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Ambient Temperature, Calf Intakes, and Weight Gains on Preweaned Dairy Calves

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AMBIENT TEMPERATURE, CALF INTAKES, AND WEIGHT GAINS ON PREWEANED DAIRY CALVES

by

Sheldon D. Holt

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ABSTRACT

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There has been little research conducted on the physiological response of calves to temperatures outside thermal neutrality and its effects on intake and weight gain. The effects of ambient temperature on Holstein dairy calves intakes and weight gain were evaluated over a 12-month period. Ambient temperature was monitored using a weather station located 1.3 kilometers from the Utah State University Caine Dairy. Calf health was monitored daily using the University of Wisconsin-Madison School of Veterinary Medicine scoring criteria. Calves were fed whole milk and free choice calf starter. Weight gain, hip height, starter intake, and weather data (temperature, wind speed, relative humidity, precipitation, and barometric pressure) were averaged for 7-day intervals beginning at birth through 13 weeks of age. A regression model was developed including starter intake, milk intake, hip and wither height, calf heath scores, and weather data with weight gain as the dependent variable for each of the 4 seasons of the year. The fall season (September, October, and November) had a negative impact on calf intake and weight gain (averaging 20 pounds (9.1 kilograms) less at 2 months) than other seasons. Calves raised in the winter months also ate significantly more starter, but had the same weight gain as other seasons. Environmental stress factors impact animal welfare and animal productivity, which in turn impacts the economics of the dairy operation and should also be used in determining husbandry practices.

(38 pages)

PUBLIC ABSTRACT

Ambient Temperature, Calf Intakes, and Weight Gains on Preweaned Dairy Calves

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There has been little research conducted on the physiological response of calves to temperatures outside thermal neutrality and its effects on intake and weight gain. The effects of ambient temperature on Holstein dairy calves intakes and weight gain were evaluated over a 12-month period at the Utah State University Caine Dairy.

Ambient temperature was monitored using a weather station located 1.3 kilometers from the dairy. Calf health was monitored daily using the University of Wisconsin-Madison School of Veterinary Medicine scoring criteria. Calves were fed whole milk and free choice calf starter. Weight gain, wither and hip height, starter intake, and weather data (temperature, wind speed, relative humidity, precipitation, and barometric pressure) were averaged for 7-day intervals beginning at birth through 13 weeks of age. A regression model was developed to describe the effects of starter intake, milk intake, hip and wither height, calf heath scores, and weather data on weight gain.

The fall season (September, October, and November) had a negative impact on calf intake and weight gain (averaging 20 pounds (9.1 kilograms) less at 2 months of age) than other seasons. The delay in reaching the desired weight for calves raised in the fall season would cost a producer an extra $57 per calf. Calves raised in the winter months also ate more starter, but had the same weight gain as other seasons. Environmental stress factors impact animal welfare and animal productivity, which in turn impacts the economics of the dairy operation.

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Sheldon D. Holt

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INTRODUCTION

The sustainability of dairy farms in the 21st century is becoming increasingly difficult. It is paramount that dairy producers find the most economical ways to raise animals and produce milk. Methods that may have proven efficient in the past may not be economical in the future. Maximizing profit requires adapting to new methods as the demands of agriculture production, consumer preference and environmental changes become more prevalent.

There is much scientific literature regarding ambient temperature and the effects on animal health. Studies documenting the health effects of ambient temperatures have been conducted on other species such as rodents, swine, poultry, and adult cattle. Research indicates that thermal (heat/cold) stresses have negative impacts on animal productivity.

An important aspect that affects the overall economics and lifetime producing ability of the dairy heifer is the rate of growth from birth to first calving. Diet and rate of growth have a direct effect on age at first calving and productivity per day of herd life (Heinrichs, 1993). Inputs, such as feed, are extremely expensive for calves. Calves are also much more susceptible to illnesses at this stage of life. This is a major investment for producers. Other literature demonstrates that cattle which were sick as calves do not produce as much milk and are culled from the herd early (Heinrichs and Heinrichs, 2011). This study will examine the effects of ambient temperature, seasonal change, feed intake, weight, and overall health on Holstein calves and how these individual aspects affect production costs. There have been many studies on thermo stress on other animals, and extensive research has been done on the effects of thermo stress on dairy cows. There has been very little research studying the effects of thermo stress on dairy calves. Calves are much less tolerant to conditions outside their thermoneutral zone. Due to the lack of information available on dairy calves, a study was implemented to determine the effects of weather conditions on Holstein dairy calf intakes, weight gains, hip and wither height, and heath scores.

LITERATURE REVIEW

Maximizing profitability is a chief concern in the agriculture industry, particularly where a substantial amount of inputs are prerequisite to meeting these objectives. Producing high quality heifers at minimum cost is a major concern facing the dairy industry. Replacement heifers represent a large portion of the total cost to produce milk and, to maintain profitability, dairy farmers will have to meet the replacement needs of their lactating herds at minimum cost (Heinrichs, 1993). Realization of this objective requires optimal overall welfare of the animal to maximize profitability with the least amount of input possible.

Management practices that ultimately affect lifetime productivity and reproductive performance of heifers begin at birth. Body weight should be recorded at day 0 and subsequent growth measures for average daily gain (ADG) taken through 8 weeks of age. Factors during the eight week period that affect growth include total starter intake (SI), total milk replacer intake (MRI), number of days with abnormal fecal scores (AFS), environmental temperature (average, minimum and maximum temperatures) and preweaning/postweaning weight (Bateman et al., 2012).

Calves should be weaned based on weight not age. Calves weaned at a lighter weight tend to have decreased total lifetime productivity. A predetermined weaning weight with a gradual weaning program is recommended. Gradually weaning a calf will minimize its stress level, leaving it less likely to get sick (Khan et al., 2011). Future productivity is heavily affected by proper nutrition and health beginning at birth and continuing through puberty. An important aspect that affects the overall economics and lifetime producing ability of the dairy heifer is the rate of growth from birth to first calving. Diet and rate of growth have a direct effect on age at first calving and productivity per day of herd life (Heinrichs, 1993; Heinrichs and Heinrich, 2011).

Most strategies for health calf management practices are based on the underlying assumption that calves begin life with inadequate passive immunity (Quigley, 2002). Calf raisers have turned to supplementing the immunity until the calf is strong enough to be protected from pathogens in the environment. Strengthening calves' immunity begins by giving the animal colostrum right after birth. This also is instrumental in preventing scours. It is estimated that approximately 15 to 20% of calves on dairy farms in the Northeastern U.S. get scours and this is the primary cause of death for one-half of all preweaned calves that die in the US (Quigley, 2002).

Generally, calves are kept in individual hutches and bottle fed twice daily. Although labor intensive, this minimizes the spread of disease by limiting contact and signs of sickness are more readily recognized. This method allows for the lowest morbidity and mortality rates.

Twice daily feeding of milk is the norm and usually results in underfeeding calves as a method to force increased starter intake. The purpose of calf starter is to transition the calf from the milk-feeding period to the dry feeding period. Calf starter must be palatable and nutritious and should be offered around day 5 after birth. Calves should remain on calf starter until they achieve 70-80 kg (155-175 lb) (Lang, 2010).

Water is the most essential and cheapest ingredient in any livestock feeding operation. A 180 kg calf will require from 10–30 liters of water daily, depending on factors like temperature, humidity and the dry matter content of the diet (Lang, 2010).

Research by Kertz et al. (1984) found that weight gain between birth and four weeks of age was reduced by 38% and starter intake by 31% for calves that did not receive supplemental water in addition to their milk replacer. To achieve maximum gains, calf raisers should provide an adequate supply of clean, easily accessible water.

Environmental Factors Affecting Growth

Feeding milk or milk replacers to young calves often means feeding them for limited amounts of energy and protein to stimulate rumen development and allow early weaning. When the weather gets too cold or too hot, animals must use energy to maintain their core body temperature. This energy detracts from growth and may have a negative effect on efficiency and even health.

The thermal environment is used to describe climatic factor affecting animal production, especially when described in terms of effective ambient temperature, (i.e., a combination of air temperature, radiation, wind, precipitation, and humidity). Seasonal variations and differences in geographical area and management systems all lead to variability in thermal environment (Ames, 1980).

Previous studies have demonstrated that animals have a range of ambient environmental temperatures in which changes in ambient temperature do not cause a change in metabolism, termed the thermoneutral zone (TNZ). This is also defined as the range of temperatures that are conducive to health and performance (Chase, 2004). All homoeothermic animals maintain a constant internal body temperature within strict limits regardless of the external environment. The TNZ of a calf less than one month old is between 50°F and 78°F (10.0°C and 26.6°C) , and any temperatures higher or lower causes a calf to spend extra energy to keep warm or cool rather than putting that energy towards growth. For a calf over 1 month old, the TNZ range is 32°F to 78°F (0.0°C and 26.6°C). Although the concept of thermoneutrality may have different meanings, the relationship between animals and the thermal environment begins with the TNZ (Ames, 1980). These critical temperatures are dependent on age, breed, body weight, thermal insulation, nutrition, time after feeding, behavior, housing, wetness of hair coat, and extent of solar radiation (Berman et al., 1985; Igono et al., 1992).

When confronted with wide differences in effective ambient temperature, livestock compensate by altering energy intake, energy loss, or energy stored. They change rates of performance such as growth rate and reproduction or milk production. A basic understanding of the relationship between animals and their thermal environment is necessary to assess the environments impact on livestock performance (Ames, 1980).

Exposure of dairy cows to ambient temperatures above the TNZ has an adverse effect on performance (Collier et al., 1982b) and is referred to as heat stress. The term heat stress is used widely and rather loosely, and may refer to climatic conditions, climatic effects on the cow, or productive or physiologic responses by the cow. Lee (1965) presented a definition of stress often used by physiologists, in which stress denotes the magnitude of forces external to the bodily system which tend to displace that system from its resting or ground state, and strain is the internal displacement from the resting or ground state brought about by the application of stress.

Heat stress indices range from simple measurement of air temperature to those that try to provide a weighted estimation of factors (Bond and Kelly, 1955), such as high ambient temperatures, high direct and indirect solar radiation, wind speed and humidity (Finch, 1984).

There is much knowledge regarding the interaction between heat stress and livestock productivity under intensive and extensive management systems in mature dairy cows. Heat is a major constraint on animal productivity (Silanikove, 1992) and has shown negative impacts on growth, milk production and reproduction as a result of changes in biological functions (Habeeb et al., 1992; Silankove, 1992). Neurons that are temperature sensitive are located throughout the animal's body and send information to the hypothalamus, which invokes numerous physiological, anatomical or behavioral changes in the attempt to maintain heat balance (Curtis, 1983). During heat stress, cows exhibit reduced feed intake, decreased activity, increased respiratory rate, and increased peripheral blood flow and sweating. "Reduced dietary intake occurs when heat stress causes the rostral cooling center of the hypothalamus to stimulate the medial satiety center which inhibits the lateral appetite center, consequently resulting in lower milk production" (Albright and Alliston, 1972).

Additional negative impacts are accounted for when considering energy expenditure. Heat production of metabolic functions accounts for approximately 31% of intake energy by a 600 kg cow producing 40 kg of milk containing 4% of fat (Coppock, 1985). Physical activity increases the amount of heat produced by skeletal muscles and body tissues. Maintenance expenditures at 95 °F (35 °C) increase by 20% over thermoneutral conditions (NRC, 1981), thus increasing the cows energy expenditure, often at the expense of milk yield. These responses have a deleterious effect on both production and physiologic status of the cow (West, 2003).

Cold stress, ambient temperature below the lower critical level of the TNZ, has negative impacts on dairy animals' welfare, thus affecting profitability by adding additional costs. This is especially true when considering calves in contrast to mature cattle. Cold and fluctuating air temperatures, plus excessive wind and/or humidity, are common weather related cold stressors and may contribute to reduced survival of newborn calves. This is in large part because calves have less body insulation and increased body surface and body mass ratios (Constable et al., 1999).

Additionally, newborn calves are more susceptible to the effects of cold exposure because their thermal defense and heat conservation mechanisms are not fully developed (Olson et al., 1980), making it increasingly vital that calves stay in the thermoneutral range. For neonatal dairy and beef calves, the lower critical temperature is generally accepted to be 50 °F (10 °C). The lower critical temperature decreases with age, from 10 °C in neonatal calves, to 8 °C in 3-week-old calves, 0 °C in 1-month-old calves, and -14 °C in 3-month-old veal calves. Factors that enhance excessive loss of body heat by calves include a relatively high ratio of body surface to body mass, thin skin, small quantity of subcutaneous fat, poor cutaneous vascular control and evaporative heat loss from the wet skin at birth (Olson et al., 1980).

Calves born in the late winter and early spring often experience sustained periods of cold during the first weeks of life. A recent study by Godden et al. (2005) documented the negative effects of winter calving on dairy calf health. Of the 438 calves evaluated, the morbidity rate of calves born in the winter was 52% compared with 13% for calves born in the summer. Similarly, calf mortality was 21% in the winter and 3% in the summer. Several studies suggest that reduced temperature alone is not the sole contributor to increased morbidity and mortality during winter calving, but that nutrition also plays a major role.

Nutrition is a determinant of the immune function, with protein-energy balance influencing cell-mediated immunity, cytokine production, complement system, phagocytic function, and antibody concentrations (Woodward, 1998; Nonnecke et al., 2009). Cold environment calves consumed more starter than warm environment calves, suggesting that the extra energy associated with increased starter intake was necessary for calves to maintain a growth rate comparable to that of the warm environment calves (Nonnecke et al., 2009).

The increased thermal demand imposed by a cold environment likely requires increased metabolic heat production. In a thermoneutral environment, the calf is not required to elicit specific heat-conserving or heat-dissipating mechanisms to maintain core body temperature (NRC, 2001; Nonnecke et al., 2009). Ensuring nutritional sufficiency during periods of cold stress may be difficult in the preruminant calf because maintenance requirements for thermoregulation are increased (Drackley, 2005; Nonnecke et al., 2009).

Mitigating Heat/Cold Stress

The ability to regulate temperature is an evolutionary adaptation that allows homeotherms to function in spite of variation in ambient temperature (Baker, 1989). The internal readjustment to maintain homeostasis in the face of external temperature changes is an adaption to the thermal environment (Finch, 1984). Methods used to mitigate environmental challenges focus on heat loss/heat production balance. Under cold stress, reduction of heat loss is key. Under heat stress, reductions of heat load or increased heat loss are the primary management tools, although heat-tolerant animals are also available (Brown-Brandl et al., 2005).

Movement of heat from the body can be accomplished by convection, radiation, evaporation of water, and expired air. Heat loss from the animal is enhanced by sweating, panting, a cooler environment, increased skin circulation (vasodilatation), shorter fur, increased water loss, increased radiating surface, and increased air movement or convection (Silanikove, 2000). Additionally, non-evaporative heat loss declines as ambient temperatures rise, making the animal more dependent upon peripheral vasodilatation and water evaporation to enhance heat loss and prevent a rise in body temperature (Berman et al., 1985). However, peripheral vasodilation is unlikely to be a major method of increasing heat dissipation in cattle because of their large body mass (Silanikove, 2000).

When water is converted from liquid to gas (evaporation), there is a loss of energy from the body. The evaporation of sweat from the body constitutes a powerful mechanism for eliminating heat. At high environmental temperatures, evaporation becomes the primary mode of heat dissipation. However, the rate of evaporation depends on the humidity in the air. Humid environments depress the rate of evaporation and make hot temperatures seem even hotter. Evaporation occurs not only through evaporation of water on the body surface (sweat) but also through respiration. In very hot climates, animals will pant to increase evaporative loss of heat (Quigley, 2001). Respiration rate is often measured as an indicator of thermal state in cattle; 20 breaths/min indicates a cool condition near the lower critical temperature and 80 breaths/min indicates a heat stress condition (Mount, 1979). Increased respiration rate or panting by cows, although not as effective as sweating for evaporative cooling, is needed to maintain homeothermy during exposure to increased heat load (Ingram and Mount, 1975; Mount, 1979).

An animal's tolerance to heat and cold is in part determined by its' surface area. Calves have a much larger surface area per unit of body weight than mature cows. Therefore, heat loss by convection and conduction are much more important to calves than cows. The surface area of an animal is a function of the animal's height and width.

Though several combinations of temperature, relative humidity, and radiant energy impact heat load in the cow, it is apparent that given sufficient night cooling, cows can tolerate relatively high daytime air temperatures. Igono et al. (1992) reported that despite high ambient temperatures during the day a cool period of less than 21 ^{o}C for 3 to 6 hours will minimize the decline in milk yield. In the northern hemisphere, the most severe heat stress is expected during the months of July and August, because the night time temperature probably does not drop below 21 °C, and the capacity to completely dissipate heat gained during the preceding day is severely hampered.

In addition to biological and environmental factors that contribute to the dissipation of heat, housing is vital. Metal roof structures, shades, sprinklers, and fans have been used to reduce the thermal load of cattle during periods of elevated ambient temperatures (Givens, 1965; Singh and Newton, 1978; Stott et al., 1976; Turner et al., 1992). At elevated ambient temperatures, calves housed under corrugated metal shade, with or without cooled air, had lower serum corticosteroids and higher immune status than did calves housed in uncovered hutches (Stott el al., 1976). According to Bond and Kelly (1955) and Muller et al. (1994), a well-designed shade structure should reduce total heat load by 30-50%. The beneficial effects of providing shade to cattle and sheep, in terms of thermoregulatory and productive responses, have been demonstrated on numerous occasions (Roman-Ponce et al., 1977; Collier et al., 1981; Roberts, 1984; Legates et al., 1991; Muller et al., 1994). The beneficial effects of providing shade shelter to cattle and sheep in improving their reproductive performance are also well established (Stott et al., 1972; Stephenson et al., 1984).

Reduction of ambient temperature through the use of shade also positively benefits calves. Increased ambient temperatures during the day will increase heating of the outer surface of the calf hutch by solar radiation. Calves maintained in hutches exposed to direct sunlight would receive an additional radiant heat load over that received in the shaded environment. Placement of the hutch in a shaded environment significantly reduced heat load. The magnitude of this reduction or improvement increased as air temperature increased and was especially beneficial during p.m. periods of heat stress (Spain and Spiers, 1995). The use of shade over calf hutches decreased the rise in hutch temperature, ameliorates heat stress and improves the thermal status of the calf (Spain and Spiers, 1995).

Studies have shown that cows that suffer from heat stress have depressed milk yields and lower calf birth weights (Collier et al., 1982a). No literature was found on the effects of heat stress on calf growth. In general, livestock with health problems and the most productive animals (e.g., highest growth rate or milk production) are at greatest risk of heat stress, thereby requiring the most attention (Brown-Brandl et al., 2005). Considering perceived thermal challenges, then assessing the potential consequences and acting accordingly, will reduce their impact.

The objective of this study was to examine the effects of ambient temperature, seasonal change, feed intake, and overall health on weight, and wither and hip height of Holstein calves and how these aspects affect production costs.

MATERIALS AND METHODS

Animals used for this study were housed at the George B. Caine Dairy Teaching and Research Center at Utah State University. Animal-related procedures were implemented following institutional guidelines for animal care and use, and normal husbandry practices for new born calves were followed (i.e. colostrum, navel treatment, etc.) Holstein heifer calves (n = 100) entered the study within the first 48 h of birth, and were placed in a hutch with a small exercise pen in front. Calves remained on the study until they were weaned. The study ran from April 2011 to February 2012.

The calves were fed twice daily at 0500 and 1700 h. Normal farm protocol was to feed all calves whole milk at the rate of 4 qts from June thru September and 6 qts during the remainder of the year. At 1 wk of age, calves were offered free choice calf starter (18% CP). The calves were allowed ad libitum starter intake up to a maximum of 3.18 kg (7 lb/d). Grain refusal was collected and recorded during each feeding to monitor individual grain intake every 12 h. Calves were weighed and hip and wither heights measured weekly. During the evening feeding, scores were given to determine the overall health of the animal. The calf health scoring was determined using the scoring criteria developed at the University Of Wisconsin School Of Veterinary Medicine University Scoring Criteria (http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_health_scoring_chart.pdf)

Weather data were collected from a weather station maintained by the USU Climate Center located 1.3 km north of the calf hutches. Hourly data was summarized into two periods: 2200 to 0959 h (AM period) and 1000 to 2159 h (PM period) to determine effects of day compared with night.

Because the normal management protocol for the dairy was to feed 4 qts milk during warmer months of the year and 6 qts during the colder months, a small trial was run as a subset of the main trial from September 27, 2011 until December 21, 2011. Calves were alternately selected, as they were born, to receive either 4 qts milk daily or 6 qts. All other management procedures remained the same.

Days since birth were categorized into 7-d intervals beginning at birth, then least squares means were computed for all variables across the whole study and then by the season of year using the Mixed Models function of SAS (version 9.3, SAS Institute Inc., Cary, NC). Seasons were defined as: Winter (December, January, and February), Spring (March, April, and May), Summer (June, July, and August), and Fall (September, October, and November). Differences between means, within variables, were determined using Tukey's means comparison and considered significantly different at $P < 0.05$.

Statistical models were developed to determine the relationship of weight gain (dependent variable) with the independent variables of feed intake, health scores and environmental factors. Models were analyzed by multiple linear regressions using the EViews statistical program (IHS EViews, Irvine, CA) to establish correlation coefficients between all independent and dependent variables. Nonsignificant variables were removed until the final model was achieved and the data set was tested for normality. The final model used to predict calf weight is as follows:

$Y = \beta_0 + \beta_1$ Intake_AM + β_2 Intake_PM + β_3 Hip height + β_4 Precipitation_AM + β_5 Precipitation_PM + β_6 RH_AM + β_7 RH_PM + β_8 Score + β_9 Temp_AM + β_{10} Temp_PM + β_{11} Wind_AM + β_{12} Wind_PM + β_{13} Wither + β_{14} Barometer_am + β_{15} Barometer_pm + β_{16} Days_Since_Birth + β_{17} Milk. Interactions were run for both models, but had such a small effect they were not included in the final prediction models. The final R-squared for the model was 0.94.

RESULTS AND DISCUSSION

Least squares means (SEM) for calf weight by 7-d periods (weeks of age) and season of year are shown in Table 1. There were 4 calves during the study that were outliers due to illness, very small at birth, would not eat grain, or a combination of these factors. These calves were left in all calculations and partially explain the increased SEM as calves get older. The least squares mean weight for the first week, for all animals in the study, was 92 lb (41.7 kg). In the first few weeks of age, calf weights were not significantly different as a function of season. By week 3, as calves began to consume calf starter, weights began to differ significantly. Calves raised during the fall months had the lowest weights for the entire study. Calves raised during the spring, summer and winter months were similar in weight, but calves raised during the spring and winter months weighed more from week 9-13.

Table 1. Least squares means (SEM) for body weight for calves by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February).

Period	Spring	Summer	Fall	Winter	Overall
1	93.1 (2.42)[a]	90.1 (1.71)[a]	93.3 (2.34)[a]	93.7 (3.01)[a]	92.0 (0.70)
2	99.0 (1.85)[a]	98.3 (1.39)[a]	94.4 (1.73)[a]	97.1 (1.65)[a]	97.3 (0.47)
3	106.9 (1.85)[a,b]	107.0 (1.36)[b]	98.2 (1.50)[a]	104.4 (1.67)[a,b]	104.0 (0.49)
4	118.7 (1.84)[b]	116.2 (1.33)[b]	105.5 (1.47)[a]	114.9 (1.52)[b]	113.5 (0.51)
5	132.8 (1.74)[b]	124.8 (1.34)[b]	115.7 (1.48)[a]	125.6 (1.48)[b]	124.2 (0.56)
6	142.8 (1.68)[b]	136.3 (1.48)[b]	126.1 (1.44)[a]	139.2 (1.46)[b]	135.6 (0.62)
7	155.9 (1.68)[b]	149.9 (1.63)[b]	137.5 (1.37)[a]	154.9 (1.52)[b]	148.5 (0.71)
8	172.3 (1.65)[b]	162.8 (1.80)[b]	150.6 (1.29)[a]	170.9 (1.50)[b]	162.7 (0.81)
9	189.2 (1.64)[c]	175.8 (1.87)[b]	164.2 (1.26)[a]	187.1 (1.49)[c]	177.4 (0.93)
10	207.4 (1.70)[c]	194.4 (1.84)[b]	178.9 (1.27)[a]	202.4 (1.54)[b,c]	193.4 (1.03)
11	225.7 (1.90)[b]	218.2 (1.88)[b]	195.9 (1.26)[a]	216.2 (1.52)[b]	210.3 (1.14)
12	242.1 (2.02)[b]	243.5 (1.91)[b]	206.3 (1.35)[a]	231.9 (1.54)	226.3 (1.35)
13	258.0 (2.08)[b,c]	267.5 (2.08)[b]	215.9 (1.46)[a]	250.3 (1.76)[c]	242.1 (1.67)

[a,b,c] $P \leq 0.05$, different superscripts significant within row

Least squares means for wither height are shown in Table 2 and least squares means for hip height are shown in Table 3. The least squares mean results for wither and hip height are very similar, but hip height is more accurate. Therefore, hip height was the factor used to quantify the animal's height growth.

For the first 3 wk, there was no statistical difference in height at the 5% level of significance, but at the 10% level of significance, spring was statistically different only from fall. Throughout all weeks, except the last, fall and winter were not statistically different. Winter and summer were only statistically different on weeks 12 and 13 with summer being statistically higher than winter. Summer was statistically higher than fall on weeks 4, 5, 7, 12, and 13. Spring was statistically higher than fall and winter week's 3-13. Spring was statistically higher than fall on weeks 5 and 7. Numerically, spring generally had the highest hip heights, fall had the lowest, and summer and winter were

Table 2. Least squares means (SEM) for wither height (inch) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February).

Period	Spring	Summer	Fall	Winter	Overall
1	30.8 (0.16)	30.1 (0.11)	30.4 (0.16)	30.9 (0.19)	30.4 (0.07)
2	31.1 (0.12)	30.9 (0.09)	30.7 (0.11)	30.8 (0.10)	30.8 (0.05)
3	31.6 (0.12)	31.6 (0.09)	31.2 (0.10)	31.1 (0.11)	31.4 (0.05)
4	32.6 (0.12)	32.0 (0.08)	31.5 (0.09)	31.7 (0.10)	31.9 (0.05)
5	33.5 (0.11)	32.5 (0.08)	32.0 (0.09)	32.4 (0.09)	32.5 (0.05)
6	34.0 (0.11)	33.1 (0.09)	32.7 (0.09)	32.9 (0.09)	33.1 (0.05)
7	34.7 (0.11)	33.9 (0.10)	33.2 (0.09)	33.5 (0.10)	33.8 (0.05)
8	35.2 (0.10)	34.7 (0.11)	33.8 (0.08)	34.3 (0.09)	34.4 (0.05)
9	35.7 (0.10)	35.0 (0.12)	34.7 (0.08)	35.0 (0.09)	35.0 (0.05)
10	36.4 (0.11)	35.5 (0.12)	35.3 (0.08)	35.7 (0.10)	35.6 (0.05)
11	36.9 (0.12)	36.4 (0.12)	35.8 (0.08)	36.1 (0.10)	36.2 (0.05)
12	37.4 (0.13)	37.8 (0.12)	36.4 (0.08)	36.6 (0.10)	36.9 (0.06)
13	38.1 (0.13)	38.6 (0.13)	36.9 (0.09)	37.3 (0.11)	37.5 (0.07)

^{a,b,c} $P \leq 0.05$ within row
^{A,B,C} $P \leq 0.10$ within row

Table 3. Least squares means (SEM) for hip height (inch) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February).

Period	Spring	Summer	Fall	Winter	Overall
1	32.8 (0.17)[a]	32.2 (0.11)[a]	32.3 (0.16)[a]	33.0 (0.19)[a]	32.5 (0.07)
2	33.0 (0.12)[a]	32.9 (0.09)[a]	32.6 (0.12)[a]	32.9 (0.11)[a]	32.9 (0.05)
3	33.8 (0.12)	33.6 (0.09)[a,b]	33.1 (0.10)[a]	33.3 (0.11)[a,b]	33.4 (0.05)
4	34.7 (0.12)[c]	34.2 (0.09)[b,c]	33.5 (0.10)[a]	33.9 (0.10)[a,b]	34.0 (0.05)
5	35.4 (0.11)[c]	34.6 (0.09)[b]	34.1 (0.10)[a]	34.6 (0.10)[a,b]	34.6 (0.05)
6	36.3 (0.11)[b]	35.4 (0.10)[a]	34.9 (0.09)[a]	35.2 (0.09)[a]	35.4 (0.05)
7	37.1 (0.11)[c]	36.1 (0.11)[b]	35.5 (0.09)[a]	35.9 (0.10)[a,b]	36.1 (0.05)
8	37.6 (0.11)[b]	36.6 (0.12)[a]	36.2 (0.08)[a]	36.6 (0.10)[a]	36.7 (0.05)
9	38.3 (0.11)[b]	37.2 (0.12)[a]	37.0 (0.08)[a]	37.4 (0.10)[a]	37.4 (0.06)
10	39.0 (0.11)[b]	37.9 (0.12)[a]	37.6 (0.08)[a]	38.1 (0.10)[a]	38.1 (0.06)
11	39.4 (0.12)[b]	38.8 (0.12)[a]	38.4 (0.08)[a]	38.6 (0.10)[a]	38.7 (0.06)
12	40.2 (0.13)[b]	40.2 (0.12)[b]	38.9 (0.09)[a]	39.3 (0.10)[a]	39.5 (0.06)
13	40.9 (0.13)[c]	41.4 (0.13)[b,c]	39.3 (0.09)[a]	40.0 (0.11)[d]	40.2 (0.07)

[a,b,c] $P \leq 0.05$ within row

similar.

Least squares means for starter intakes are shown in Table 4. The means are for AM and PM intake by season of year over the whole study. The first 4 weekly periods are not statistically different when comparing AM intakes across all seasons, but in week 5 and 6, spring had significantly lower intakes than fall. For all other weeks spring and fall are not statistically different. Summer and spring were not statistically different other than weeks 10 and 11 in which summer was significantly lower. Spring and summer were statistically the same for all weeks other than week 10, and summer was significantly lower. Fall, winter, and summer, are not significantly different, and winter, spring, and summer, are not significantly different. At week 6, spring intakes were significantly lower than fall and winter, but intakes were statistically the same as summer. At week 7, winter was statistically higher than spring and summer, but not statistically different from fall. At weeks 8 and 9, winter had significantly higher intakes in the AM period then spring, summer, and fall which are not significantly different from each other. During the summer, week 10 was significantly lower than all other seasons. Winter was significantly higher than fall and summer, but not different from spring. Spring and fall were not different. During the winter, week 11 was significantly higher than summer, but not different from fall and spring. At week 12, winter was significantly higher than fall. Week 13 winter was higher than summer and fall but not different from spring.

PM intakes for weeks 1 thru 7 were statistically the same across all seasons. In week 8, fall was significantly lower than winter and summer. Summer and spring were not different and summer and winter were not different, but winter intakes were larger than spring. Week 9 fall, summer, and spring were statistically the same, but winter intakes were significantly higher than all other seasons. Week 10 of summer was not significantly different from all of the seasons, but winter and spring were significantly higher than fall. Week 11 thru 13 of fall was significantly lower than all other season, and summer spring and winter were not different from each other. Numerically, AM intakes in the winter, fall and spring were either equal to or higher than the PM intakes for the same period. Summer had the opposite effect with AM intakes equal to, or lower than, the PM intakes; due to increased heat in the PM period during the summer season. The calves ate later in the day after the temperature had decreased. All other seasons, calves were not exposed to such high temperatures resulting in higher consumption during the daylight hours. In the winter months cold temperatures dropped below the TNZ and calves tended to consume more in the day when the ambient temperature was "warmer" and they were not exposed to as much cold stress. Numerically, calves had the highest intakes during the winter season; intakes from week 7 on were numerically higher than the other seasons. Total intake from weeks 1 thru 3 for all seasons was similar. Weeks 4 through 6 in winter and fall had the highest intakes. Intakes for week 6 in summer, spring, and fall were all similar and winter had the highest total intakes from week 6 throughout the rest of the study.

Calves that were raised during the winter months consumed more calf starter than calves born in any other months. Increased intake during the winter months can be contributed to the need for more caloric intake to maintain body temperature and growth rate comparable to animals that were raised in warmer months. The cold-environment calves required increased metabolic heat production to compensate for the increased thermal demand imposed by the cold environment. On average for the entire trial, calves consumed slightly more in the AM period.

As a management guide, it has been suggested that the weaning criteria for calves should be when a calf has doubled its birth weight (i.e. 184 lb (83.5 kg) in our study) and consuming at least three lb of grain for three consecutive days (www.calfandheifer.org). On average, calves in this study doubled their birth weight and were ready to be weaned by 63 d of age, which is similar to normal weaning age on dairies in the U.S. The body weight leveled off after daily starter intake reached maximum amount offered. The calves were kept on the trial for an average of 91 d, exceeding the weaning requirements based on general industry standards, and requiring more caloric intake than was offered. Their weight gains slowed until they eventually reached a plateau due to the restricted starter intake

Least squares means for temperature (^{o}C) by period (week of age), season of year, and AM and PM daily time periods within season are shown in Table 5. Differences

Table 4. Least squares means (SEM) for total concentrate intake (lb) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February). Diurnal periods were defined by averaging intake by “AM” (2200 h to 0959 h) or “PM” (1000 h to 2159 h).

Period	Spring			Summer			Fall			Winter			Overall
	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	
1	0.0[a]	0.0[a]	0.1 (0.17)	0.0[a]	0.0[a]	0.1 (0.11)	0.0[a]	0.0[a]	0.0 (0.15)	0.0[a]	0.0[a]	0.1 (0.17)	0.1 (0.09)
2	0.2[a]	0.0[a]	0.2 (0.12)	0.1[a]	0.1[a]	0.2 (0.09)	0.2[a]	0.0[a]	0.2 (0.11)	0.1[a]	0.0[a]	0.2 (0.10)	0.2 (0.14)
3	0.2[a]	0.1[a]	0.3 (0.12)	0.2[a]	0.2[a]	0.4 (0.09)	0.3[a]	0.1[a]	0.4 (0.10)	0.2[a]	0.1[a]	0.3 (0.10)	0.4 (0.23)
4	0.4[a]	0.3[a]	0.7 (0.13)	0.4[a]	0.4[a]	0.8 (0.09)	0.5[a]	0.3[a]	0.8 (0.10)	0.5[a]	0.3[a]	0.8 (0.10)	0.8 (0.35)
5	0.5[b]	0.5[a]	1.0 (0.12)	0.7[a,b]	0.6[a]	1.2 (0.09)	0.9[a]	0.6[a]	1.6 (0.10)	0.7[a,b]	0.7[a]	1.4 (0.10)	1.03 (0.50)
6	0.8[b]	0.8[a]	1.5 (0.11)	0.9[a,b]	0.9[a]	1.8 (0.10)	1.1[a]	0.9[a]	2.0 (0.10)	1.2[c]	1.0[a]	2.2 (0.10)	1.9 (0.64)
7	1.3[a]	1.2[a]	2.5 (0.11)	1.2[a]	1.4[a]	2.5 (0.11)	1.5[a]	1.2[a]	2.7 (0.09)	1.7[b]	1.4[a]	3.1 (0.10)	2.7 (0.78)
8	1.7[a]	1.7[a,b]	3.4 (0.11)	1.7[a]	1.9[b,c]	3.6 (0.12)	1.8[a]	1.5[a]	3.2 (0.09)	2.3[b]	2.1[c]	4.3 (0.10)	3.6 (0.90)
9	2.2[a]	2.1[a]	4.3 (0.11)	2.1[a]	2.0[a]	4.2 (0.12)	2.1[a]	1.8[a]	4.0 (0.09)	2.7[b]	2.6[b]	5.2 (0.10)	4.4 (0.93)
10	2.7[a,c]	2.7[b]	5.4 (0.12)	2.2[b]	2.5[a,b]	4.6 (0.12)	2.6[a]	2.3[a]	4.9 (0.09)	2.9[c]	2.8[b]	5.7 (0.10)	5.1 (0.91)
11	3.1[a,b]	3.1[b]	6.1 (0.13)	2.8[b]	3.0[b]	5.9 (0.13)	2.9[a]	2.7[a]	5.6 (0.09)	3.2[a]	3.2[b]	6.3 (0.10)	5.9 (0.84)
12	3.2[a,b]	3.2[b]	6.4 (0.13)	3.2[a,b]	3.3[b]	6.5 (0.13)	3.0[a]	2.8[a]	5.7 (0.09)	3.4[b]	3.4[b]	6.8 (0.10)	6.3 (0.78)
13	3.3[a,b]	3.3[b]	6.6 (0.14)	3.1[a]	3.2	6.4 (0.14)	3.0[a]	2.8[a]	5.8 (0.10)	3.5[b]	3.5[b]	6.9 (0.12)	6.3 (0.78)

[a,b,c] $P \leq 0.05$ within row

between the average maximum and minimum temperatures for each period and season are shown in Figure 1. In the AM, week 6 was the only week where spring was statistically different from fall. For the PM daily time period, weeks 2, 4, 12, and 13 of fall and spring were not significantly different, but all other periods of fall were significantly lower than spring. Week 3 of spring was different from fall at the 10% level of significance and all other weeks were different at the 5% level. Summer temperatures were significantly higher than all other seasons for all periods in the AM and PM. Winter temperatures were significantly lower for all periods AM and PM.

Least squares means for relative humidity % (RH) by week since birth and season of year are shown in Table 6 and least squares means for wind speed are shown in Table 7. Least squares means for calf health scores by week since birth and season of year are in Table 8.

The first 2 wk after birth, calves ate minimal amounts of grain and growth was similar in all seasons. By week 4, calves began consuming more grain and increasing their growth rates and the effects of seasonality became more prominent. Animals raised during the fall period had the most environmental stress over any other period resulting in the lowest body weights. During the day they experience temperatures above their TNZ and at night they experience temperatures below their TNZ. Because calves were stressed both day and night, it was difficult for them to acclimate. Summer had the second lowest weight suggesting that heat stress had a larger negative effect on calf weight gains than cold stress. Body weights were highest in the spring, due to the fact that the calves raised in the spring had the least exposure to thermostress, the animals were the least stressed and more energy could be used for growth as opposed to trying

Table 5. Least squares means for daily temperature (^{o}C) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February). Diurnal periods were defined by averaging intake by "AM" (2200 h to 0959 h) or "PM" (1000 h to 2159 h). The difference between the daily periods are listed under the column 'Diff'.

	Spring			Summer			Fall			Winter		
Period	AM	PM	Diff	AM	PM	Diff	AM	PM	Diff	AM	PM	Diff
1	4.3[a]	8.4[c]	4.2	17.4[b]	26.2[b]	8.8	5.4[a]	12.5[a]	7.1	-3.7[c]	0.2[d]	3.9
2	4.3[a]	9.2[a]	4.9	17.0[b]	26.2[b]	9.2	5.0[a]	11.5[a]	6.5	-4.7[c]	-0.5[c]	4.2
3	4.2[a]	8.2[C]	4.1	17.1[b]	25.9[b]	8.8	5.2[a]	11.3[a]	6.1	-4.8[c]	0.2[d]	5.0
4	4.1[a]	8.9[a]	4.8	16.7[b]	26.2[b]	9.5	4.4[a]	10.7[a]	6.4	-2.6[c]	1.2[c]	3.8
5	3.8[a]	8.4[c]	4.7	16.9[b]	26.2[b]	9.3	5.0[a]	12.0[a]	7.0	-4.8[c]	-0.6[d]	4.2
6	4.2[b]	9.5[c]	5.3	16.9[c]	25.9[b]	9.0	6.9[a]	14.6[a]	7.7	-4.4[d]	-0.6[d]	3.8
7	5.4[a]	10.5[c]	5.1	17.1[b]	26.1[b]	9.0	7.9[a]	14.7[a]	6.8	-4.7[c]	-1.0[d]	3.7
8	6.0[a]	10.8[c]	4.8	17.0[b]	26.6[b]	9.6	8.0[a]	15.4[a]	7.3	-5.4[c]	-0.9[d]	4.5
9	5.4[a]	10.3[c]	5.0	16.8[b]	25.7[b]	8.9	7.6[a]	14.9[a]	7.3	-4.2[c]	0.1[d]	4.3
10	5.1[a]	10.5[c]	5.4	16.5[b]	24.7[b]	8.3	7.2[a]	14.5[a]	7.3	-5.0[c]	-0.3[d]	4.7
11	5.6[a]	10.9[c]	5.4	13.8[b]	22.2[b]	8.5	7.1[a]	14.2[a]	7.1	-5.0[c]	-0.5[d]	4.4
12	5.4[a]	10.2[a]	4.8	12.9[b]	21.0[b]	8.1	5.8[a]	12.8[a]	7.0	-5.2[c]	-1.0[d]	4.2
13	5.3[a]	10.1[a]	4.8	13.2[b]	21.8[b]	8.6	3.5[a]	10.2[a]	6.7	-4.8[c]	-1.2[c]	3.6

[a,b,c] $P \leq 0.05$ within row

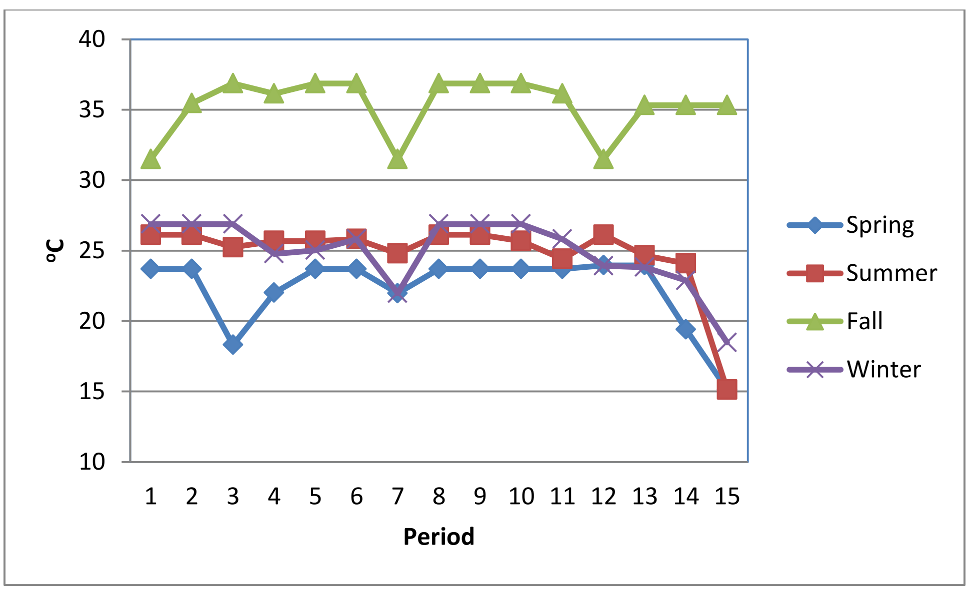

Figure 1. Absolute differences between the average minimum and maximum temperatures (^{o}C) for each period (week since birth) and season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February).

to maintain body temperature.

A model was developed to describe the effects of environmental factors and feed intake on weight gain. The original model contained all of the independent variables that were observed and recorded. Weight was the dependent variable predicted by various independent variables.

Table 6. Least squares means for relative humidity (%) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February). Diurnal periods were defined by averaging intake by "AM" (2200 h to 0959 h) or "PM" (1000 h to 2159 h). The difference between the daily periods are listed under the column 'Diff'.

Period	Spring			Summer			Fall			Winter		
	AM	PM	Diff	AM	PM	Diff	AM	PM	Diff	AM	PM	Diff
1	77.5	64.9	12.7	63.0	42.2	20.7	72.5	52.6	19.9	77.5	67.6	9.9
2	75.2	59.8	15.5	62.5	40.8	21.7	72.9	54.9	18.0	82.4	71.4	11.0
3	76.9	63.3	13.6	63.1	42.9	20.2	73.6	56.1	17.5	77.9	66.2	11.7
4	77.1	60.0	17.1	61.1	39.0	22.1	75.5	58.6	16.8	77.4	66.9	10.5
5	72.4	57.8	14.6	60.5	39.7	20.9	72.9	53.8	19.1	78.0	66.4	11.6
6	73.9	55.9	18.1	62.2	41.9	20.3	69.6	50.2	19.4	75.9	66.6	9.3
7	74.2	58.8	15.5	63.6	41.7	21.9	70.2	52.3	18.0	82.6	74.8	7.8
8	75.8	59.5	16.3	58.2	36.8	21.4	70.5	51.7	18.9	81.4	71.0	10.4
9	74.8	57.6	17.2	60.5	40.6	19.9	70.9	52.5	18.4	78.7	67.9	10.8
10	75.9	56.9	19.0	63.4	43.9	19.5	71.7	52.9	18.9	80.0	67.1	12.9
11	76.0	59.3	16.7	64.0	42.2	21.8	72.6	53.6	19.1	77.4	65.5	11.9
12	74.2	58.6	15.7	68.5	48.3	20.2	74.4	54.7	19.8	78.2	68.4	9.8
13	75.9	59.1	16.8	67.4	45.0	22.4	75.8	56.5	19.3	80.7	72.3	8.4
Ave	75.4	59.3	16.1	62.9	41.9	21.0	72.5	53.9	18.7	79.1	68.6	10.5

The R-squared of the resulting model was 0.9397; demonstrating high predictability power between the model and calf weight. However, due to the high correlation between hip and wither heights, and to prevent multicollinearity, wither height was removed from the model. Wither was chosen because there was higher probability of measurement error. The correlation between wither height and hip height had a value of 0.9782.

Table 7. Least squares means for wind speed (m/s) by period (week since birth) and by season of year. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February). Diurnal periods were defined by averaging intake by “AM” (2200 h to 0959 h) or “PM” (1000 h to 2159 h).

Period	Spring		Summer		Fall		Winter	
	AM	PM	AM	PM	AM	PM	AM	PM
1	1.34	2.08	0.93	1.11	1.27	1.51	1.62	1.67
2	1.33	2.44	0.84	1.13	1.26	1.48	1.09	1.31
3	1.31	2.18	1.03	1.14	1.20	1.58	1.46	1.51
4	1.43	2.09	1.11	1.27	1.16	1.35	1.61	1.68
5	1.44	2.26	1.15	1.27	1.17	1.39	1.57	1.72
6	1.53	2.44	1.09	1.29	1.22	1.48	1.65	1.77
7	1.40	2.07	0.92	1.03	1.32	1.59	1.17	1.15
8	1.42	1.94	1.10	1.26	1.30	1.50	1.24	1.36
9	1.34	2.26	1.26	1.52	1.28	1.42	1.46	1.61
10	1.40	2.08	1.28	1.52	1.28	1.45	1.24	1.32
11	1.40	2.06	0.99	1.44	1.28	1.53	1.57	1.66
12	1.47	2.18	0.97	1.18	1.18	1.46	1.38	1.60
13	1.41	2.33	0.73	1.11	1.11	1.32	1.43	1.43

Table 8. Least squares means (SEM) for overall calf health scores. Seasons were defined as: spring (March through May), summer (June through August), fall (September through November), and winter (December to February). Scores ranged from 0 to 3 in 6 categories. The smaller the number, the better health of the calf.

Period	Spring	Summer	Fall	Winter
1	0.78 (0.10)	0.66 (0.06)	0.21 (0.05)	0.10 (0.03)
2	0.70 (0.22)	0.51 (0.06)	0.65 (0.09)	0.22 (0.05)
3	0.56 (0.46)	0.54 (0.06)	0.56 (0.07)	0.46 (0.07)
4	0.62 (0.15)	0.59 (0.06)	0.41 (0.06)	0.15 (0.04)
5	0.69 (0.13)	0.56 (0.07)	0.39 (0.06)	0.13 (0.04)
6	0.58 (0.15)	0.76 (0.10)	0.64 (0.07)	0.15 (0.04)
7	0.65 (0.15)	0.62 (0.07)	0.68 (0.08)	0.15 (0.04)
8	0.47 (0.19)	0.63 (0.08)	0.61 (0.07)	0.19 (0.04)
9	0.77 (0.16)	0.81 (0.10)	0.62 (0.08)	0.16 (0.05)
10	0.56 (0.16)	0.87 (0.09)	0.62 (0.07)	0.16 (0.04)
11	0.61 (0.21)	0.62 (0.09)	0.63 (0.06)	0.21 (0.05)
12	0.74 (0.17)	0.61 (0.09)	0.48 (0.06)	0.17 (0.05)
13	0.83 (0.22)	0.81 (0.11)	0.50 (0.07)	0.22 (0.06)

Many of the terms were divided into an AM and PM period. The correlation was expected to be amplified. After removing wither height, variables were removed one at a time, removing the least significant variable, and running the model again. This was repeated until all remaining factors were significant at least at a 5% level. An F-test was run to see if the variables removed were jointly significant. The final model is shown in Table 9.

The R-squared was high in this model due to auto correlation. We ran robust estimators which inflated the R-squared, but the coefficients had been adjusted for the inflation. We also ran it in different functional forms such as using logs or other exponents, but all resulted in poorer statistical results.

Each day since birth increased body weight by 0.34 lb. Hip height was positively correlated with weight gain; every inch that the subject animal gains in height predicted the animal would gain 10.68 lb (4.84 kg). Additionally, feed was positively correlated. For every ounce of feed consumed during the AM period they were predicted to grow 0.198 lb (89.8 g) until they reached the maximum starter offered. During the PM period they were predicted to grow 0.298 lb (135.2 g) for every ounce of feed. Intake AM and PM both had a positive impact on the dependent variable with the PM intake having a larger impact. Calf health score was a dummy variable. If the cumulative calf score was three or higher, the calf was valued at 1; if less than 3 it was valued as a 0.

Score had a negative impact of -0.655 lb (-297.1 g) on the dependent variable. Milk was also a dummy variable. If the calf was offered 6 qts of milk, it received a value of 1; if it was offered 4 qts of milk it received a value of 0. Milk was positively correlated with weight gain; animals that received 6 qts were predicted to be 1.83 lb (830.1 g) heavier

Table 9. Final multivariate regression model of calf weight as the dependent variable and the following variables as the independent variables. The final R-squared was 0.9394.

Variable	Coefficient	SEM	Probability
Intercept	-255.248	5.1852	0.0000
Days since birth	0.349	0.0162	0.0000
Hip	10.688	0.1477	0.0000
Intake, AM	0.198	0.0148	0.0000
Intake, PM	0.298	0.0137	0.0000
Milk6	1.828	0.4249	0.0000
Precipitation, AM	2.499	0.8532	0.0034
Precipitation PM	-2.092	0.9407	0.0262
Relative humidity AM	-0.119	0.0255	0.0000
Relative humidity PM	0.054	0.0241	0.0256
Score	-0.655	0.2226	0.0033
Temperature AM	0.147	0.0822	0.0741
Temperature PM	-0.190	0.0801	0.0174
Wind speed AM	-1.679	0.2597	0.0000

than those that received 4. Every millimeter of precipitation during the PM period had a negative impact on calf weight of 2.09 lb (948 g). Every millimeter of precipitation during the AM period had a positive impact on calf weight of 2.50 lb (1.13 kg). Precipitation during the AM period probably helped cool the animals in the summer, while the cloud cover helped keep temperatures higher in the winter.

The AM temperature coefficient was 0.14 and the PM was -0.19 suggesting that the PM had a negative effect of a magnitude greater than the AM temperature. Night temperatures are generally much cooler than the day and an increase in the temperature will result in less cold stress and more weight gain. In the warmer months, higher PM temperatures had a larger negative impact on calf weight gain.

Calves were routinely fed different amounts of milk depending on the time of year. In order to quantitate the effect of milk intake on weight gain, a group of calves were alternately fed either 4 or 6 qts of whole milk during the fall season of 2011 (October, November and December). Another model was run just for this time period with milk intake defined by a dummy variable; calves offered 6 qts were assigned a 1 and 4 qts assigned 0. The resulting model for this period, with weight as the dependent variable, is shown in Table 10. Days since birth had a small positive impact with a coefficient of 0.002, and a very high P-value, but this factor was left in because it was used to separate this time period from the rest of the study. Hip height had a positive coefficient of 16.0. Barometer PM was significant at the 5% level of significance with a positive coefficient of 0.39. Intake AM and PM were both positively correlated, AM period having a coefficient of 0.11 and PM period was 0.27. Calves that received 6 qts were predicted to be 2.55 lb heavier than those that received 4 qts. Calf health score was a dummy variable recorded the same as the other trial. It had a negative coefficient of -2.25, meaning calves with a heath score of 3 or above were predicted to weigh 2.25 lb less than those with a heath score under 3. Temperature AM had a negative coefficient of -0.34 and wind speed PM was positively correlated with a coefficient of 2.70.

Proper weaning of the calves can save money. Calves that should be weaned and are not are consuming extra milk/MR and calf starter that increases the cost of production. Table 11 shows the cost of whole milk and MR at different prices and quantities.

Table 12 shows the cost of starter grain consumed from birth up to the week listed. By week 5, mean starter intake was over 1.5 lb per day. This level of intake meets the minimum weaning criteria for many dairy operations. Using Tables 11 and 12, the cost can be computed for weaning calves, depending on the price and quantity for milk/MR and calf starter. The calf starter in this study contained 18% protein and Bovatec at a cost

Table 10. Final multivariate regression model of calf weight as the dependent variable and the following variables as the independent variables for calves that were fed either 6 quarts of milk per day or 4 quarts. The final R-squared was 0.944.

Variable	Coefficient	SEM	Probability
Intercept	-693.052	55.6849	0.0000
Days since birth	0.002	0.0104	0.8537
Hip	16.013	0.2986	0.0000
Intake, AM	0.108	0.0278	0.0001
Intake, PM	0.270	0.0281	0.0000
Milk6	-2.551	0.7648	0.0009
Relative humidity AM	-0.124	0.0432	0.0043
Relative humidity PM	0.205	0.0477	0.0000
Score	-2.253	0.3925	0.0000
Temperature AM	-0.336	0.1457	0.0213
Temperature PM	0.262	0.1411	0.0637
Wind speed AM	1.519	0.4879	0.0019
Barometer PM	0.394	0.0829	0.0000

Table 11. Calculated costs for whole milk and a 20:20 milk replacer (MR), per day, at varying feeding rates.

Milk, $/cwt	Cost/day, milk		MR, $/50 lb	Cost/day, MR	
	4 qt	6 qt	bag	1 lb	1.5 lb
$14.00	$1.20	$1.81	$58	$1.16	$1.74
$14.50	$1.25	$1.87	$59	$1.18	$1.77
$15.00	$1.29	$1.93	$60	$1.20	$1.80
$15.50	$1.33	$2.00	$61	$1.22	$1.83
$16.00	$1.38	$2.06	$62	$1.24	$1.86
$16.50	$1.42	$2.13	$63	$1.26	$1.89
$17.00	$1.46	$2.19	$64	$1.28	$1.92
$17.50	$1.50	$2.26	$65	$1.30	$1.95
$18.00	$1.55	$2.32	$66	$1.32	$1.98

$13.99 for a 50 lb bag. The calculations do not account for the cost of labor that would be incurred for not weaning calves sooner. For example, if a calf was fed the normal 4 qts of whole milk/day at $16.50/cwt, the total milk cost would be $49.70 ($1.42/d x 35 d) and the grain cost would be $5.17 for a total feed cost from birth to 35 d of age of $54.87. Using the same quantity of milk and price, the cost to raise a calf to 8 wk of age would be

$79.52 for whole milk (56 d * $1.42) and $21.14 for starter for a total feed cost of $100.66. This is an increase of $45.79 per calf to wean at 8 wk compared to 5 wk. The difference between each week grows larger the longer weaning is delayed. However, it is important that calves are ready to be weaned and are consuming enough grain.

We compared the results from our trial using the following weaning requirements: animals needed to consume at least 2 lb of grain per day and double their birth weight. On average, calves reached this birth weight at ~63 d; weight was the limiting factor, rather than starter intake. Most calves should have been weaned by at least 9 weeks, but many were not weaned until 11 and 12 wk. During the study, milk price averaged around $19.72 and ranged from $16.59 to $22.72. Milk cost per day for 6 qts of milk was $2.54. Therefore, by 63 d of age, it would cost $160.26 for milk and $29.62 for grain; a total intake cost of $189.88. If the animal was weaned at 11 wk, consuming the same amount of milk with the same milk price, it would cost $195.88 and calf starter would cost $50.91, for a total feed cost of $246.79. Therefore, it costs $56.90 more per calf for animals that are weaned at 11 wk as opposed to 9 wk. The calves in the study had doubled their birth weight by 63 d (9 wk) and were consuming 4.4 lb (2 kg) of calf starter per day. This means the calves could have been weaned at this point.

Seasonality can affect the age at which a calf reaches weaning criteria. An average calf on this study doubled its body weight by week 9, 10, 11, and 9 for spring, summer, fall, and winter, respectively. An average calf consumed a minimum of 2 lb of starter per day by week 7, 7, 6, and 6 for spring, summer, fall, and winter, respectively. In terms of weaning, total weight was the limiting factor.

Table 12. Average cost of starter grain from birth to the following weeks of age.

Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
$5.17	$8.89	$14.12	$21.14	$29.62	$39.48	$50.91	$62.98

CONCLUSIONS

The goal of a replacement heifer rearing program is to provide the opportunity for the heifer to fully develop her lactation potential at the desired age with minimal expense. The first and most important step in this process is proper development of the young calf. Although calves are usually weaned at 8 wk or older, many producers use early weaning programs to lower the costs of feed and labor. Calves tend to scour less when consuming solid feeds compared with liquid feeds.

Many studies have been conducted supporting the idea that the earlier you can get a calf to begin consumption of calf starter, and the more calf starter the calf consumes, the greater the weight gain. Calves that consume more grain and begin grain consumption at an earlier age will reach weaning requirements sooner. Data from this study adds information on seasonal effects and shows that calves raised in the spring will reach weaning requirements sooner than any other season of the year. In this study, spring appeared to have environmental conditions most consistent with a calf's TNZ. To promote optimal growth in this climate, heating calves in winter and heat mitigation in the summer should be considered.

During the fall season, calves had the lowest weight gain and body measurements – due to increased temperature extremes on the lower and upper critical regions of the TNZ. During the afternoon, calves were exposed to temperatures above their TNZ, and in the early morning they were exposed to temperatures below their TNZ. Being exposed to extremes at both ends of thermostress is more taxing on the calf than being exposed to temperatures above or below their TNZ. This research supports the initial hypothesis that heat stress has more of a negative impact than that of cold stress. This is vital to producers as it can impact animal production and profitability in dairy cattle by lowering feed intake, milk production, and reproduction. Being able to wean calves earlier equates to higher profit margins. There are a number of housing alterations that can be made to decrease the impact of thermostress. The challenge with these is to balance the investment cost versus the projected production and economic responses. When looking at calf housing, environmental factors need to be considered along with overcrowding, length of time in the hutch, availability of shade, and ventilation.

Some solutions to these environmental problems include the use of fans and/or misters/sprinklers. Fans provide a great source to increase airflow. The goal of the misters or sprinklers is to increase evaporative cooling by wetting the skin. Another solution to help with heat mitigation is to remove the hutches and set up individual pens with a large canopy covering the pens. This would create shade and allow for much better ventilation than the hutches. The current problem with hutches is the limited ventilation and they may be hotter in the direct sun (Chase).

In addition to housing and facilities changes, changes to calf rations can be considered, i.e., using higher quality feed and shifting feeding times to a more conducive ambient temperature. A simple but effective way to help relieve calves from heat stress is having a source of water that is readily available. Cows' holding areas have a source of constant water available that they can obtain at their convenience. However, in calves' pens they are dependent on water being provided by the feeder. Often the calves drink or spill all their water before the feeders return to refill the water bucket. A lack of water is a major contributor to heat stress. Cold weather mitigation techniques are more limited and not as cost effective. These techniques include housing the calves in an indoor or heated structure. Another solution may be to blanket the animal.

Ideally all of these strategies would be used as a means to minimize the effects of thermal stress and contribute to an overall increase in health of the calves. To allow calves to be the most profitable, a balance needs to be found in identifying which practices would be the most cost effective and which will cost more than they will provide in return. Overall, there would be an economic benefit to implementing some type of thermostress abatement practice for dairy calves.

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