the summer period **[Figure 9]**.

Significant differences in average activity by breed, season, and breed by season interactions were observed in this study. Jerseys averaged 140.7 steps/hr, while Holsteins only averaged 100.5 steps/hr ($p < 0.0001$) **[Table 1]**. The average activity for each season was 123.5 steps/hr in the winter period, 129.7 steps/hr in the spring period, and 108.7 steps/hr in the summer period ($p < 0.0001$) **[Table 5]**. Lastly, on the breed by season interaction, the average activity for Holsteins was 101.7 steps/hr in the winter period, 105.7 steps/hr in the spring period, and 94.2 steps/hr in the summer period. The average activity for the Jersey were 145.4 steps/hr in the winter period, 153.6 steps/hr in the spring period, and 123.1 steps/hr in the summer period **[Figure 10]**.

Average rest bouts were also analyzed and showed significant differences in the season and breed by season interactions. The average rest bout for Holsteins was 6.5 times/d, while the average for Jerseys was 6.8 times/d **[Table 1]**. The winter period average rest bout was 5.7 times/d, while the average for the spring period was 6.7 times/d, and the average for the summer period was 7.6 times/d **[Figure 6]**. In the breed by season interaction, the averages for Holsteins were 5.7 times/d in the winter period, 6.3 times/d in the spring period, and 7.4 times/d in the summer period **[Figure 11]**. The averages for the Jerseys were 5.6 times/d in the winter period, 7.1 times/d in the spring period, and 7.8 times/d in the summer period **[Table 6]**.

Average rest time showed significant differences in the season and breed by season interactions. The average rest time for Holsteins was 289.9 minutes, while the average for Jerseys was 267.0 minutes **[Table 1]**. The average rest time for the summer period was 262.3 minutes, 292.9 minutes in the spring period, and 280.3 minutes in the winter period. For the breed by season interaction, the averages for Holsteins were 264.5

minutes in the summer period, 305.8 minutes in the spring period, and 299.6 minutes in the winter period **[Table 7]**. The averages for Jerseys were 260.0 minutes in the summer period, 280.0 minutes in the spring period, and 261.0 minutes in the winter period **[Figure 12]**.

The average temperature for the summer period was 25.8°C, the average for the spring period was 18.0°C, and the average for the winter period was 8.5°C **[Table 8]**. The average relative humidity for the summer period was 81.3%, the average for the spring period was 71.1%, and the winter period was 74.5%. Using the formula, THI =0.8*T + RH*(T-14.4) + 46.4, the THI for the summer period was 76.3, the THI for the spring period was 63.3, and the THI for the winter period was 48.5 **[Figure 13]**.

The compost bedded pack temperatures were also compiled during each research period. The average pack temperature for the winter season was 64.4°F. The average pack temperature for the spring period was 95.3°F, and the average temperature for the summer period was 111.8°F. From this data, we can conclude that as the ambient temperature increased, the compost bedded pack temperatures increased as well.

Discussion

Beginning with the milk production, the results showed that overall, for both breeds, Holsteins produced more milk during each season. When milk production was broken down by breed over each season, Holsteins produced more milk in the winter and Jerseys produced their highest amount of milk in the spring on average. This breed by season interaction is important because it allows producers to understand the season in which each breed of cow produces the most milk respectively.

Conductivity is an important factor to check in a milking operation, because it gives a good indication about whether a specific cow is having a problem with mastitis. Normally, a higher conductivity score indicates a high incidence of mastitis in a cow or herd. This research determined that Holstein cows had the highest conductivity in the summer period. Jerseys showed a consistent increase in conductivity values as temperature increased with each research period. The conductivity values for the Holsteins increased over each seasonal period as well, but the Holsteins overall had a higher conductivity in each period of this research.

Average activity for dairy cows is a good indication of the activity level of the cows. In this study, Jerseys were more active than Holstein cows and averaged more steps/hr in each of the three research periods. There was a steady decline over the three periods in both breeds for average steps/hr; however, Jerseys were still more active than the Holsteins, even in the summer months.

Average rest bouts show the number of times a cow lies down in a day. Holsteins tended to lay down more in the winter period, and Jerseys tended to lay down more in the spring and summer periods. Average rest time is the average minutes in day that a cow lays down. In this study, Holstein cows lay down for longer amounts of time in each of the three seasons. The temperature data showed that there was mild heat stress in the summer period as indicated by the THI of 76.3.

Conclusion

This research showed very specific results pertaining to milk yield, conductivity, and activity of Holstein and Jersey cows at the MTSU dairy farm. The main result from this research is that each breed of cow shows differences in their optimum temperature range. This range allowed each breed to be more comfortable and produce more milk. For Jerseys, this optimum temperature range was found in the spring period. During this spring period, Jerseys produced milk at a higher capacity and had a higher activity level, as compared to the other seasons. The optimum temperature range for Holsteins occurred during the winter season, which allowed the Holsteins to produce more milk on average.

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APPENDIX

Table 1. Average cow production and activity measurements by breed.

	Holstein	**Jersey**	**SEM**	**P. Value**
Milk Yield, kg/d	24.4	18.5	0.9912	<0.0001
Conductivity, mS	9.8	9.5	0.1079	0.0818
Average Activity, steps/hr	100.5	140.7	5.6336	<0.0001
Average Rest Bout, times/d	6.5	6.8	0.3240	0.4372
Average Rest Time, minutes	289.9	267.0	10.8293	0.1391

Table 2. Average cow production and activity measurements by season.

	Winter	**Spring**	**Summer**	**SEM**	**P. Value**
Milk Yield, kg/d	21.2	22.1	21.1	0.7135	<0.0001
Conductivity, mS	9.3	9.6	10.0	0.0801	<0.0001
Average Activity, steps/hr	123.5	129.7	108.7	4.0019	<0.0001
Average Rest Bout times/d	5.7	6.7	7.6	0.2327	<0.0001
Average Rest Time, minutes	280.3	292.9	262.3	7.7712	<0.0001

Table 3. Milk production by breed and season.

	Season	Milk Yield, kg/d	SEM	P. Value
Holstein	Winter	25.1	1.0514	<0.0001
	Spring	24.7	1.0523	<0.0001
	Summer	23.4	1.0513	<0.0001
Jersey	Winter	17.4	0.9673	<0.0001
	Spring	19.5	0.9655	<0.0001
	Summer	18.7	0.9609	<0.0001

Table 4. Conductivity by breed and season.

	Season	Conductivity, mS/cm	SEM	P. Value
Holstein	Winter	9.44	0.1175	<0.0001
	Spring	9.82	0.1176	<0.0001
	Summer	10.11	0.1175	<0.0001
Jersey	Winter	9.20	0.1100	<0.0001
	Spring	9.42	0.1092	<0.0001
	Summer	9.94	0.1078	<0.0001

Table 5. Average activity by breed and season.

	Season	Average Activity, steps/hr	SEM	P. Value
Holstein	Winter	101.65	5.9144	<0.0001
	Spring	105.74	5.9145	<0.0001
	Summer	94.23	5.9134	<0.0001
Jersey	Winter	145.42	5.3967	<0.0001
	Spring	153.56	5.3942	<0.0001
	Summer	123.12	5.3888	<0.0001

Table 6. Average rest bouts by breed and season.

	Season	Average rest bouts, times/d	SEM	P. Value
Holstein	Winter	5.73	0.3428	<0.0001
	Spring	6.33	0.3431	<0.0001
	Summer	7.38	0.3427	<0.0001
Jersey	Winter	5.58	0.3148	<0.0001
	Spring	7.15	0.3144	<0.0001
	Summer	7.79	0.3131	<0.0001

Table 7. Average rest time by breed and season.

	Season	Average rest time, minutes/d	SEM	P. Value
Holstein	Winter	299.59	11.4586	<0.0001
	Spring	305.76	11.4666	<0.0001
	Summer	264.47	11.4550	<0.0001
Jersey	Winter	261.02	10.5235	<0.0001
	Spring	279.98	10.5093	<0.0001
	Summer	260.05	10.4649	<0.0001

Table 8: Environmental averages for each season.

	Winter	Spring	Summer
Temperature, °C	8.5	18.0	25.8
Relative Humidity, %	74.5	70.9	81.3
THI	48.5	63.4	76.3

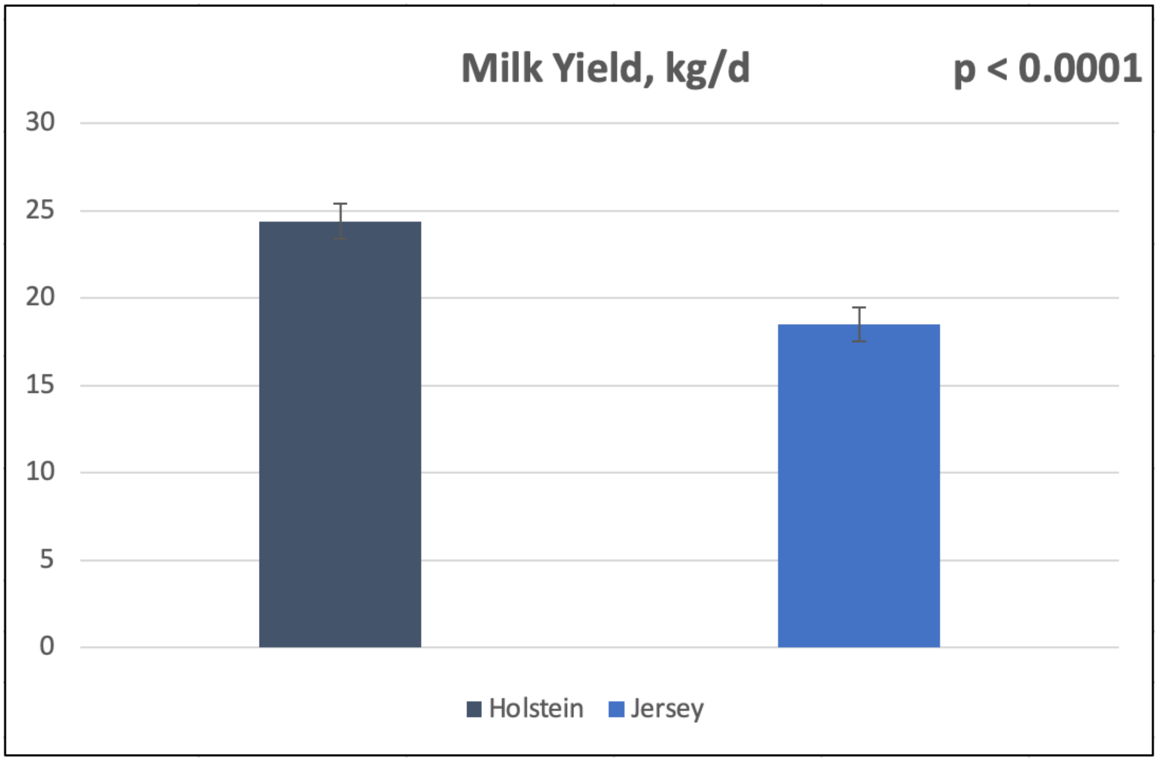

Figure 1. Average daily milk yield by breed.

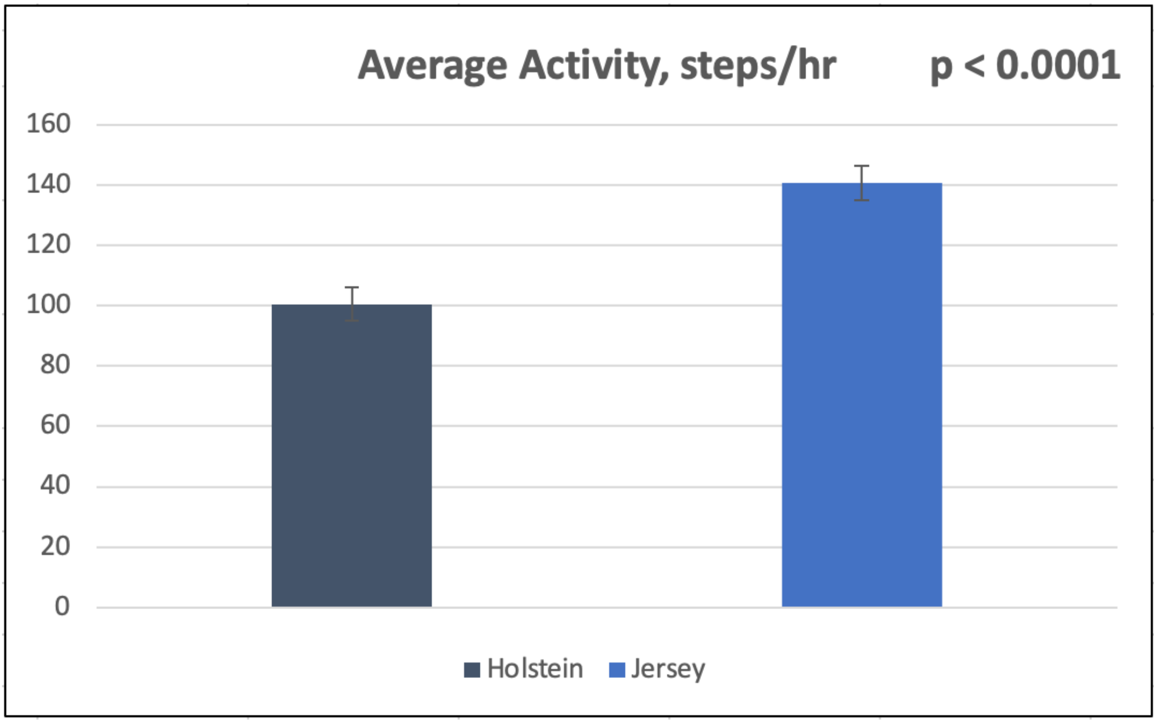

Figure 2. Average activity by breed.

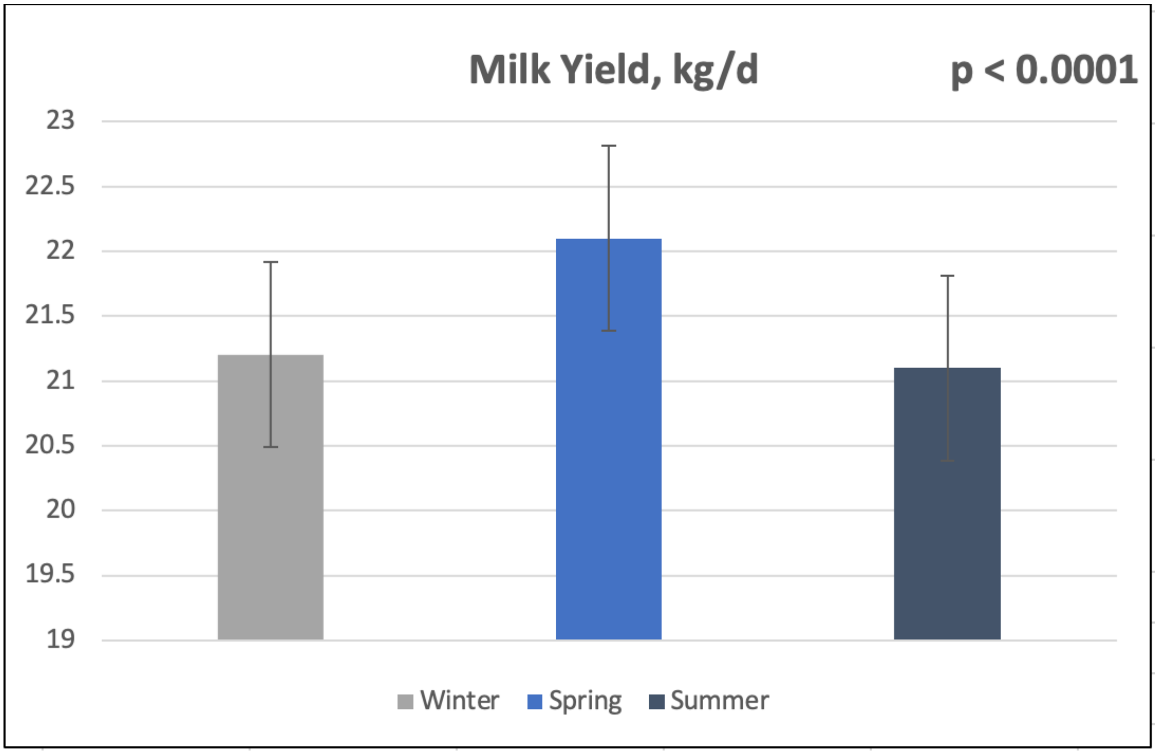

Figure 3. Average daily milk yield by season.

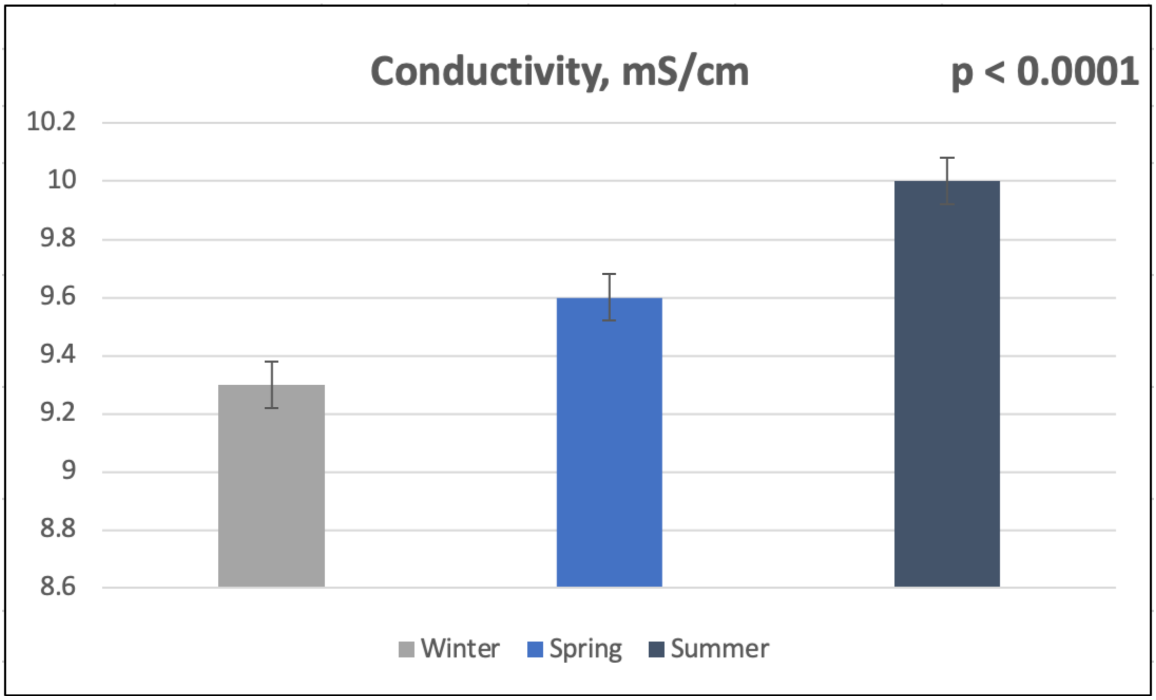

Figure 4. Average milk conductivity by season.

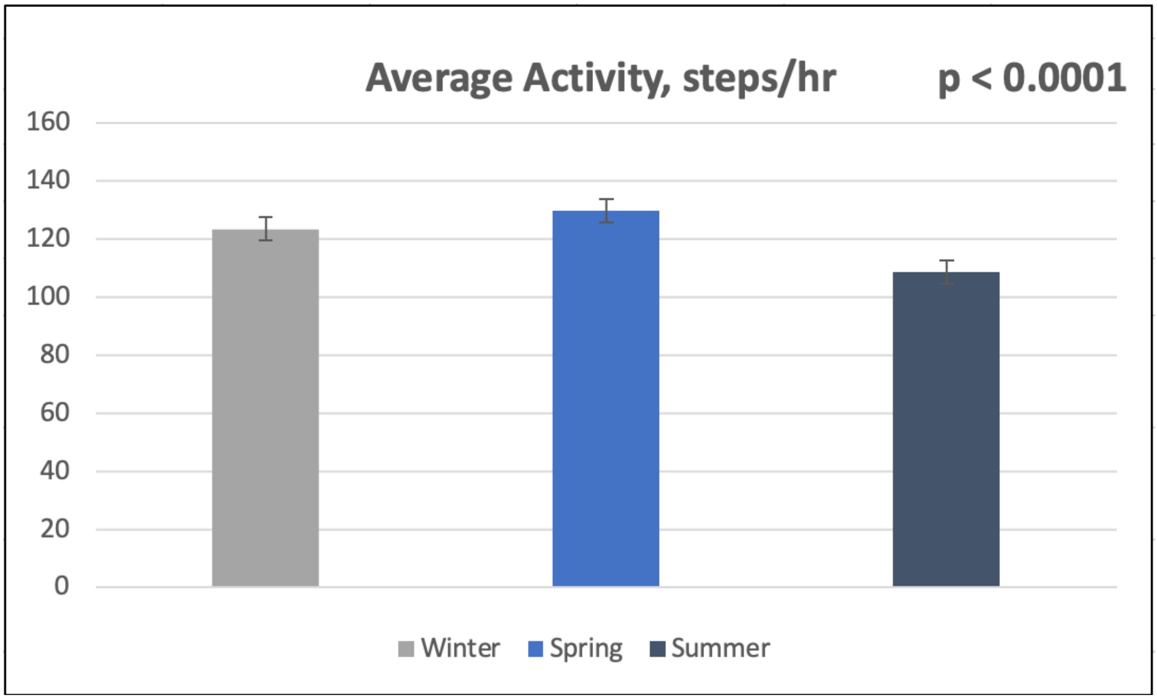

Figure 5: Average activity of all cows by season.

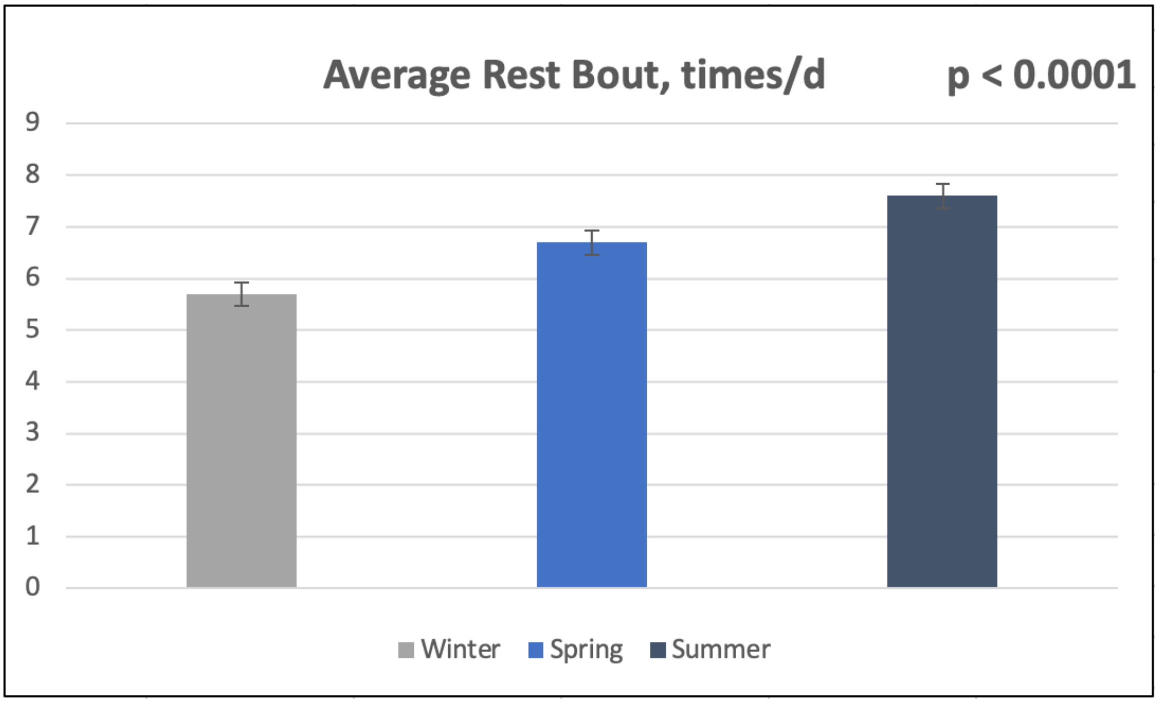

Figure 6: Average rest bout by season of all cows.

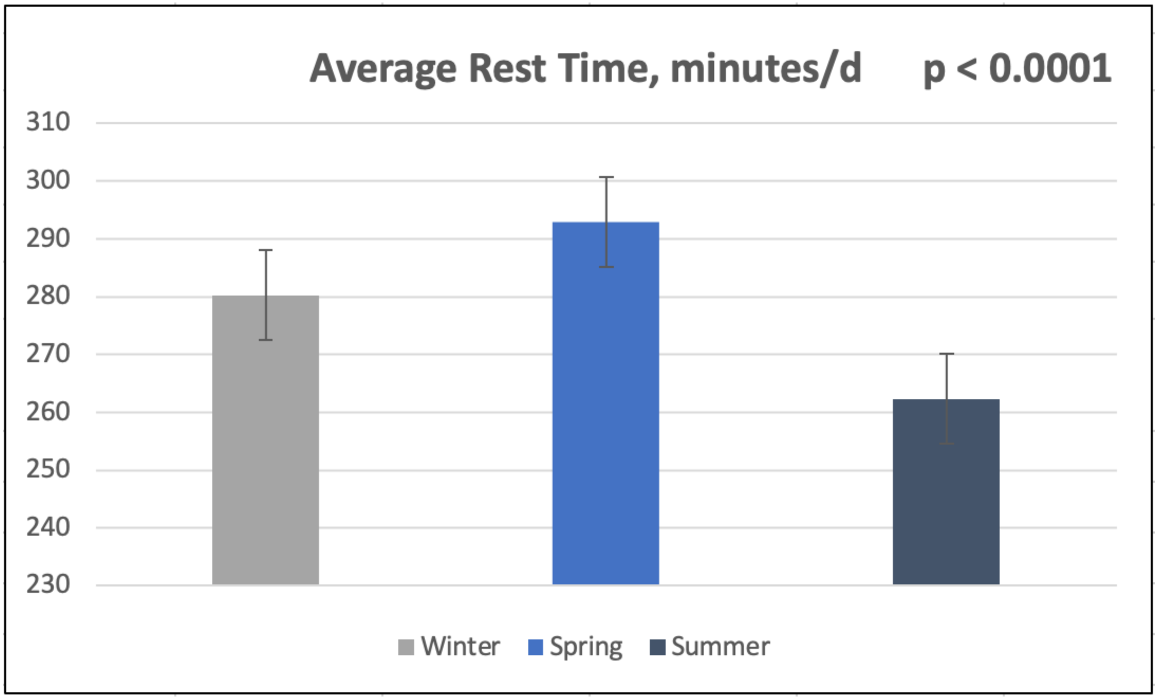

Figure 7. Average rest time by season of all cows.

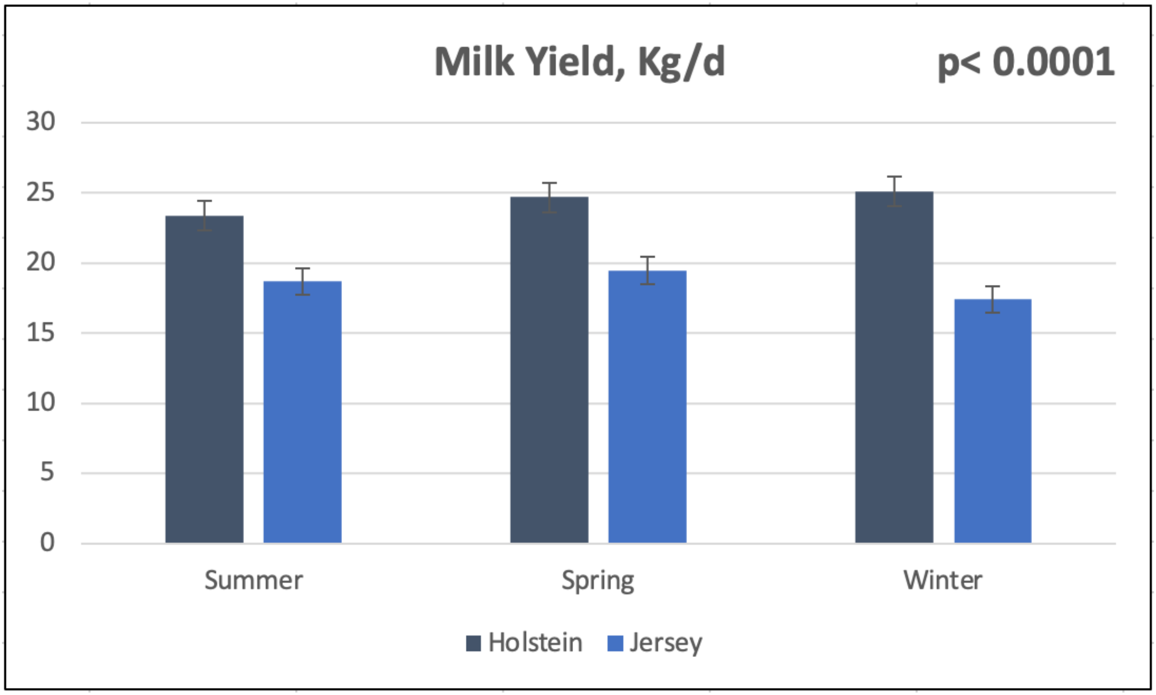

Figure 8. Average daily milk yield by breed for each season.

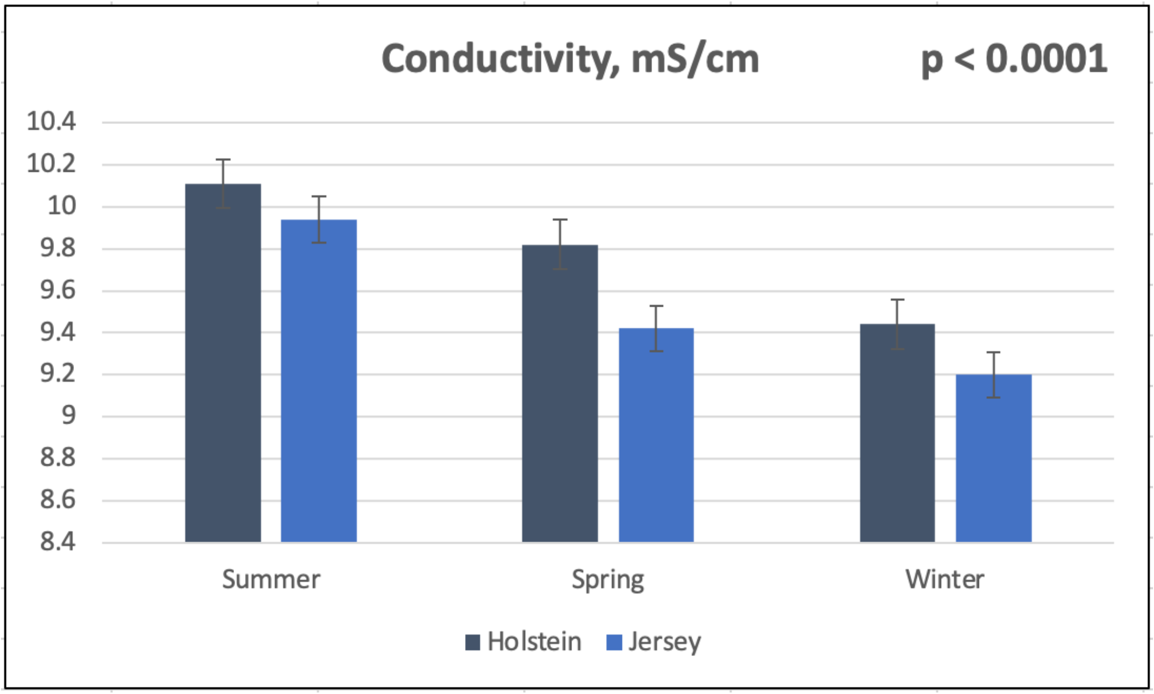

Figure 9. Average milk conductivity for each breed during each season.

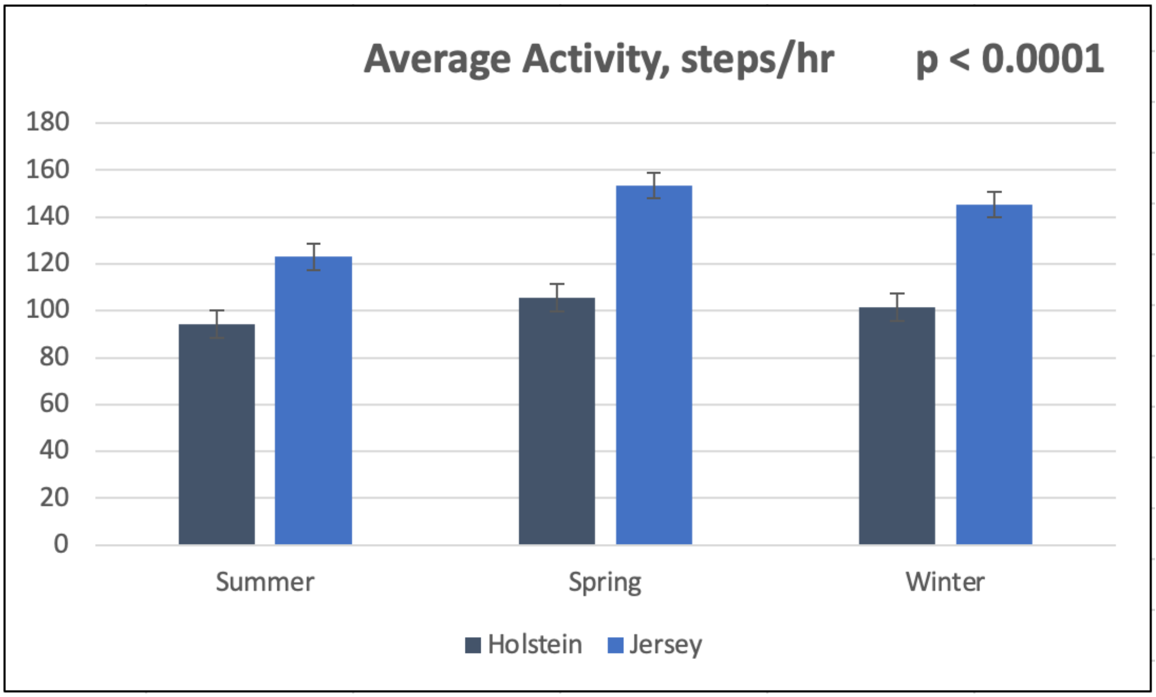

Figure 10. Average activity for each breed during each season.

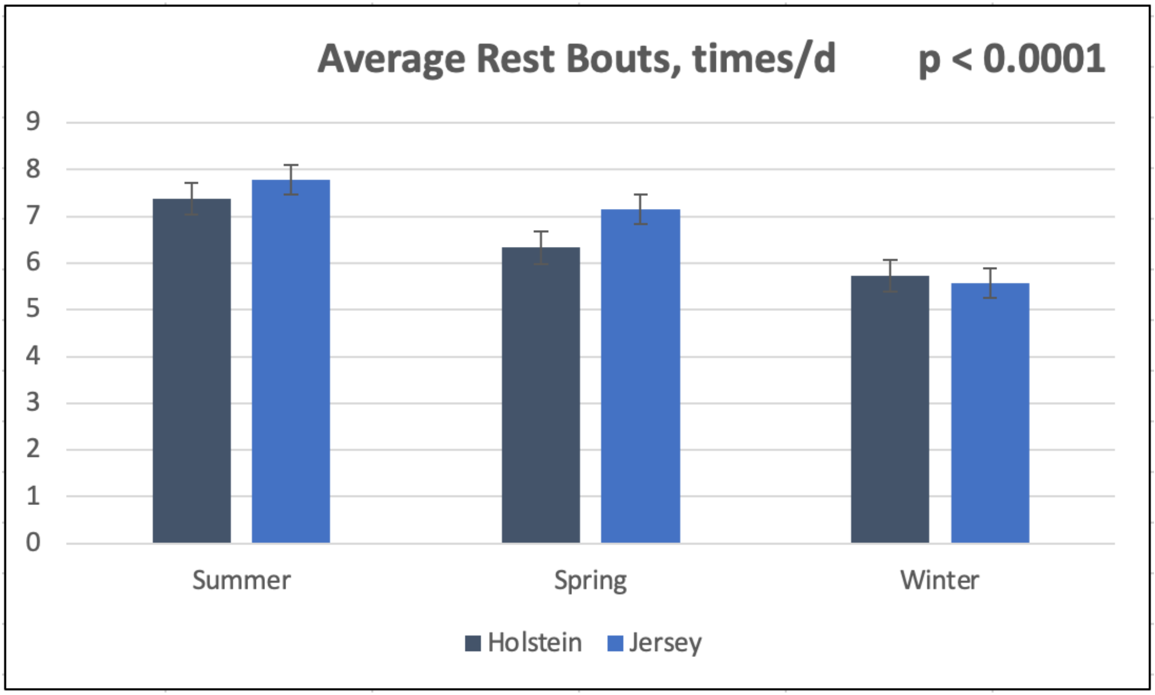

Figure 11. Average rest bouts by breed for each season.

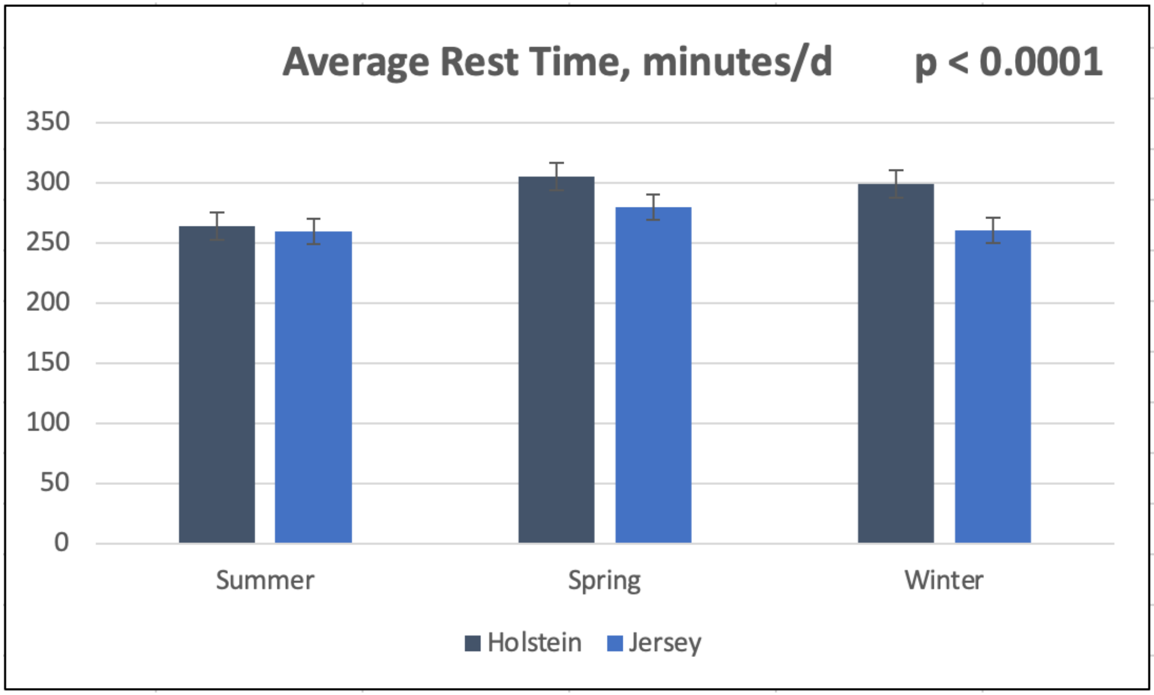

Figure 12. Average rest time by breed for each season.

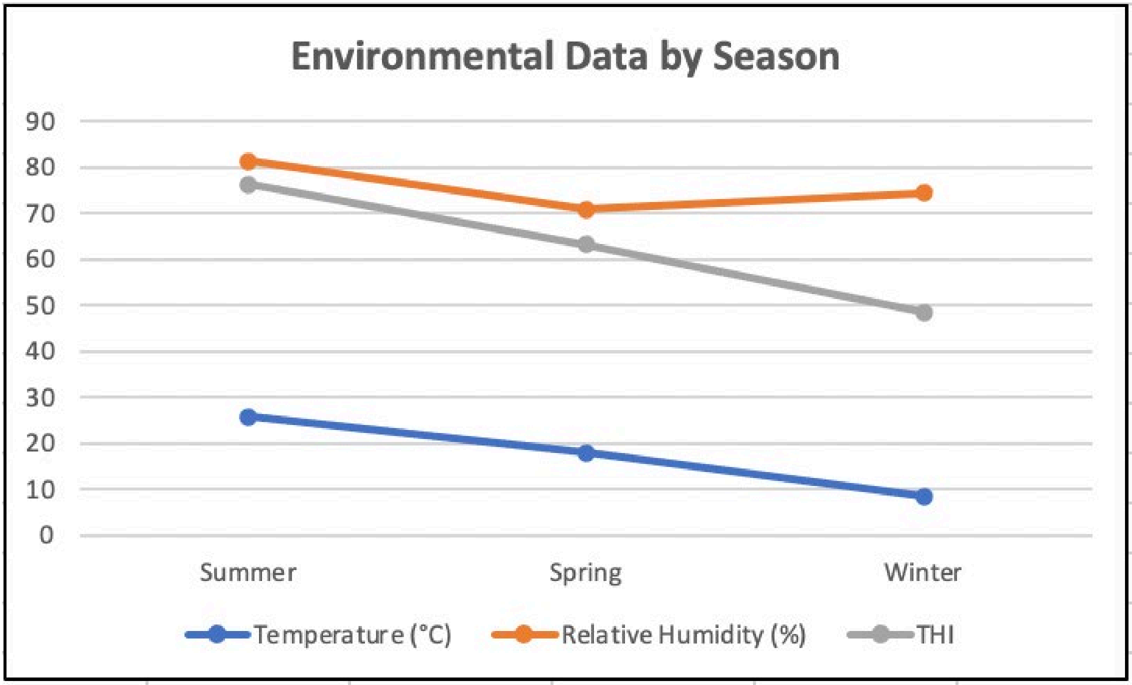

Figure 13. Temperature, relative humidity, and THI data for each season.