8-2022

Impact of Increasing Level of Milk Production on Cow and Calf Behavior and Performance in the Nebraska Sandhills

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IMPACT OF INCREASING LEVEL OF MILK PRODUCTION ON COW AND CALF BEHAVIOR AND PERFORMANCE IN THE NEBRASKA SANDHILLS

by

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A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professors

J. Travis Mulliniks and Mitchell B. Stephenson

Lincoln, Nebraska

August, 2022

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University of Nebraska, 2022

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Selection for increased milk production across the United States has resulted in variable cow and calf production responses. Better understanding of calf nursing and grazing behaviors may provide opportunities to help estimate how milk and grazed forage intake influence variability in calf performance. In a 2-yr study, cow-calf pairs (n = 65) were equipped with neck collars containing global positioning system (GPS) units to validate the efficacy of high-frequency GPS data to accurately identify calf nursing events and grazing behavior. Data were collected during 3-wk tracking periods during early lactation (calf age 65.4 ± 10.0 d; **EARLY**) and late lactation (calf age 162 ± 22.3 d; **LATE**). Calf behavior was visually observed for a total of 350 hrs and was used in a training dataset for a random forest (RF) classification model. Out of bag (OOB) estimates of individual behaviors indicated relatively low misclassification error rates, less than 4%, suggesting that high frequency GPS tracking can be used to effectively classify calf nursing and grazing behaviors. Behavior prediction results in this study match ranges reported in previous literature, supporting the efficacy of this technique to assess behavior in beef calves. In a 2-yr study, crossbred cow-calf pairs (n = 118) from March- and May-calving herds were used to determine the impact of increasing total milk production on cow body weight (BW), body condition score (BCS), reproductive performance, calf BW, and calf average daily gain (ADG). On approximately 30, 60, 90, 120, and 210 d postpartum, individual cow 24-h milk yield was estimated with weigh-suckle-weigh techniques. Milk area under the curve (AUC) values were calculated and data were analyzed using linear regression analysis. Cow BW, BW change, and reproductive performance were not ($P > 0.12$) associated with milk AUC, except for a tendency ($P = 0.09$) for lower BW at breeding. At weaning, cow BCS was negatively associated ($P = 0.09$) with increasing milk AUC but was not associated at any other physiological stage. A significant positive association with calf average daily gain (ADG) was observed from birth to age 120 d and a tendency ($P = 0.09$) for a positive association was observed from age 120 d to weaning. Steer ADG in the finishing phase was not ($P = 0.63$) associated with dam milk production. In this environment, increasing milk production had a positive increase in calf growth during the pre-weaning phase without any negative impacts on overall cow-calf production.

Acknowledgements

"I can do all things through Him who strengthens me" - Philippians 4:13

It is with gratitude that I recognize my parents who have made many sacrifices over the past two decades to support my education. Thank you to them and my sister for listening to my drama and always appreciating my pictures of cows, sunsets, and grass.

I am grateful to my committee for their patience and confidence in my abilities. Thank you to my advisor, Dr. Travis Mulliniks, whose insight challenged me to think more critically. I am grateful for your adept mentorship in all subjects of life including beef cattle, leadership, and craft coffee. To my advisor, Dr. Mitch Stephenson, I appreciate your optimistic, encouraging, and motivational approach and enjoyed working with you throughout my program in Nebraska. Thanks to Dr. Jim MacDonald for serving on my committee, supporting my time in Lincoln, and answering any questions.

The research outlined in this thesis would not have been completed without the creativity and work ethic of the crew at GSL. Jacki Musgrave, John Nollette, Roger Carpenter, and Andy Applegarth deserve recognition for their contributions to the cattle and data management required by this project. I am very grateful for the opportunity to learn from each of them while experiencing the uniqueness of cattle ranching in the Nebraska Sandhills.

Thank you, Nicole, for being a great lab mate to navigate the adventure of grad school with. Thanks to Joslyn for your patience with my lab ignorance, as well as your ability to lighten the mood with your humor. I would also like to recognize the data collection and lab assistance of numerous others at UNL including Allie, TL, Alex, Kacie, Tasha, Sam, and Kylie. Your help and friendship enhanced my time in Nebraska.

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CHAPTER I: REVIEW OF LITERATURE

Introduction

Optimizing forage resource utilization is necessary for cow-calf producers to maintain profitability and may be accomplished through management strategies that address their unique operation's environment. Genetic trends in the United States show increased selection focus on traits such as milk production to increase calf weight at weaning (Lalman et al., 2019a). Calf milk and forage intake have an inverse relationship (Ansotegui et al., 1991). Thus, cow milk production may have variable calf growth responses in different forage quality environments. Cow energy requirements increase with increased milk production and can lead to increased input costs to maintain performance (Ferrell and Jenkins, 1984). In some environments, the intentional selection for increased genetic potential for milk may not consistently improve calf growth and increased input costs may not be economically efficient. The research outlined in this thesis describes our efforts to understand the impact of level of cow milk production on cow body weight, body condition score, reproductive performance, and calf behavior and growth in the Nebraska Sandhills environment.

Nebraska Sandhills Calving Seasons

Cow-calf producers often select production systems based on optimal ability of available forage to meet cow nutrient requirements. The annual forage production in the Nebraska Sandhills is dependent on environmental factors, such as quantity and timing of precipitation during the growing season (Guretzky et al., 2016; Stephenson et al., 2019). Plant maturation is the greatest influence on forage quality and is due to the result of physiological development of structural carbohydrates in the plant (Moore and Moser, 1995). As plants mature, crude protein content decreases and cell wall substrates (neutral detergent fiber) increase (Lardy et al., 1997). In the Nebraska Sandhills, forage quantity is still low in April, but Volesky et al. (2007) reported crude protein content increased from 10.7% to 13.9% in May. March calving is one system that is practiced to align the high nutrient requirements for cattle in at peak lactation with the high-quality forage growth stage in April-June. In a March-calving system, forage quality and quantity are often inadequate to meet the requirements of late gestation, so supplemental feed is used to mitigate deficiencies (Clark et al., 1997). To avoid weather-related challenges of spring calving, some Sandhills operations calve in the summer. However, these later-calving situations push peak lactation and the breeding season into late summer or early fall when forage quality is declining. Therefore, these cows may require more supplemental feed during the breeding season to maintain productivity.

Season of calving affects cow reproductive performance differently among milk production levels as demonstrated by Mulliniks and Adams (2019). These authors demonstrated that while March-calving herds enter the breeding season with all requirements met, May-calving herds are deficient in metabolizable protein (MP) and energy required for maintenance (NEm). Using a cow body weight of 545 kg, Mulliniks and Adams (2019) modeled breeding season NEm and MP balance of grazing March and May herds with peak milk production ranging from 9-13 kg/d. At all March-calving milk production levels, NEm and MP requirements were met at initiation of the breeding season, but milk production over 12.7 kg/d led to a NEm deficiency by June 11. Cows with milk production over 9 kg/d concluded the breeding season in a negative MP balance. In comparison, May-calving cows of all milk levels were in a negative NEm and

MP balance before breeding season even began. This deficiency in May herds has been shown to negatively impact pregnancy rates in heifers (Springman et al., 2017).

Milk Production on Cow Performance

Lactation poses a severe metabolic challenge for cows. Within some environments, available dietary nutrient supply is unable to adequately provide for the increased requirements of cows during the lactation period. To fulfill these metabolic demands, homeorhetic adaptations are utilized (Bauman and Currie, 1980) within both mammary and non-mammary tissue (Bell, 1995). Increased gluconeogenesis, decreased glucose utilization in peripheral tissue, and increased utilization of ketones and non-esterified fatty acid (NEFA) are mechanisms employed to sustain maternal tissues (Bell, 1995). Lactating cows will also mobilize muscle and adipose tissue to support amino acid requirements for milk production (McCabe and Boerman, 2020). When protein is deficient in the diet, mammary gland catabolism of certain essential amino acids is reduced and they are used for milk protein synthesis instead (McCabe and Boerman, 2020). The mammary gland lacks the ability to synthesize glucose from other precursors and relies on sufficient blood glucose levels to provide for lactose production, glycolysis, and the pentose phosphate pathway (Zhao et al., 1999; Zhao et al., 2014a; Zhao et al., 2014b). Rumen fermentation of rangeland diets results in production of 3 main volatile fatty acids: acetate, propionate, and butyrate. Because propionate is a key factor in glucose production through gluconeogenesis (Young, 1977; Majdoub et al., 2003), diet can influence glucose availability for mammary absorption. Glucose, acetate, and oxygen uptake increase dramatically in mammary tissue 0.5-2 d prior to parturition in preparation for the increase in milk secretion (Davis et al., 1979).

The relationship between nutrient supply and cow function results in altered performance depending on forage intake quality and physiological state of the cow. This is due to the prioritization of nutrients toward maintenance of the animal before being partitioned to growth, reserves, and reproduction (Short et al., 1990). It has been shown that energy requirements for maintenance are increased in cows with higher milk potential, mainly due to increased internal organ size and metabolic demands (Ferrell and Jenkins, 1984). Increased milk production has been reported to result in a 12-14% increase in energy requirements (van Oijen et al., 1993). In an assessment of cows with low (8.5 kg · d^{-1}) compared to medium (9.6 kg · d^{-1}) and high (10.5 kg · d^{-1}) milk production, Montaño-Bermudez et al. (1990) reported an 11% increase in energy required. Lactating cows consuming energy above maintenance requirements will partition a larger proportion of energy toward maternal tissue; thus, the efficiency of milk production decreases with greater level of milk produced in high quality forage environments (Lalman at al., 2013). With an increased energy demand for maintenance, higher milk potential can limit nutrient availability for energy reserves and reproduction.

Johnson et al. (2003) reported an 8% increase in forage consumption for high milk EPD cows compared to low, with every kg increase in milk resulting in an increased 0.33 and 0.37 kg dry matter intake (DMI) during early and late lactation, respectively. Hatfield et al. (1989) also reported that increased milk potential results in greater DMI. Thus, increased genetic potential for milk results in a need for more feed inputs. With feed costs comprising 63% of the annual cow cost (Miller et al., 2001), it may be advantageous for producers to focus on methods of lowering the maintenance requirements of their cowherd to conserve forage. Cow body weight (BW) and condition score change are useful tools to determine whether a cow's energy requirements exceed the available forage resource supply (Lalman et al., 2013). Weaning date can be manipulated based on current rangeland conditions and adjusting weaning date is a valuable tool to conserve forage and allows cows to better maintain body weight (Story et al., 2000; Grings et al, 2005) by removing the increased nutrient requirements of lactation.

To remain profitable, producers should aim for their cows to reproduce and wean one calf per year (Bond and Wiltbank, 1970). Therefore, managing for reproduction should be a priority. In restricted forage environments (low quality or quantity) or physiological states (such as lactation) that put cows in negative energy balance, reproductive performance can be decreased (Wiltbank et al., 1962; Edwards et al., 2017). Mulliniks et al. (2011) reported a relationship between milk production and postpartum interval with every 1 $kg \cdot d^{-1}$ increase in milk production associated with ~5.5 d increase in postpartum interval. Even in an environment where forage quantity was sufficient, Edwards et al. (2017) reported the lowest pregnancy rates in cows with the highest milk production. This may be due to the increased energy requirement for lactation competing with reproductive processes. In contrast, Beal et al. (1990) found no impact of milk production level on reproductive performance. It is important to manage for optimum reproductive performance in each given environment while considering the costs of strategy implementation (Short et al., 1990).

Milk Production on Calf Performance

Calf growth is dependent on nutrients from milk produced by the dam, the amount of milk consumed by the calf, and the amount of forage grazed by the calf. However, inconsistent calf growth responses have been observed in the United States with cows similar in milk production levels, suggesting variability in calf milk and forage intake (Mulliniks et al., 2020). Increased efforts to improve output-related traits, such as calf weaning weight, have been observed in the primary beef breeds in the United States (Kuehn and Thallman, 2016). While calf weaning weight does play a role in profitability, a profitability model by Miller et al. (2001) reported only a 5% contribution. Cow milk yield has a positive effect on pre-weaning calf growth, but the extent and timing of this effect can be variable. Brown and Brown (2002) concluded that the association between milk production and calf average daily gain (ADG) is higher in lower milking cows and varies among breeds and environments. In agreement, Liu et al. (2015) reported that the regression equations of milk yield to calf ADG varied between breeds with a linear relationship in British and tropical breeds and a quadratic relationship in European breeds. With decreased milk availability, calves will compensate by increasing forage intake (Lusby et al., 1976; Ansotegui et al., 1990; Tedeschi and Fox, 2009). This relationship between milk and forage intake may play a key role in calf performance outcomes in environments with differing forage quality. Abdelshami et al., (2005) found similar birth to slaughter conversion efficiencies regardless of milk intake level, although weaning weight was higher with increased milk production. However, Wyatt et al., 1977 reported that the pre-weaning efficiency of conversion from milk to gain declined 51-72% when increasing milk intake from ~5 kg · d^{-1} to ~10 kg · d^{-1}. Therefore, although absolute calf body weight may be increased by higher milk intake, inputs to reach the same benchmark will also increase and the value may not be outweighed. Abdelsami et al., (2005) reported that level of milk intake had little influence on post-weaning calf

ADG. During a 75-d backgrounding period, Mulliniks et al. (2018) found lower ADG in progeny of higher milk-producing cows until d 35, but no difference in overall ADG for the entire period. Lewis et al. (1990) observed post-weaning compensatory gain in calves with lower milk consumption. This suggests calf development differences that may stem from different proportions of milk and forage intake during the pre-weaning phase.

Conclusion

Cow-calf producers have focused on improving calf growth through selection for increased milk production. However, this focus may not consider overall efficiency of production with potential negative effects on cow reproduction and variability in calf growth response observed. The impact of milk production changes in different forage environments and over time throughout the calf's life. Further research is needed to understand the relationship between milk and forage intake in beef calves and how environmental factors drive cow and calf performance.

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CHAPTER II: VALIDATION OF HIGH FREQUENCY GLOBAL POSITIONING SYSTEM DATA TO PREDICT NURSING AND GRAZING BEHAVIOR IN RANGE BEEF CALVES

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Abstract

Quantifying milk and forage intake of range beef calves in beef production systems are challenging. Nursing and grazing behaviors of suckling calves may provide opportunities to help estimate differences in nursing and grazing intakes that drive variability in calf performance. Therefore, the objective of this study was to validate the efficacy of using high-frequency global positioning system (GPS) data to accurately identify calf nursing events and grazing behavior. In a 2-yr study, cow-calf pairs (n = 65) were equipped with neck collars containing GPS units (frequency = 1 hz) for 3-wk tracking periods during early lactation (calf age 65.4 ± 10.0 d; **EARLY**) and late lactation (calf age 162 ± 22.3 d; **LATE**). Calf behavior was visually observed for a total of 350 hrs and was used in a training dataset for a random forest (RF) classification model. Livestock behavior was the response variable and 8 GPS data classification metrics derived from the GPS coordinates were used as predictors. Out of bag (OOB) estimates of individual behaviors indicated relatively low misclassification error rates, less than 4%, for calf nursing, grazing, and resting behaviors. The RF model was used to predict behavior for all unobserved calf GPS observations. Daily nursing and grazing mean times were 44.3 ± 13.0 min and 387 ± 55.9 min during the EARLY period and 36.6 ± 11.7 min and 422 ± 41.7 min during the LATE period. Number of nursing bouts was 4.32 ± 1.11 bouts · d^{-1} during the EARLY period and 3.66 ± 1.11 bouts · d^{-1} for the LATE period. Behavior prediction results over the two, 3-wk periods match ranges reported in previous literature supporting the efficacy of this technique to assess behavior in beef calves. The low model misclassification error rates indicate that high-frequency GPS data can be used as a method of collecting continuous calf behavior in an extensive rangeland setting.

Keywords: calf behavior, GPS, grazing, nursing, validation

INTRODUCTION

Calf growth is dependent on nutrients from milk produced by the dam, the amount of milk consumed by the calf, and theamount of forage grazed by the calf. However, inconsistent calf growth responses have been observed in the United States with cows that have similar milk production levels, suggesting variability in calf milk and forage intake (Mulliniks et al., 2020). The correlation between a dam's level of milk production and calf average daily gain declines after peak lactation (Ansotegui et al., 1991). It has been suggested that this decline may be due to the interaction between nursing and forage intake of the calf (Clutter and Nielson, 1987; Ansotegui et al., 1991).

In ruminants, foraging behavior and intake is challenging to reliably predict because it is influenced by multiple variables including nutritive value of the forage plant community, physical and physiological animal factors, and environmental factors (Galyean and Gunter, 2016). For livestock grazing within large pastures of extensive rangeland systems, forage intake is impossible to capture over extended periods of time without intensive data collection. External markers (i.e. chromic oxide and titanium dioxide) and internal markers (i.e. indigestible NDF and ADF) can be used to estimate dry matter intake based on fecal output and dry matter digestibility (Velásquez et al., 2021), but use of these techniques are labor intensive and require dosing animals, collecting feces, and conducting extensive laboratory analysis. These methods in extensive rangeland systems may alter grazing behavior and ultimately provide highly inaccurate estimates of actual forage intake. As a result, there are limitations on the number of animals that can be assessed, and it is not a practical method for continuous intake estimation where cattle are managed within extensive environments. Wireless sensors have been proposed as an approach for estimating intake by validating behavior prediction algorithms with use of markers (Greenwood et al., 2014). Metrics including chewing behavior and acoustics have been measured using technology and correlated with intake (Galli et al., 2011; Galli et al., 2018; Raynor et al., 2021). Amount of time spent grazing and resting, determined with 3-axis accelerometer-based algorithms, has shown to be correlated with dry matter intake in beef cattle (Greenwood et al., 2017). Thus, animal behavior assessment has been used as a proxy to estimate intake in grazing cattle.

In the past, the majority of behavior data have been collected through direct visual observations (Chambers, 1959; Odde et al., 1985; Day et al., 1987; Stěhulová et al., 2013). However, challenges with visually observing animals over 24 hr periods often limit the quantity of data collected. Additionally, there is minimal ability to evaluate the behavior of large numbers of animals in remote environments. Recent advances in precision livestock technology allows for continuous remote monitoring of livestock and has successfully been utilized to monitor grazing patterns and distribution, detect livestock health issues, and assess social behaviors in extensive rangeland environments (Bailey et al., 2021). The use of global positioning system (GPS) tracking and accelerometers provide a reliable mode of evaluating grazing behavior (González et al., 2015; Brennan et al., 2021). Several studies have utilized these technologies to determine mature cow and yearling behaviors (Augustine and Derner, 2013; González et al., 2015; Brennan et al., 2021; Raynor et al., 2021), but few studies have specifically evaluated calf behaviors. Kour et al. (2018) used halter-mounted accelerometers to successfully discern nursing versus non-nursing behavior and predict nursing bouts and bout duration in beef calves. In the study, the authors indicated that the location of the accelerometer on the cheek of the halter was important in correlating calf movements and that attaching on a collar did not provide strong results to predict behavior. These halter-mounted accelerometers were used in a relatively small 7-ha paddock (Kour et al., 2021a; Kour et al., 2021b), and in rangeland situations, halters may not be practical over long time periods in remote locations.

The use of high frequency GPS locations has been suggested as a viable tool to distinguish specific animal behaviors without the need of an added accelerometer sensor (González et al., 2015). Accelerometers may give poor readings based on where they are located on the animal (Kour et al., 2021a and 2021b). Use of only GPS units may be beneficial in developing a global model that is more consistent across units and less sensitivite to location placement on the animal. Determining behavior with only high frequency GPS data (<1 hz) provides opportunities to limit the number of sensors needed to answer livestock behavior-related questions and improve understanding of cow-calf relationships, nursing behavior, and grazing behavior of calves. The objective of this study was to validate the use of high frequency GPS data to accurately predict calf nursing and grazing behavior in an extensive rangeland environment.

MATERIALS AND METHODS

All animal management and handling procedures were in compliance with the University of Nebraska Institutional Care and Animal Use Committee (IACUC #2251).

Study Site and Cattle

This study was conducted in 2020 and 2021 at Gudmundsen Sandhills Laboratory (GSL) located 11 km northeast of Whitman, Nebraska (42.081895, -101.448515; elevation 1,075 m). The site is positioned in a semi-arid ecosystem that relies on timing and quantity of precipitation during the growing season for optimum cool- and warm-season forage production. Annual rainfall received at GSL in 2020 and 2021 was 88.1% and 85.7%, respectively, of the 35-yr average (493 mm). Peak standing forage biomass was 93.0% (2020) and 85.7% (2021) of the 18-yr average (2,032 kg · ha^{-1}; obtained via personal communication with Jess Milby).

Mature March- and May-calving crossbred cows (4-6 yr old) were managed by calving season in two herds. Each herd contained the same number of steer and heifer calves. Data were collected on cow-calf pairs (*n* = 65) in 3-wk tracking periods. These periods were early lactation (calf age 65.4 ± 10.0 d; **EARLY**) and late lactation (calf age 162 ± 22.3 d; **LATE**) during the pre-weaning phase. Individual calf data were pooled by EARLY or LATE period regardless of year or calving season to validate the efficacy of using high frequency GPS data to develop universal models to predict visually observed behaviors.

All cattle grazed pastures containing plant communities typical of native upland Sandhills rangeland with a mixture of warm- and cool-season grasses, forbs, and shrubs. Sandhills forage quality is highest during the growing season, which is typically May-September. Cattle had *ad libitum* access to water throughout the study. One 160 ha pasture was utilized during all EARLY tracking periods. During the LATE period, the

March herd grazed a 542 ha pasture in year 1 and a 286 ha pasture in year 2. The May herd grazed a 235 ha pasture during the LATE period in both years.

GPS Tracking

Cows and their respective calves were fitted with neck collars labeled to ensure each animal received the same collar during both tracking periods and corresponded to each cow and calf pair. Collars were buckled tightly enough to prevent animals from slipping them off, but loosely enough to prevent neck movement restrictions. The collars were constructed by the University of Maine (Knight et al., 2018). Each collar contained a GPS tracking device (Columbus P-1 Professional Data Logger, GPSWebShop, Inc., Niagara Falls, NY) configured to collect location fixes at 1 s intervals. To extend the battery life, each GPS device was modified by wiring to a lithium-ion battery pack (Part #31812-02, Tenergy Power, Fremont, CA). Fully charged GPS units were checked for connectivity and assembled in the neck collars the day prior to equipping the animals. Following each data collection period, the collars were removed from the animals, disassembled, and batteries recharged. The GPS data was downloaded to a hard drive in CSV file format.

Field Observations

Visual observations were recorded for individual animals on multiple days during each tracking period. Observations were primarily conducted during morning (0600 to 1000 h) and evening (1600 to 2000 h). All observations were recorded by 1-3 trained technicians. During an observation period, the animal’s continuous behavior was recorded along with the time at which the behavior began and ended (Augustine and Derner, 2013). Grazing, resting, and walking behavior was noted for cows and calves;

nursing behavior was also recorded for calves. The resting classification included standing and laying. Behaviors were only recorded if they were performed for at least 1 min. Simultaneous behaviors, such as nursing and walking, were documented in the observer's notes. Observations were conducted from a vehicle using binoculars and from a great enough distance to prevent altered behavior due to human presence. In some cases, an acclimation period was allowed following the observer's entry to the pasture to allow the cattle to settle and resume natural behavior. At the end of each observation day, field notes were inputted to a CSV file and included the date, behavior classification, behavior start and stop times, and comments. A total of 2,453 nursing, 7,612 grazing, 10,556 resting, and 382 resting field observation minutes were recorded on the calves. This included 239 individually observed nursing events.

Data Processing

For analysis, all behaviors were grouped into four categories: grazing, walking, nursing, and resting. Laying and standing observations were included in the resting behavior category. Following download, GPS data was processed using Python (Python Software Foundation). For the paired cow-calf GPS data sets, data was subsampled at 5-sec intervals to reduce data size. A total of 249,286 5-sec observations were recorded. Observations were used as a training dataset for a random forest classification model. Cow-calf GPS data frames were then merged based on date timestamp to create a single dataset composed on the date timestamp, calf latitude and longitude GPS coordinates, and cow latitude and longitude GPS coordinates. GPS timestamps were corrected for local time (Mountain Standard Time) to ensure correct pairing of cow-calf GPS data with field behavior observations. All GPS coordinates were converted to the Universal Transverse

Mercator (UTM) coordinate system to generate distance-based metrics for behavior classification.

Eight distance-based metrics were calculated from the paired cow-calf GPS coordinate data to aid in behavior classification. These metrics include distance between sequential points for the calf (Calf distance), distance between sequential points for the cow (Cow distance), distance between the cow and the calf (Cow Calf distance), a summation of the total distance (Cow distance + Calf distance + Cow Calf distance), and a count of the number of consecutive points the cow and calf were within 10 m of each other (Count 10 m). All distances were calculated using the Euclidean distance method.

Three additional metrics were calculated based on a moving window algorithm to capture movement patterns associated with the cow and calf traveling or remaining stationary based on GPS location data (Brennan et al., 2021). A 601-GPS point window (made up of the calf point of interest plus the 300 fixes prior and the 300 fixes after) was created corresponding to a 25 min time frame. For each point of interest, the number of other calf GPS points within that window that are within a 10 m radius was determined as that fix's Calf Count. Similarly, for each calf GPS point, the number of cow GPS locations that were within a 10m radius was calculated as the Calf Cow Count. The count variable for any fix, including the point of interest, had a maximum value of 600 (reached only if all other points in the window for the point of interest were within 10 m of a given point). The Calf Sum variable for each FOI was calculated by summing the counts for all fixes in the 601-point window (max = 360,000).

Statistical Analysis

The random forest algorithm (RF) was used to classify behavior as either grazing, resting, nursing, or walking. RF is an ensemble decision tree classifier which combines bootstrap sampling to construct several individual decision trees (forest) from which a class probability is assigned (Mellor et al., 2013). RF and tree-based models have been used to successfully classify livestock behavior using GPS and accelerometer derived metrics (Augustine and Derner 2013; Homburger et al. 2014; Dutta et al. 2015; Gonzalez et al. 2015; Mansbridge et al. 2018; Gou et al. 2019; Brennan et al. 2021). For the RF model, the Random Forest package of the Comprehensive R Archive Network (CRAN) implemented by Liaw and Wiener (2002) was utilized. The random forest models were built using 500 decision trees and the default number of nodes at each split. Yearly models were constructed for 2020 and 2021 as well as a combined global model that included data from all years. Livestock behavior was the response variable and the 8 distance metrics derived from the GPS coordinates were the predictors. The datasets used to build these models included only those data for which calf field observations, calf GPS, and cow GPS data were available. To test the accuracy of each model, a fivefold cross validation method was used. Error rates for each behavior and model accuracy was averaged across all folds. Following the model testing and validation stage, a final RF model was constructed using all available data from 2020 and 2021.

The final RF model was used to predict behavior for all unobserved observations for the GPS collared calves. Predictions were then used to calculate daily time spent grazing, resting, walking, and nursing for each collared calf. In addition, the number and duration of nursing bouts per day for each calf were calculated.

RESULTS AND DISCUSSION

Model

Classification accuracy rates for the RF models in 2020, 2021, and combined can be seen in Table 2.1. Overall, 2020 had a slightly greater accuracy rate compared to the 2021 and combined model. Prediction accuracy declined only slightly (<1%) by combining training data across years. Pooled two-year data likely included more outliers in behavior from each year which may have reduced the prediction accuracy, but likely better captured more natural range of behaviors for cows and calves on rangelands. Similarity in model accuracy between the cross-validation folds indicated that the RF models were not overfitting or underfitting in any year. Due to similarity in predictive accuracy, the combined RF model was selected to classify all unobserved data for both years. For the combined RF model, training (out of bag (OOB)) error rate was 96.49%. Out of bag accuracy in random forest models is considered an unbiased estimate of the overall classification accuracy (Breiman, 2001). Out of bag estimates of individual behaviors indicate low misclassification error rates (<4%) for grazing, resting, and nursing behaviors (Table 2.2). However, walking behavior had the highest misclassification error rate at 24.2%, of which 17.6% of that error was walking location being misclassified as grazing behaviors.

The variable importance plot (Figure 2.1) indicated that Calf Count, Calf Sum, and Calf Cow Count were the top three metrics for model accuracy, and each of these metrics were derived from the moving window algorithm. The ‘sum’ and ‘count’ metrics derived from the cow and calf GPS coordinates were likely important in identifying association and duration when cow/calf pairs were close to each other and not moving, which may indicate nursing behavior or resting behavior depending on the duration association. Likewise low Calf Count values may indicate movement, which would be indicative of grazing or resting behavior.

Behavior

Mean daily behaviors are shown in Table 2.3 and Figure 2.2. During the EARLY period, daily nursing time (mean ± SD) was 44.3 ± 13.0 min and during the LATE period was 36.6 ± 11.7 min. Nursing bout duration was 9.94 ± 0.93 min at the EARLY period and 9.54 ± 0.88 min at the LATE period. The number of nursing bouts per day was 4.32 ± 1.11 and 3.66 ± 1.11 during EARLY and LATE periods, respectively.

Mean daily nursing time predicted by our model was within the range of values reported in previous literature. Total daily nursing time has been shown to differ depending on stage of lactation, with values of 44 to 64 min · d^{-1} reported based on single-day visual observations collected at timepoints between 52 and 167 days postpartum (Day et al., 1987). This study noted a range of 4.5 to 8.6 bouts · d^{-1}, which is greater than the results in the current study. However, Day et al. (1987) was conducted in a small pasture and nursing behavior was subjectively determined through visual observation. These authors also reported a decline in total nursing time and number of nursing bouts with increased days postpartum, but bout duration did not change. In contrast, Odde et al. (1985) reported a larger time range (11 to 99 min · d^{-1}; mean of 46 min) of nursing per calf through visual observation, and no differences in number of nursing bouts (mean 5 bouts · d^{-1}) as days postpartum increased. Kour et al. (2021a) reported no difference in 24-h calf nursing time between 1 and 4 mo of age (82.3 ± 4.84 vs. 77.2 ± 7.35 min, respectively). Differences in individual dam milking ability in these studies may explain some of the variability in time spent nursing. It has been recognized that milk availability and calf motivation influence nursing behavior (de Passillé and Rushen, 2006). These contributions present complexities with estimating milk intake with the authors reporting lower milk levels resulted in an increase in nursing bout frequency and decrease in bout duration. Through validation of the current study, high frequency GPS tracking has the potential to provide insight to the variables in these complex relationships. Consequently, there is a broad application of this technology that may contribute to advancements in livestock research in rangeland settings.

Time calves spent grazing in our study was greater than in previous studies (Chambers, 1959; Sowell et al., 1996), which may be due to our ability to collect behavior data throughout the entire 24-h day. Daily grazing time was 387 ± 55.9 min during the EARLY period and 422 ± 41.7 min during the LATE period. Mean grazing time on pasture increased from 128 to 337 min over a 62-d period by dairy-breed calves (Chambers, 1959). The authors noted that calf age was unknown in this study. In another study, March-born calf daily grazing time ranged from 168 to 222 min in June and 324 to 342 min in September (Sowell et al., 1996). However, it is important to note that both these studies relied on visual observations which were only conducted during daylight hours from sunrise to sunset. Thus, these values may have underestimated total grazing time compared to studies that record grazing time continuously. The standard deviation in daily behavior mean time difference between EARLY and LATE periods was 10.6 min for nursing behavior and 59.9 min for grazing behavior.

This variability suggests there are numerous factors influencing behavior which warrant further investigation. Validation of the efficacy of this model to predict nursing and grazing behaviors with high accuracy was effective and will provide the ability to further explore the relationships between calf behavior and production variables. High frequency GPS data provides a consistent mode of measuring continuous calf behaviors without requiring intensive cattle management and labor inputs.

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Table 2.1. Accuracy rates (%) from the random forest (RF) model. A fivefold cross-validation approach was used to test model accuracy. Accuracy rate for each behavior and the overall rate is the average for each of the five folds.

Year	Grazing	Nursing	Resting	Walking	Overall
2020	98.1	96.9	97.9	77.8	97.6
2021	98.0	95.5	97.9	79.7	97.4
Combined	97.5	95.4	97.0	73.5	96.6

Table 2.2. Out of bag misclassification error rates (%) for each behavior class from the from the random forest (RF) model using all data from 2020 and 2021

	Grazing	Nursing	Resting	Walking	Class Error Rate
Grazing	86205	151	2538	132	3.17
Nursing	363	23257	478	56	3.71
Resting	3558	192	123787	104	3.02
Walking	742	70	209	3194	24.22

Table 2.3. Mean daily GPS-predicted time for calves from 2020 and 2021 during early lactation and late lactation tracking periods

Behavior, min · d^{-1}	EARLY[1]	SD	LATE[2]	SD
Nursing	44.3	13.0	36.6	11.7
Grazing	388	55.9	422	41.7
Resting	895	100	884	80.9
Walking	8.69	1.75	10.1	2.00

[1]Early lactation (Calf age ± SD = 65.4 ± 10.0 d)

[2]Late lactation (Calf age ± SD = 162 ± 22.3 d)

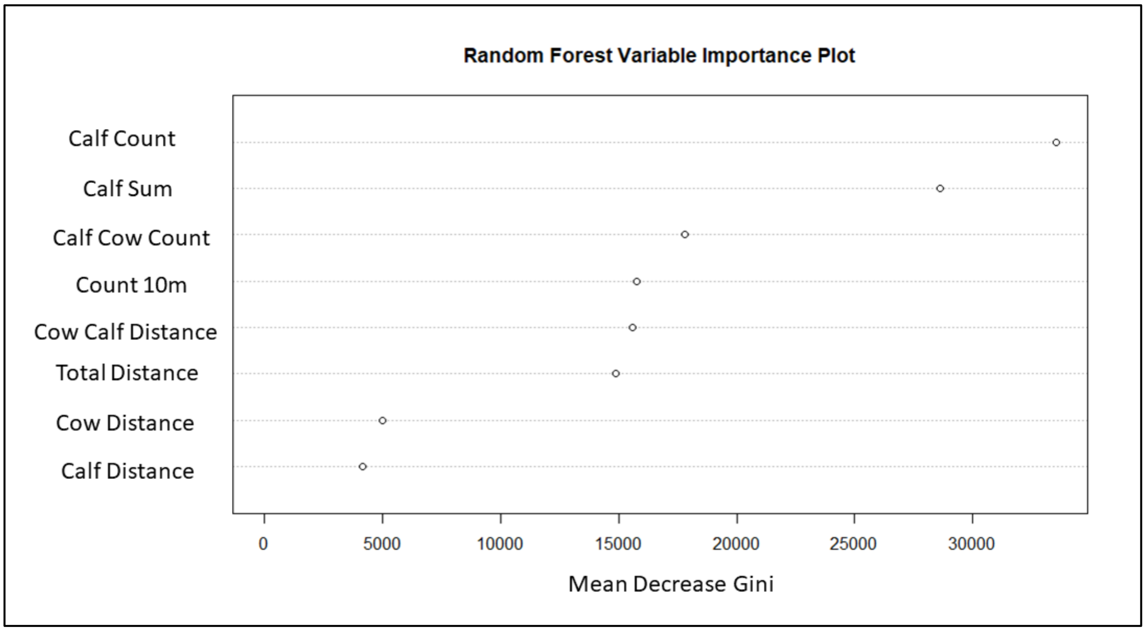

Figure 2.1. Variable importance plot for the random forest (RF) model using 2020 and 2021 data combined. The plot ranks the 8 predictor variables in order of importance to model accuracy.

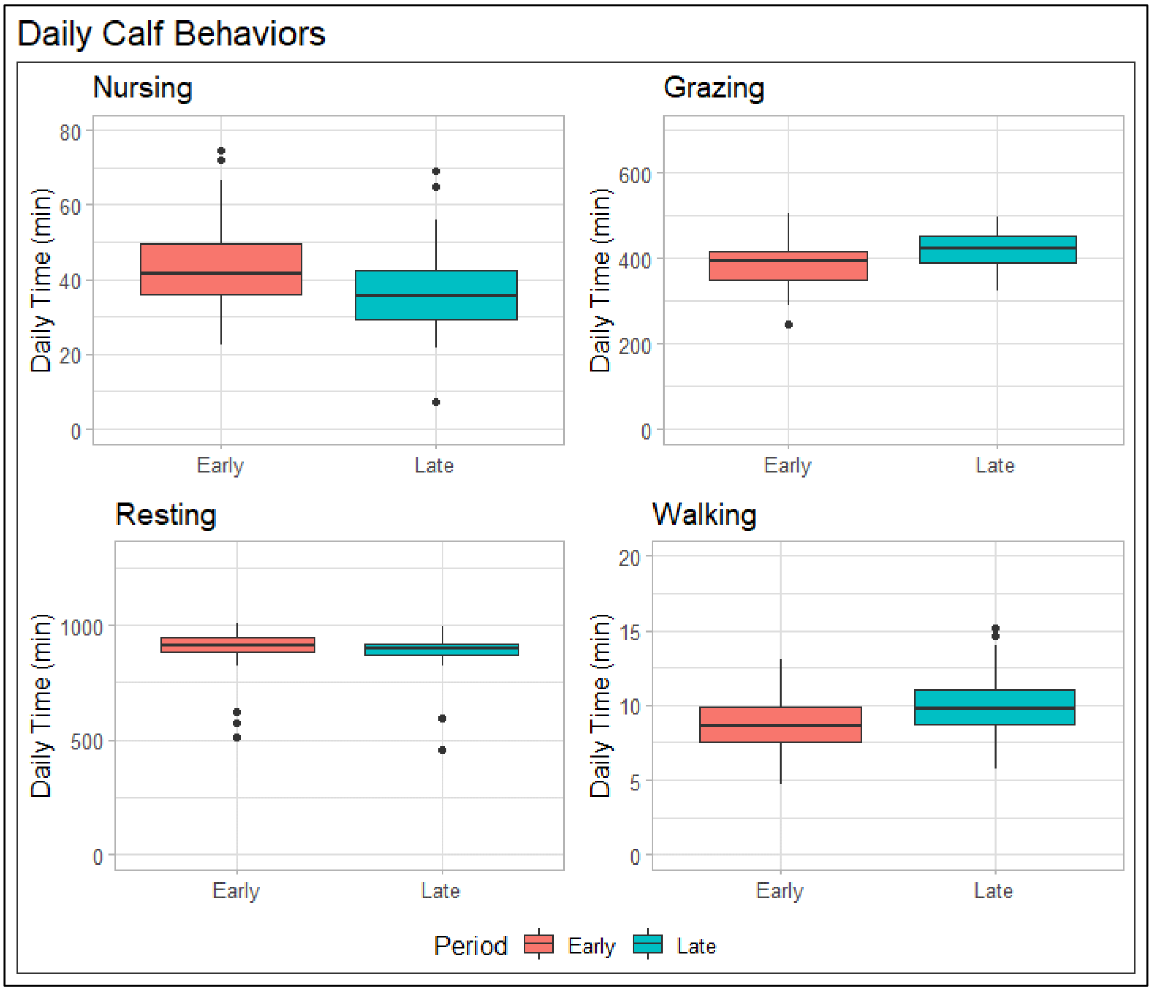

Figure 2.2. Mean daily GPS-predicted time calves spent nursing, grazing, resting, and walking during early lactation (calf age 65.4 ± 10.0 d) and late lactation (calf age 162 ± 22.3 d) tracking periods

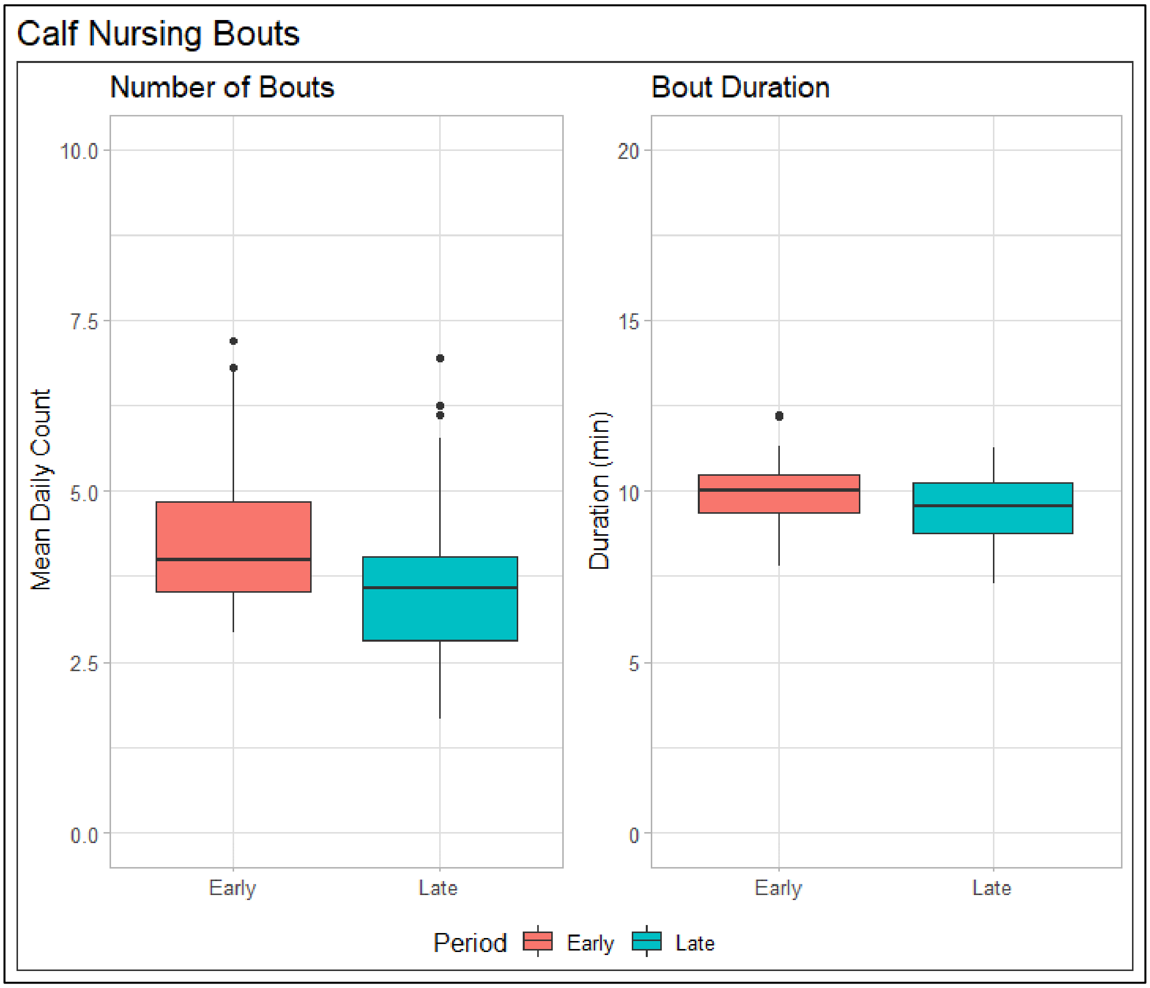

Figure 2.3. Mean GPS-predicted calf nursing bout number and duration during early lactation (calf age 65.4 ± 10.0 d) and late lactation (calf age 162 ± 22.3 d) tracking periods

CHAPTER III: IMPACT OF INCREASING LEVEL OF MILK PRODUCTION ON COW AND CALF PERFORMANCE IN THE NEBRASKA SANDHILLS

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Abstract

Selection for increased milk production across the United States has resulted in variable cow and calf productivity responses. The objective of this study was to determine the impact of increasing level of milk production on cow body weight, condition score, and reproductive performance, and calf growth in the Nebraska Sandhills. In a 2-yr study, data were collected on 118 crossbred cow-calf pairs from March- and May-calving herds. On approximately 30, 60, 90, 120, and 210 d postpartum, individual cow 24-h milk yield was estimated through weigh-suckle-weigh techniques. Cow body weight (BW) and body condition score (BCS) were collected weekly through breeding. Calf BW was recorded at each milking. Milk area under the curve (AUC) values were calculated and data were analyzed using linear regression analysis. Cow BW, BW change, and reproductive performance were not ($P > 0.12$) associated with milk AUC, except for a tendency ($P = 0.09$) for lower BW at breeding. At weaning, cow BCS was negatively associated ($P = 0.02$) with increasing milk AUC but was not associated at any other physiological stage. Pre-weaning calf BW was positively associated ($P < 0.01$) with increased milk AUC at each weight date. A significant positive association with calf average daily gain (ADG) was observed from birth to age 120 d and a tendency ($P = 0.09$) for a positive association was observed from age 120 d to weaning. Steer ADG in the finishing phase was not ($P = 0.63$) associated with dam milk production. In this environment, increasing milk production had a positive increase in calf growth during the pre-weaning phase without any negative impacts on overall cow-calf production.

Keywords: beef cattle, calf growth, milk production

INTRODUCTION

Across the United States, there is spatial and temporal variability in forage resource environments (Zimmer et al., 2021). Therefore, genetic selection and cow-calf management practices must be tailored to each unique environment to optimize forage resource utilization and animal productivity. Increased efforts to improve output-related traits, such as calf weaning weight, have been observed (Kuehn and Thallman, 2016). Mixed results have been concurrently observed with increased selection for calf growth through increasing dam milk production (Mulliniks et al., 2020), which may be due to differences in forage intake (Grings et al., 2008). With decreased milk availability, calves will compensate by increasing forage intake (Lusby et al., 1976; Ansotegui et al., 1990; Tedeschi and Fox, 2009). This relationship between milk and forage intake may play a key role in calf performance outcomes in environments differing in forage quality.

Lactation creates one of the periods of highest nutrient demand for a beef cow (NASEM, 2016). This demand can result in cows partitioning nutrients away from reproduction and body reserves (Short et al., 1990), which can result in cows experiencing negative energy balance and have a negative impact on reproductive performance. Mulliniks et al. (2011) reported a relationship between milk production and postpartum interval with every 1 kg/d increase in milk production associated with ~5.5 d increase in postpartum interval. Even in an environment where forage supply was sufficient, Edwards et al. (2017) reported the lowest pregnancy rates in cows with the highest milk production.

Therefore, the objective of this study was to evaluate the effects of increasing total milk yield on cow BW, cow BCS, cow reproductive performance, calf BW, and calf gain in beef cattle grazing Nebraska Sandhills native range.

MATERIALS AND METHODS

All animal management and handling procedures were in compliance with the University of Nebraska Institutional Care and Animal Use Committee (IACUC #2251).

This study took place during 2 consecutive years (2020-2021) at Gudmundsen Sandhills Laboratory (GSL) located 11 km northeast of Whitman, Nebraska (42.081895, -101.448515; elevation 1,075 m). The ranch is positioned in a semi-arid ecosystem that relies on timing and quantity of precipitation during the growing season (typically May-September) for optimum cool- and warm-season forage production. Annual rainfall in 2020 and 2021 was 88.1% and 85.7%, respectively, of the 35-yr average (493 mm). August standing forage was 93.0% (2020) and 85.7% (2021) of the 18-yr average (2,032 kg/ha). Precipitation and forage production values were actual amounts recorded at GSL (forage production obtained via personal communication with Jess Milby). Forage in the upland range pastures was typical of native Sandhills range and was comprised of warm-season grasses (~50%) including little bluestem (*Schizachyrium scoparium*), sand bluestem (*Andropogon hallii*), prairie sandreed (*Calamovilfa longifolia*), switchgrass (*Panicum virgatum*), and blue grama (*Bouteloua gracilis*). Cool-season grasses, including Scribner's rosette grass (*Dichanthelium scribnerianum*), prairie junegrass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*), and Kentucky bluegrass (*Poa *pratensis*), consisted of ~30% of total forage production. Forbs and shrubs were also present in the pastures.

Cow Management and Data Collection

Mature Red Angus/Simmental crossbred cows from a March-calving herd (*n* = 59) ranged from 4- to 6-yr-old and May-calving herd (*n* = 59) ranged from 4- to 7-yr-old. At the initiation of the study, cows were selected at ~30 d post-calving based on initial milk production estimated using a traditional weigh-suckle-weigh technique to have cows with low to high milk production. Cows and calves were separated by 1000 h, paired and allowed to nurse at 1630 h, then separated again until the following morning at 0700 h. Beginning at 0700 h, calves were weighed, paired with their dam and allowed to nurse, then weighed again. Milk production was estimated by calf pre- and post-suckle body weight difference and extrapolated to 24-h yield based on duration of separation. Cows were stratified by cow age, body weight (BW), body condition score (BCS), calving date, calf sex, calf age, and birth weight. At approximately d 60, 90, 120, and 210 postpartum, milk production was measured using a modified weigh-suckle-weigh technique described by Waterman et al. (2006). The day prior to milking, cows and calves were separated before 1000 h, paired and allowed to nurse at 1630 h, then separated again for approximately 14 h until machine milked. Each cow received an intramuscular injection of oxytocin (20 IU; Vedo Inc., St. Joseph, MO) 10 min prior to milking to facilitate milk letdown. Milking began at 0630 h the following day and was completed using a portable milking machine (Porta-Milker, Coburn Company Inc., Whitewater, WI) until machine pressure could not extract any additional fluid. Milk weight, time of last separation, and time of milking initiation were recorded for calculation of 24-h milk yield. The 24-h milk yield and days in milk at each timepoint were used to calculate area under the curve (AUC) for each cow, which was a representation of cumulative milk production throughout the lactation period.

At calving each year, the March herd calved in a drylot while being fed meadow hay for ~60 d postpartum. Weekly hay samples were dried in a forced air oven at 60° C for 48 h and composited for analysis. In contrast, the May-calving herd calved on native range pastures. After 60 d postpartum, both herds were managed similarly between years. In each year, March- and May-calving herds grazed a 160 ha upland native pasture throughout the duration of the breeding season, then grazed pastures ranging 235-543 ha until weaning. Forage nutritive value was determined at each milking timepoint on diet samples collected by 3 esophageal fistulated cows in the study pasture. The esophageal fistulated cows were taken off feed for approximately 24 h prior to diet collection days but had *ad libitum* access to water. On the day of diet collection, the cows were hauled in a livestock trailer to a representative area of the study pasture. Esophageal cannulas were removed, a collection bag was strapped around each cow’s neck, and the animals were allowed to graze for approximately 20 min or until an adequate quantity was obtained. Following diet collection, the cannulas were replaced, and cows were returned to their pasture. Diet extrusa and any saliva captured in the collection bag were transferred to jars and freeze-dried. All forage samples were ground through a 1 mm screen using a Wiley mill. Analysis for crude protein (CP) and total digestible nutrients (TDN) was completed by a commercial laboratory (Ward Labs, Kearney, NE). Neutral detergent fiber (NDF) content of diet samples was estimated using an ANKOM. Diet quality for 2020 and 2021 is presented in Table 3.1.

Cow body weight (BW) and body condition score (BCS; 1 = emaciated, 9 = obese; Wagner et al., 1988) were collected prior to calving, weekly from the onset of the study to the breeding season, and at weaning. Body condition score was determined visually and through palpation by a trained technician. For cow BW analysis, pre-calving, pre-breeding, breeding, and weaning values were used. Pre-breeding and breeding BW were the average of the two weekly weights at the start of each respective period. Body weight change at these timepoints was determined relative to the pre-calving BW. All cows were bred via natural service (1:15 bull:cow) during a 45-d breeding season. Pregnancy diagnosis was conducted via transrectal palpation by a local veterinarian ~90 d following bull removal, and open cows were culled. Percent of cows calving in the first 21-d of the calving season was calculated with the start of the calving season coinciding with the first day that 2 or more cows calved.

Blood samples were collected via coccygeal venipuncture into serum separator tubes (Corvac, Kendall Healthcare, St. Louis, MO) weekly from the onset of the study until the onset of the breeding season. Samples were allowed to clot for 1-h at room temperature, then were centrifuged at 2,200 x *g* at 4°C for 20 min. Harvested serum was stored in plastic vials at -20°C until further analysis. A commercial enzyme-linked immunoassay kit (DGR International, Inc., Springfield, NJ) was used with a 96-well microplate spectrophotometer (Epoch, BioTek, Winooski, VT) to determine circulating serum progesterone concentrations. Cows were considered cycling before the start of the breeding season if two consecutive samples were ≥ 1.0 ng/mL. The intra- and inter-assay CV were, respectively, 7.65 and 3.48.

Pre-weaning Calf Management

Calf BW was recorded at birth and on all days the cows were milked (~ d 30, 60, 90, 120, and weaning) without adjustment for dam age or calf sex. At birth, all calves were tagged and received a 7-way clostridial vaccine (Alpha 7, Boehringer/Ingelheim, Duluth, GA). At approximately 21 d of age, bull calves were castrated, and all calves received vaccinations for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, bovine parainfluenza virus-3, bovine respiratory syncytial virus, mannheimia haemolytica, and pasteurella multocida (Bovi-Shield Gold One Shot, Zoetis, Parsippany-Troy Hills, NJ). In addition, a 7-way clostridial vaccine (Vision 7, Merck, Kenilworth, NJ) was also given at this time. At 60 d of age, calves received a second 7-way (Vision 7) and an injectable insecticide (1.1 mL/cwt; Cydectin, Bayer, Shawnee Mission, KS). At weaning, calves received a vaccination for haemophilus somnus (Somubac, Zoetis) and a Bovi-Shield Gold 5 vaccination (Bovi-Shield Gold 5, Zoetis), as well as a pour-on insecticide (Promectin B, Vedco, Saint Joseph, MO). A second dose of each vaccine was administered 14 d later. All March-born steers were implanted at weaning (year 1: Component TE-IS, Elanco, Greenfield, IN; year 2: Synovex Choice, Zoetis). May-born steers were implanted with 25.7 mg estradiol (Compudose, Elanco) at weaning.

Post-weaning Steer Management

Post-weaning steer management differed by season of calving. March-born calves were weaned Nov 1 and May-born calves were weaned Dec 1. All calves were fed ad libitum meadow hay and 0.45 kg/d dry distillers grain for 2 wk. March steers were then transported 48 km to the West Central Research and Extension Center (WCREC) in North Platte, NE. Following a 2 wk acclimation period, steers were placed in a GrowSafe feeding system (GrowSafe Systems Ltd., Airdrie, AB, Canada). A 2-d average weight was recorded 10 d after GrowSafe entry and considered the initial feedlot entry BW. Approximately 100 d before slaughter, steers were implanted with 28 mg estradiol benzoate and 200 mg trenbolone acetate (Synovex Plus, Zoetis).

May-born steers were backgrounded over winter to gain either 0.45 or 0.9 kg/d, then grazed upland native range from May to September. In May, steers were implanted (Component ES, Zoetis). In September, steers were shipped to WCREC and managed similarly to the March-born steers in the GrowSafe feeding system. Upon feedlot entry, all May steers were implanted with 200 mg trenbolone acetate, 20 mg estradiol USP, and 29 mg tylosin tartrate (Component TE-200, Elanco). A common finishing diet of 48% dry rolled corn, 40% corn gluten feed, 7% prairie hay, and 5% supplement was fed throughout both herd’s finishing periods. Average daily gain (ADG) feedlot performance were recorded for all steers.

Statistical Analysis

All analyses were performed using SAS 9.4 PROC GLIMMIX (SAS, Cary, NC). A similar initial model was used to analyze both the cow and progeny performance data. To account for differences in calving season (March or May) and differences among years, a SEASONYR term was determined. To account for differences in birth date within calving season, days within calving season was determined (CDATE). The initial model included the fixed effects of calf gender (CALFSEX; Heifer, Steer), cow age (COWAGE; 4, 5, 6), linear Milk AUC (MILKAUC), and linear and quadratic CDATE and the random effect of SEASONYR and residual error. For the behavior data, which was measured both early and late in the year, an additional fixed effect of time (TIME; Early, Late) and the random effect of SEASONYR was replaced by

Cowid(SEASONYR), to account for the repeated measurements on the same experimental unit. In order to account for the differences between seasons and between years, the error term used for testing the MILKAUC effect was the Cowid(SEASONYR) random effect. All other effects were tested over the residual. Non-significant terms ($P > 0.05$) were dropped to produce the final model. A normal distribution was assumed for all measures, except for cow pregnancy rate and cycling rate where a binomial distribution was assumed. Binomial data was evaluated using the odds and odds ratio. Odds (*0*) are the probability (*p*) of the event occurring over the event not occurring (1-*p*). Odds ratio is the ratio of the odds for two different levels. Significance was determined at $P \leq 0.05$ and tendency was determined at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Cow Performance

Means for 24-h milk production at each timepoint during the lactation period are shown in Table 3.2 for March-calving and May-calving cows. Milk yield values ranged from 6.50 - 9.38 kg at 30 d postpartum and 2.11 - 3.64 kg at weaning ~210 d postpartum.

Cow BW was not influenced by milk AUC (Table 3.3) at pre-calve ($P = 0.37$), pre-breed ($P = 0.17$), or weaning ($P = 0.13$). At breeding, cow BW tended ($P = 0.09$) to be negatively associated with milk AUC with a 0.05 kg decrease in BW for every 1 kg increase in milk AUC. This decrease may be due to the timing of high mobilization of body reserves due to peak lactation requirements, which aligns in the production cycle near the approach of the breeding season. Cows will metabolically adapt to lactation by mobilizing muscle mass and adipose tissue, and increasing rate of gluconeogenesis

(Bauman and Currie, 1980; McCabe and Boerman, 2020). Thus, lactation will be prioritized at the expense of the cow's body reserves. Body weight change was not influenced by milk AUC when assessed at pre-breed (*P* = 0.42), breed (*P* = 0.19), or weaning (*P* = 0.12) relative to pre-calving. Increased milk AUC did not influence BCS at pre-calve (*P* = 0.97; Table 3.4), pre-breed (*P* = 0.48), or breed (*P* = 0.55). At weaning, BCS decreased (*P* = 0.02) by 0.0006 points for every 1 kg increase in milk AUC. The lack of association between increasing milk production on BW and BCS in the current study may indicate that the level of milk production needed to see increased BW loss and mobilization was not high enough in the given environment and management. In a restricted feed environment, such as the current study, BW and BCS would be expected to have an inverse relationship with milk production due to increased nutritional requirements by lactation (Minick et al., 2001).

In this study, the odds of cows becoming pregnant were not influenced (*P* = 0.58; Table 3.5) by increasing milk AUC. The odds of cows cycling before the start of the breeding season were not influenced (*P* = 0.53) by milk AUC. In contrast, Edwards et al. (2017) reported a decline in reproductive performance with higher milk production reporting lower AI and final pregnancy rates in cows with higher milk production. This would be expected due to energy repartitioning away from reproduction to support lactation (Short et al., 1990). However, in the current study, the smaller sample size may be limiting the ability to find a difference in reproductive performance.

Calf Performance

Calf birth weight was unaffected by milk AUC (*P* = 0.28; Table 3.6). Calf pre-weaning BW was positively associated with increased milk AUC at age 30 (*P* < 0.01), 60

(P < 0.01), 90 (P < 0.01), and 120 (P < 0.01) d. A positive association was also observed between milk AUC and calf BW at weaning (P < 0.01) with a 0.05 kg increase in weight for every 1 kg increase in milk AUC. As expected with the increased calf BW, ADG from birth to 30 d (P < 0.01), 30 to 60 d (P = 0.04), and 60 to 90 d (P < 0.01) was positively influenced by increasing milk AUC. However, d 120 to weaning calf ADG tended (P = 0.09) to be positively associated with increasing milk AUC. Overall ADG from birth to weaning was positively associated (P < 0.01) with increased milk AUC. In agreement, Boggs et al. (1980) reported the correlation between level of milk production and calf ADG declines as the lactation period progresses. It has been suggested that this decline may be due to the interaction between nursing and forage intake of the calf (Clutter and Nielson, 1987; Ansotegui et al., 1991). Brown and Brown (2002) noted a stronger magnitude of association between milk production and pre-weaning ADG in lower-milking dams, suggesting that these calves were better able to utilize all the milk produced by their dam.

Regression coefficients used to estimate the influence of milk AUC on post-weaning steer performance are reported in Table 3.7. Average daily gain in the finishing phase was not associated (P = 0.63) with milk AUC. Biological efficiency has shown to have an inverse relationship with milk production level, with inputs (i.e. energy fed) contributing more to variation in efficiency than outputs (i.e. weaning and slaughter weight) (van Oijen et al., 1993).

In summary, increasing total milk produced throughout the lactation period had minimal influence on the cow production parameters assessed in this study in the Nebraska Sandhills forage environment. In general, BW, BCS, and reproductive productivity were maintained regardless of total milk produced during the lactation period. This suggests that the genetic potential for milk in the current study's cowherd is effectively supported by the environmental forage quality conditions. Although our data indicate milk production increases pre-weaning calf growth, this relationship weakens after 120 d, which may be due to the increase in forage intake and reliance on forage to meet requirements of the growing calf. Further examination of post-weaning calf efficiency will provide understanding of how of dam milk yield selection impacts the overall beef production system.

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Table 3.1. Forage analysis[1] of range diet by month (dry matter basis)

	Hay[2]	May	June	July	August	September	November	December
CP, %								
2020	5.7	-	9.3	7.5	8.3	6.9	4.6	4.4
2021	6.0	12.9	8.8	8.8	6.7	6.4	5.0	5.2
TDN, %								
2020	54.5	-	58.8	57.1	62.9	55.6	55.1	53.6
2021	55.3	62.5	61.8	65.6	56.8	62.3	54.0	49.0
NDF, %								
2020	69.9	-	61.1	67.4	42.9	60.1	64.8	60.5
2021	63.3	53.4	51.7	42.3	53.8	50.4	70.7	66.2

[1]Forage quality samples were collected from esophageal fistulated cows
[2]Weekly hay samples in the March-calving herd were composited from 30-60 d postpartum

Table 3.2. 24-h milk yield (mean ± SD) for March- and May-calving herds at each milking timepoint throughout lactation

Item	2020		2021	
24 hr milk yield, kg	March	May	March	May
d 30[1]	6.89 ± 1.94	8.32 ± 2.28	6.50 ± 1.90	9.38 ± 3.29
d 60[2]	4.43 ± 0.89	6.11 ± 1.63	5.54 ± 1.15	7.17 ± 1.23
d 90[2]	5.80 ± 1.07	5.50 ± 1.24	6.48 ± 1.20	6.84 ± 1.01
d 120[2]	4.78 ± 0.90	3.75 ± 0.76	6.25 ± 1.11	4.07 ± 0.82
d 210[2]	2.11 ± 0.82	2.54 ± 1.03	3.31 ± 1.22	3.64 ± 1.06

[1]Milk yield estimated with a traditional weigh-suckle-weigh

[2]Milk yield estimated with a modified weigh-suckle-weigh using a milking machine

Table 3.3. Regression coefficients used to evaluate the influence of increasing cow cumulative milk produced[1] throughout the lactation period on cow body weight (BW) and BW change

Measurement	Estimate	SEM	*P*-value
Body weight, kg			
Pre-calve	-0.02	0.02	0.37
Pre-breed[2]	-0.04	0.03	0.17
Breed[2]	-0.05	0.03	0.09
Wean	-0.04	0.03	0.13
Body weight change[3], kg			
Pre-breed	-0.01	0.01	0.42
Breed	-0.02	0.02	0.19
Wean	-0.02	0.01	0.12

[1]milk area under the curve
[2]Average of two consecutive weekly weights at the beginning of the period
[3]Relative to pre-calve weight

Table 3.4. Regression coefficients used to evaluate the influence of increasing cow cumulative milk produced[1] throughout the lactation period on cow body condition score

Measurement	Estimate	SEM	*P*-value
Body condition score[2]			
Pre-calve	<0.0001	0.0002	0.97
Pre-breed[3]	-0.0001	0.0002	0.48
Breed[3]	-0.0001	0.0002	0.55
Wean	-0.0001	0.0002	0.02

[1]milk area under the curve
[2]Scale of 1 (emaciated) to 9 (obese)
[3]Average of two consecutive weekly body condition scores at the beginning of the period

Table 3.5. Regression coefficients used to evaluate the influence of increasing cow cumulative milk produced[1] throughout the lactation period on cow reproductive performance

Measurement	Estimate	SEM	*P*-value
Pregnancy rate, %	-0.001	0.002	0.58
Cycling[2], %	-0.001	0.002	0.53

[1]milk area under the curve

[2]Cycling before the start of the breeding season; evaluated by weekly serum progesterone concentration

Table 3.6. Regression coefficients used to evaluate the influence of increasing cow cumulative milk produced[1] throughout the lactation period on calf pre-weaning body weight and average daily gain

Measurement	Estimate	SEM	*P*-value
Body weight, kg			
Birth	-0.002	0.002	0.28
d 30	0.018	0.005	<0.01
d 60	0.024	0.005	<0.01
d 90	0.034	0.007	<0.01
d 120	0.040	0.008	<0.01
d 210 (wean)	0.050	0.010	<0.01
Average daily gain, kg/d			
Birth - d 30	0.001	<0.001	<0.01
d 30 - 60	<0.001	<0.001	0.04
d 60 - 90	<0.001	<0.001	<0.01
d 90 - 120	<0.001	<0.001	0.01
d 120 - 210 (wean)	<0.001	<0.001	0.09
Birth - wean	<0.001	<0.001	<0.01

[1]milk area under the curve

Table 3.7. Regression coefficients used to evaluate the influence of increasing cow cumulative milk produced[1] throughout the lactation period on steer calf feedlot performance

Measurement	Estimate	SEM	*P*-value
Feedlot performance			
Average daily gain, kg/d	0.0001	0.0002	0.63

[1]milk area under the curve