ENERGY REQUIREMENTS AND PRODUCTION EFFICIENCY OF LACTATING BEEF COWS IN A DRYLOT SYSTEM

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“Courage is being scared to death… but saddling up anyway.”

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“And now these three remain: faith, hope, and love. But the greatest of these is love.”

-1st Corinthians 13:13

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Abstract: Population growth and alternative use of agricultural lands continues at an alarming rate, posing many challenges to food growers worldwide— particularly for meat-animal producers. Limited grazing land availability, adverse weather conditions, excess feedyard capacity, and volatility in the market are among the factors that have stimulated interest in the expansion of semi-confinement and confinement systems (controlled environments) for beef cattle production. The purpose of this research is to define cow and calf responses to a range of feed intakes and resulting energy provided to the cows. A total of 40 lactating beef cows were fed 135, 159, 176, 200, and 223 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$ for 111 d until weaning. This range of feed energy was accomplished by increasing the amount of feed provided using the same diet across all treatments. The diet consisted primarily of Sweet Bran® (wet corn gluten feed), prairie hay, cracked corn, and mineral supplement. Steer calves were offered the same diet as *ad libitum* creep feed along with milk and did not have access to cow feed. Body weight, body condition, milk yield and composition, and body composition were measured on cows; BW, creep intake, and body composition was also taken for steer calves. Eight cows were fed each of the energy intake levels in separate pens. Dependent variables were regressed on the linear and quadratic terms of energy intake. Increasing cow energy intake beyond maternal tissue maintenance is inefficient, as cows gained BW ($P < .05$) and condition ($P < .01$) and calves became fleshy ($P < .05$). Milk production increased ($P < .01$) as intake increased, which was not well-utilized by the calf. Additionally, cows maintained maternal tissue maintenance during lactation at an intake of 157 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$ and maintenance energy requirement was calculated at 84.7 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$, based on feed energy values. Utilizing digestibility data, a lactating beef cow required 108 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$.

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Item	Term
ADG	average daily gain
ADIA	acid detergent insoluble ash
ADIN	acid detergent insoluble nitrogen
BCS	body condition score
BF	back fat
BW	body weight
$BW^{0.75}$	metabolic body weight
CE	controlled environment
CIDR	controlled internal drug release
CP	crude protein
DM	dry matter
DMI	dry matter intake
E	energy content of milk
EBW	empty body weight
EE	ether extract
IMF	intramuscular fat
IVNDF	*in-vitro* neutral detergent fiber
ME	metabolizable energy
MM	milking machine
MML	maternal tissue maintenance intake level of lactating beef cows in a drylot
NDF_{CP}	crude protein-free neutral detergent fiber
NE	net energy
NRC	National Research Council
RE	retained energy
REA	ribeye area
RF	rump fat
TBE	total body energy
TDN	total digestible nutrients
TMR	total mixed ration
WSW	weigh-suckle-weigh
WW	weaning weight

CHAPTER I

REVIEW OF THE LITERATURE

Nutrient Partitioning

Feed Energy to Calf BW

One of the most important, yet overlooked, cow characteristics in calf production is the conversion of cow intake to calf performance. Genetics and environment determine calf performance during two periods of cow to calf nutrient conversion: prenatally through transfer of nutrients via the umbilicus and postnatally by nursing. Uterine environment and nutrient availability conditions the fetus for the postnatal environment (Ford and Long, 2012). Both under- and over-nutrition of the dam can have adverse effects on the growth and development of the calf *in utero* (Du et al., 2010; Ford and Long, 2012). Nutrition of the pregnant dam not only effects development of the fetus, but programs the fetus for the outside, perceived environment, which affects lifetime growth of offspring (Du et al., 2010). Over- and under-feeding gestating cows has been linked to obesity, cardiovascular problems (Ford and Long, 2012), decreased hyperplasia in muscle fibers, and a change in musculoskeletal composition (Du et al., 2010).

Postnatally, milk yield, milk composition, and the interaction of milk with other nutrients (forage or mixed ration) available to the calf can affect its growth and performance. Some of the factors that can affect milk yield and composition include genetics, nutrition, body composition, physiological state of the dam, and suckling-rate of the offspring. One study aimed to estimate energy requirements of maintenance plus lactation in various breeds of cows and described differences among breeds in their ability to convert cow energy intake to calf body weight (**BW**) gain (Jenkins et al., 1991). Calves from Angus x Hereford -sired cows weighed less at birth and continued to weigh less throughout the trial than the Brown Swiss, Chianina, Gelbvieh, Maine Anjou, and Red Poll sire-breeds. These other breeds consumed more feed (with the exception of the Red Poll-sired cows) and, in turn, produced more milk. The authors also reported that calves from higher-milking cows consumed less creep feed than their counterparts (Jenkins et al., 1991). Pairs originating from Angus x Hereford–sired dams had an increased or equal efficiency as the other breed-types that had greater milk and/or growth potential. Although cows with higher milk yields were able to produce heavier calves, those cows required more energy to maintain BW, thus were less efficient (Jenkins et al., 1991). It has also been found that cows that produce lower milk yields become fatter by the end of lactation (Mondragon et al., 1983), which may be attributed to the partitioning of nutrients to fat deposits rather than milk production. In this case, cows with a tendency to gain BW may be putting more energy into lipid storage rather than using those nutrients for milk production. In successive parities, it was found that fatter cows had reduced milk yields compared to thin cows (Mondragon et al., 1983). Regardless of milk production, excessive fleshiness is not a desirable trait for cows due to the increased energy requirements and, in warmer climates, extra insulation (NRC, 2000).

Wyatt et al. (1977) found that increased milk production decreased the conversion of milk to calf gain efficiency by 51-72% and decreased forage intake of calves by 32 or 38%, depending on genetics. However, those calves receiving low levels of milk, although more efficient, had smaller weaning weights (**WW**) and gained less quickly than their counterparts.

A study examining the effect of energy intake of the cow on milk production, subsequent calf gain, and creep feed intake of the calf was performed using a 63% total digestible nutrients (**TDN**) diet fed at 120% or 100% NRC (1976) of estimated cow energy requirements (Bartle et al., 1984). Energy requirements of the cows were estimated by Bartle et al. (1984) using the following equation by Petit and Micol (1981):

$$REQ\ (Mcal\ ME) = 0.12 * BW^{0.75} + 1.3 * milk\ production\ (kg),$$

where REQ = energy requirement in Mcal of ME and $BW^{0.75}$ = metabolic body weight. Calves did not have access to cow feed and half of the calves in each treatment were allowed creep feed, whereas the other half did not have feed other than milk until average daily gain (**ADG**) reached a specified critical point (Bartle et al., 1984). Results from this trial yielded no difference in calf BW between treatments, even though cows fed 120% energy requirements produced more milk (0.2 kg) than the 100% treatment. Altogether, the calves required 7.5 kg of milk plus 2.3 kg of creep feed in order to gain 1 kg/d (Bartle et al., 1984). The authors also indicate that by wk-9 of lactation, milk can only sustain a calf's maintenance requirements; thus, supplemental feed is needed for gain at this time point.

Digestibility

Digestibility is the percentage of a feedstuff that is absorbed into the body after digestion. The simplest technique to determine digestibility is to measure how much feed is taken in minus fecal output (Cochran and Galyean, 1994). In the past, nutrient values of the feed alone have been used to estimate digestibility (Mertens, 1987). It is known, however, that differences in animal type, sex, stage of production, and environment play a large role (Mertens, 1987). Much of the available data on digestibility come from maintenance experiments conducted on sheep and feeder cattle, which are tabulated as "book-values" (Tyrrell and Moe, 1975); this research is applied to beef cows, although little digestibility work has been completed directly with beef cows. Linear regression on digestible energy of a total mixed ration (**TMR**) fed to lactating dairy cows has been shown to account for 86% of the variation in the net energy (**NE**) requirement for milk when they are applied to dairy cows (Tyrrell and Moe, 1975). These authors indicate that NRC-predicted TDN values consistently overestimate the observed values for lactating cows by an average of 12%. In the same way, the digestibility of a certain diet fed to high-producing dairy cows was significantly lower than that of the same diet fed to steers fed at maintenance (Moe et al., 1965). It was concluded (via regression analysis) that TDN gradually declines as intake increases, even up to an increase of 5x maintenance level (Moe et al., 1965). Digestion has also been found to decrease in lactating cows as compared to when they are dry (Tyrrell and Moe, 1975). This conclusion, along with other results reviewed by Tyrrell and Moe (1975), indicate that the main reason book values are not accurate for a TMR fed to lactating cows is due to differences in intake, such that as intake increases, digestibility decreases (Tyrrell and Moe, 1975; Shaver et al., 1986; Okine and Mathison, 1991). This can be easily explained by the reduction in retention time with greater feed intake, which is necessary for greater intake (Shaver et al., 1986; Okine and Mathison, 1991). Diet composition also plays a factor in determining the rate of decline in digestibility (Moe et al., 1965). Some diets have been shown to decrease TDN more rapidly than others as intake of those diets increases (Moe et al., 1965). The reason for this variability is mostly due to different ingredients (or the same ingredients from differing sources) and different forms of ingredients (long, chopped, pelleted, etc.). The type of diet also plays a role in digestibility. As the proportion of concentrate to hay or silage of the TMR increases, digestibility also decreases (Tyrrell and Moe, 1975). Shaver et al. (1986) concluded that digestability decreases as the proportion of grain increases, which is most likely due to a reduction in ruminal pH resulting in reduced digestion in the rumen. Likewise, digestibility was reduced for lactating cows fed a 68% concentrate (15.95% corn silage, 15.95% alfalfa haylage, 53.17% shelled corn, 11.83% soybean meal, 3.1% vitamin/mineral mix) diet compared to cows fed an 83% forage (41.43% corn silage, 41.42% alfalfa haylage, 7.35% shelled corn, 7.65% soybean meal, 2.15% vitamin/mineral mix) diet (Colucci et al., 1982). The authors proposed that the decline in digestibility was due to an increased grain rate of passage, although they did not measure rate of passage. For high-concentrate diets, methods of slowing passage rate could be used to take full advantage of the increased energy density of the diet by giving the gastrointestinal tract more time for digestion and absorption. Achieving this goal, however, would most-likely require adding roughage to the diet, thereby decreasing the energy concentration.

Broderick (2003) reported a linear increase in apparent digestibility of organic matter and dry matter, while NDF and ADF apparent digestibility decreased linearly for cows fed increasing levels of energy. In cows that were limit-fed to 80% *ad libitum* intake, dry matter digestibility was improved compared with cows at 90 or 100% *ad libitum*, which were both similar (Clark et al., 2007). In that study, the authors attempted to keep energy constant between feeding treatments and they admit that the greater energy density of the 80% restriction ration could have attributed to their results other than just that of dry matter intake (Clark et al., 2007). Separating the two variables is difficult. Another method would be to use the same diet for each treatment, thereby eliminating the effects of energy density. The problem with this approach is not only is DMI restricted, but energy is also restricted.

Methods of measuring *in vivo* digestibility have been reviewed by Cochran and Galyean (1994). The authors review a plethora of literature to aid researchers in choosing the best procedures to fit particular studies. Emphasis is placed on variable control, feed and water intake, preferred sampling methods and time of sampling, as well as marker selection, among other topics (Cochran and Galyean, 1994). Finally, they discuss digestibility calculations and analysis. Careful consideration of these research methods should be observed according to a researcher's goals and limitations. One must know how the results will be analyzed and reported before protocols begin to limit unnecessary work and avoid mistakes in collecting and pooling samples. Common limitations include resources (pen space, type of enclosure, animal number, laboratory equipment, etc.), time, and personnel.

Body Condition

The body condition of a cow determines her productivity, reproductive ability (especially length of anestrus), health, and profitability (NRC, 2000; Schroder and Staufenbiel, 2006; Selk, 2008). Cows will utilize body tissue as an energy source in order to make up for a deficit in feed energy (NRC, 2000; Schroder and Staufenbiel, 2006). This is especially important for periods of high energy demand when the animal cannot physically consume enough feed to meet requirements. Schroder and Staufenbiel (2006) estimated that 30% of milk produced in the first month of lactation can be attributed to body energy reserves. Thus, cows that lose condition in the first month after parturition should produce more milk.

It is imperative for producers to estimate body condition of the cow herd at critical time points throughout the production year (breeding, pre-calving, calving, etc.) so adjustments to feed and supplements can be made in order to accommodate optimal condition. Traditionally, body condition scoring (**BCS**; 1-9 scale) is utilized as a predictor of body fat and energy reserves (NRC, 2000; Selk, 2008). The subjectivity of BCS has demonstrated a need for an objective measurement of body condition (Schroder and Staufenbiel, 2006). Ultrasonography has been touted as a quick and easy indicator of energy stores in dairy herds through accurate back fat measurements (Schroder and Staufenbiel, 2006). The use of ultrasound is also gaining ground in the beef industry, especially amongst purebred operations. Trubenbach et al. (2014a) used ultrasonography to measure back fat at the 12th rib, rump fat, intramuscular fat, and ribeye area. Calculated BCS was determined based on back fat thickness (Herd and Sprott, 1998) and were used to estimate body energy reserves, retained energy, and heat energy utilizing equations from the NRC (2000).

Lactation

Lactation Efficiency

Willham (1972) questioned whether or not beef producers should be selecting dams with greater potential for milk production. Research at the time suggested more milk could be useful early in the lactation period since calves are more limited in their ability to utilize forage (Willham, 1972). However, at the point where calves have a well-developed rumen, more milk might not be desired, especially if extra intake is used for lipid deposition rather than lean muscle development (Willham, 1972). Excessive fleshiness in weaned calves is undesirable to buyers, because they are paying for more BW in fat and those calves have less opportunity for added growth in the feeder stage. During the transition to a functioning ruminant, it may be desirable to select for cows that have a more rapid decline in lactation. It is also important to match the calves' growth requirements if extra feed (in the form of creep or otherwise) is to be offered. Exceeding the calf's ability to utilize extra nutrients by producing more milk is inefficient (Willham, 1972).

A study by van Oijen et al. (1993) concluded that, while WW of calves from low milking dams is lower than calves from high milkers, low milkers are more biologically and economically efficient. Calves from medium- and high-milking cows required more energy per unit gain (van Oijen et al., 1993). Montano-Bermudez and Nielsen (1990) found that calves from lower milking cows are not only more efficient, but had better post-weaning performance compared to cows that yielded more milk. In a similar paper, it was found that low milking cows required 12% less energy than medium and high milkers to maintain BW, whether they were lactating or dry (Montano-Bermudez et al., 1990). Miller et al. (1999) reported that cows on a higher energy intake diet tended to produce more milk ($P < 0.10$). Greater milking cows lost back fat but did not have a change in BW (Miller et al., 1999). This is in agreeance with Mondragon et al. (1983), whose research indicated that BW was not associated with milk yield, however fleshiness of the cow was. Increased loss of back fat in high-producing cows is indicative of body energy reserve usage. The fact that cows lose condition while maintaining BW could be due to increased visceral organ mass, which would be necessary to produce more milk and process extra nutrients.

In a study comparing high and low milking cows, it was determined that calf WW in the high milking group was 22 and 23% greater ($P < 0.05$) than cows that gave less milk in a drylot and rangeland system, respectively (Wyatt et al., 1977). Calves with access to more milk in a range setting required 27.6 kg more milk for every 1 kg of extra BW gain compared with calves in the low milking group (Wyatt et al., 1977). The authors suggest the difference in efficiency may be due to replacement of milk for grass in the low milkers' calves. Thus, grass that is directly fed to the calf is more efficient than grass fed to the cow in order to produce additional milk. In the same study, calves receiving more milk consumed less creep feed (26%, $P < 0.05$) in a drylot than their lower milk-intake counterparts (Wyatt et al., 1977). The increased milk intake for this group translated to 21% more DE ($P < 0.05$) and an extra requirement of 26.3 kg of milk per kilogram of additional gain (Wyatt et al., 1977).

Miller et al. (1999) reviewed conflicting results in the literature as to whether or not increased milk yield in a beef cow increases or decreases efficiency of the calf. It has been documented that increased milk production generates larger calf BW and larger saleable calf BW is more profitable at harvest (Miller et al., 1999). Although higher-milking cows required more energy intake, total feed intake for the pairs was not different between high and low milking cows. Due to greater profitability at harvest as well as a lack of a significant increase in feed, the authors concluded that calves from cows that produced more milk were more efficient after the breed, dam age, and birth BW effects (Miller et al., 1999). In that study, cows were fed with the goal of keeping body condition constant. Different breeds in each group resulted in a range in milk yield, creating the possibility that those cows which milked higher partitioned the available energy to do so without significantly increasing feed intake to the pair. In general, it is expected that higher-milking cows require more feed, thereby reducing pair efficiency.

Milk Yield and Composition

A comprehensive review of milk yield and composition of beef cows in the literature can be seen in Table 1. Some studies have found that milk yield and/or composition explains 60% (Rodrigues et al., 2014) or 66% (Boggs et al., 1980) of the variation in calf WW. Dams with male offspring tend to milk more than those with female calves (Rodrigues et al., 2014), which may be attributed to increased aggressiveness (suckling frequency) of the male (Albertini et al., 2012). Milk yield was increased 11.7% by cows with male offspring according to Albertini et al. (2012), who also reported an increase of 11.4% and 11.9% in energy and protein, respectively, for those dams.

Table 1. Milk yield and composition of beef cows in the literature.

Source	Milk Yield, kg/d	Fat, %	Protein, %	Lactose, %
Linneen, 2014[1]				
Day of Lactation:				
41	14.1	-	-	-
60	10.7	-	-	-
Hudson et al., 2010[1]				
Early Weaned	7.53 ± 3.31	3.56 ± 0.17	2.91 ± 0.06	5.00 ± 0.05
Late Weaned	7.62 ± 3.31	3.68 ± 0.17	2.85 ± 0.06	4.96 ± 0.05
Rodrigues et al., 2014[1]	7.0 ± 0.4	3.21 ± 0.11	2.90 ± 0.04	4.65 ± 0.03
Winterholler et al., 2012[1]	8.28 ± 0.61	2.11 ± 0.22	3.05 ± 0.05	4.97 ± 0.05
Johnson et al., 2003[3]				
Primiparous	9.83 ± 2.13	-	-	-
Multiparous	5.65 ± 2.13	-	-	-
NRC, 2000[2]	8.0[1]	4.03 ± 1.24	3.38 ± 0.27	4.75 ± 0.91
Miller et al., 1999[4]				
Day of Lactation:				
68	5.72 ± 2.29	-	-	-
117	5.15 ± 2.13	-	-	-
185	3.71 ± 1.70	-	-	-
Marston et al., 1992[1,6]	9.6 ± 0.3	4.30 ± 0.15	3.49 ± 0.05	4.89 ± 0.03
Jenkins et al., 1991[1]	6.8	-	-	-
Beal et al. 1990				
Weigh-Suckle-Weigh	5.2 ± 0.5	-	-	-
Machine-Milked	5.1 ± 0.2	4.1 ± 0.07	3.32 ± 0.02	4.7 ± 0.03
Bartle et al. 1984				
120% NRC (1976)	6.1	-	-	-
100% NRC (1976)	5.9	-	-	-
Mondragon et al. 1983[5]				
Machine Milked				
1st calf	4.8 ± 1.7	3.1 ± 0.72	3.4 ± 0.28	5.2 ± 0.22

(Table 1. Cont.)

2nd calf	6.4	3.0	3.3	5.3
3rd calf	5.6	2.3	3.3	5.3
Weigh-Suckle Weigh				
1st calf	7.6 ± 2.3	-	-	-
2nd calf	9.2	-	-	-
3rd calf	9.4			
Bond and Wiltbank, 1970[7]				
High Energy				
1st lactation	3.3	-	-	-
2nd lactation	4.3	-	-	-
Low Energy				
1st lactation	2.4	-	-	-
2nd lactation	4.9	-	-	-
Kropp, 1970[8]				
Range				
Moderate	5.45	-	-	-
High	5.84	-	-	-
Drylot				
Moderate	4.73	2.57	-	-
High	4.84	2.78	-	-

[1]Angus cows
[2]Estimates for beef cows
[3]Brangus cows
[4]Purebred Hereford cows
[5]British breeds
[6]Compostition measured at 60 d postpartum
[7] Angus heifers fed differing energy levels during 1st and 2nd lactations
[8]Hereford cows received either high or moderate energy supplement in the winter

In early lactation, Boggs et al. (1980) found cows ranging in age of 4-8 yr produced more milk than younger and older cows; additionally, that age range narrowed to 5-8 yr during summer months. They also found that 3 yr old cows produced the least amount of milk in early lactation, but there was no difference between 3 and 4 yr cows compared with cows 9 yr or older.

It has been shown that milk containing higher levels of fat and protein promotes calf ADG during the suckling phase (Rodrigues et al., 2014). In contrast, studies reviewed by Mondragon et al. (1983) indicate milk composition has little effect on suckling calf performance. The authors of that study indicated that as lactation progressed, percent protein, total solids, and fat increased, but at a slow rate, while lactose dropped significantly (Rodrigues et al., 2014). Fat has been found to be more variable than other milk constituents and is negatively correlated with milk production (Rodrigues et al., 2014). Albertini et al. (2012) also found that protein, as well as energy, was higher at the end of lactation than at the beginning ($P < 0.01$). In another study (Mondragon et al., 1983) milk yield was comparable across the lactation period for the 1st calf, but dropped across lactation periods for the 2nd and 3rd calves. Like Rodrigues et al. (2014), Mondragon et al. (1983) saw an increase in percent milk protein, however, they contrasted in that milk fat decreased and lactose remained fairly constant in the study by Mondragon et al. (1983). Although unsure as to the cause of the decreased milk fat, the authors attribute it to low fat recovery in the milk (a possible indication of a problem with the machine) or incomplete let-down (Mondragon et al., 1983). Energy content of the milk can be calculated using 2 similar equations (eq. 4 – 16 and eq. 4 – 17), and corresponds to the NE_m needed for the production of milk (NRC, 2000).

Increased energy intake can result in a linear increase in BW gain, milk yield and milk components (protein, lactose, and SNF; Broderick, 2003). In another trial comparing two different energy intakes, cows receiving a high energy ration (120%; NRC, 1976) produced more milk than cows receiving 100% estimated energy requirements by 0.2 kg/d (Bartle et al., 1984). Additionally, weekly milk production only dropped by 0.05 kg/wk for the 120% treatment compared to 0.45 kg/wk for the 100% treated cows. Similarly, Moe et al. (1965) reported an increase in milk production as feed energy increases, although at a diminishing rate. The reasons for this reduced productive efficiency are 3-fold. As energy intake increases: 1) nutritive value of the feed decreases, 2) more fat is stored as body reserve (inefficient), and 3) body energy reserve is used when energy intake is insufficient (Moe et al., 1965). They also point to the idea that increased milk production is possible, but only to the acceptable level of fleshiness of the cow (Moe et al., 1965). It is obvious that an increase in feed intake beyond maintenance is required for milk production. Increased intake negatively influences efficiency of production through decreased digestibility of the feed, however, increasing intake also partitions more feed to production in such a way that reduces the proportion of total feed that goes toward maintenance, thereby increasing efficiency. Although, increasing energy intake will help the cow to produce more milk, in turn producing more saleable calf BW, it is not enough to overcome the extra cost of feed (Miller et al., 1999).

Milking Technique

Weigh-suckle-weigh. Weigh-suckle-weigh (**WSW**) is a commonly used method for determining milk production. Calves are separated from their dams for a period of time, weighed, and then allowed to suckle until satiety. After nursing, calves are immediately weighed and the difference in calf BW is determined to be milk yield. Rodrigues et al. (2014) used WSW and machine milking techniques to measure milk yield. Weigh-suckle-weigh was performed every 21 d for a total of 10 measurements (Rodrigues et al., 2014). The day before the WSW procedure, pairs were separated for 6 h, reunited for 45 min to allow them to suckle-out, and then re-separated overnight for 12 h (Rodrigues et al., 2014). Two other studies utilized a 4 h (Clutter and Nielsen, 1987) and 12 h (Bartle et al., 1984) separation on the day before milking and were separated overnight until milking. In the study by Bartle et al. (1984) calves suckled for 30 min after the initial separation and were re-separated for 12 h before WSW. Boggs et al. (1980) separated pairs for 10 h, allowed calves to nurse out, and then separated again for 12 h overnight. Their procedure included 3 WSW days that were averaged and used to estimate 24 h milk once every mon for a total of 6 mon. Weigh-suckle-weigh accounted for 13% of the variation in WW (Rodrigues et al., 2014). Albertini et al. (2012) suggested that performing WSW at least 12 times during the lactation period was necessary to achieve an r^2 of .80.

Milking Machine. Several studies used a milking machine (**MM**) at the beginning, middle, and end of lactation to directly measure yield and composition (Marston et al., 1992; Rodrigues et al., 2014). Rodrigues et al. (2014) separated pairs for 6 h the day before milking with a 45 min suckle-out period, and 12 h overnight separation. Marston et al. (1992) separated pairs for 4-7 h before allowing calves to nurse for 45 min and had an overnight separation of approximately 8 h. Oxytocin was given intravenously at a dosage of 30 IU (Rodrigues et al., 2014) or 40 IU (Marston et al., 1992) to warrant milk let-down, the udders were washed and massaged, and the cow was milked until milk flow ceased. After the milking claw was removed, each quarter was hand stripped to ensure complete udder evacuation (Marston et al., 1992). One advantage of MM is that after weighing the milk, samples can be taken and analyzed for milk components (Marston et al., 1992; Rodrigues et al., 2014). Some authors suggest milking with a machine is preferred to WSW (Albertini et al., 2012; Rodrigues et al., 2014). Standard errors were lower using MM estimates than WSW. Furthermore, WSW estimates of milk yield were reliably higher than the MM method (Mondragon et al., 1983). Machine milking accounted for 25% of the variation observed in WW, compared to 13% for WSW (Rodrigues et al., 2014). Overall, the MM method is typically more accurate than WSW and has more power to distinguish significant differences according to the lower observed standard errors. Albertini et al. (2012) reported the coefficient of variance of the WSW procedure to be 54% greater than MM. In that study, the repeatability of these milk yields measured by MM was approximately twice that of WSW (Albertini et al., 2012). Albertini et al. (2012) recommended using a 16 h interval, 6 times during the lactation period ($r^2 = .80$) when utilizing the MM technique. Beal et al. (1990) reported a high correlation (R = 0.97) between two observations (3-d apart) of machine milked data, whereas the correlation was low (R = 0.35) for the WSW technique. Repeatability of milk production in beef cows as determined by milking machine is comparable to Holstein milk production repeatability (Beal et al., 1990).

Energy Requirements of Lactating Beef Cows

Approximately 70-75% of annual feed cost for a cow is spent to meet maintenance energy requirements (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Evans et al., 2000). Fifty percent of the energy required for beef production is spent in maintaining the cow (Montano-Bermudez et al., 1990; Miller et al., 1999). Maintenance energy requirement is defined as the energy required to maintain the animal's body tissue within the thermal neutral zone and does not address changes in production cycle (Evans et al., 2000). The ME required for maintenance accounts for 70% of the total ME required for a beef cow in production (NRC, 2000). The NRC (2000) estimates NE_m to be 0.077 Mcal/$EBW^{0.75}$, where empty metabolic BW ($EBW^{0.75}$) is measured in kilograms.

Visceral organ mass accounts for a large percent of the variation in maintenance requirements and it has been shown that increased visceral organ mass increases maintenance requirements (Evans et al., 2000). Thus, metabolic BW (most commonly defined as $BW^{0.75}$; NRC, 2000) is used (Evans et al., 2000). Lactation not only increases energy requirements as a whole, but due to increased tissue mass, also increases basal maintenance needs (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Evans et al., 2000; Jenkins et al., 2000). Increased milk output requires much more energy and nutrient intake, not only for the milk itself, but for the increased maintenance demands due to larger organ size (primarily larger mammary glands). More production necessitates a larger "factory" and a larger factory requires more upkeep and maintenance.

Montano-Bermudez and Nielsen (1990) calculated the maintenance metabolizable energy required for gestation and lactation in cows with high, medium, and low genetic milking potential. The maintenance energy requirements for gestation and lactation were 97 and 126, 114 and 148, and 110 and 141 kcal $ME \cdot BW(kg)^{-0.75} \cdot d^{-1}$ for low, medium, and high milkers, respectively (Montano-Bermudez and Nielsen, 1990). In that same study, it was reported that cows genetically marked for lower milk production consumed less energy than cows with a higher genetic potential for milk, even when genetic potential for mature size is the same. Van Oijen et al. (1993) used the same methods as Montano-Bermudez and Nielsen (1990), but assumed equal maintenance and reproduction between groups; they reported maintenance energy requirements for gestation and lactation for low milkers as 97 and 126 kcal ME·BW(kg)$^{-0.75}$·d^{-1} and 112 and 145 kcal ME·BW(kg)$^{-0.75}$·d^{-1} for medium and high milkers, respectfully. The difference in maintenance energy requirements between the high and medium groups were not significantly different, so they averaged the two groups to calculate efficiency with those assumptions (van Oijen et al., 1993). Montano-Bermudez et al. (1990) concluded that 23% of the variation in maintenance energy requirement was explained by differences in milk production. In that paper, regression analysis reports that for each 1 kg increase in milk produced, her maintenance requirement would increase by 1.6 kcal/d (Montano-Bermudez et al., 1990). It has been shown that cows that produce more milk have higher energy requirements (Miller et al., 1999), which can have a negative impact on rebreeding interval (Willham, 1972). Boggs et al. (1980) found a 1.4-d postponement in rebreeding for every extra kilogram of milk produced.

Limit-Feeding Drylot Cows

It is evident that grazing cattle expend more energy than cattle in a drylot due to the increased need for travel, but it is not well known if there is a difference in energy demand for other functions, such as ruminating, feed prehension, standing, etc. (NRC, 2000). It has been estimated that animals in a drylot have maintenance energy requirements that are 10 to 20% and 50% lower compared with grazing animals in good and bad grazing conditions, respectively (CSIRO, 1990).

Limiting DMI improves diet digestibility, ADG, and feed efficiency in finishing steers (Clark et al., 2007). As intake increases beyond maintenance, organs enlarge as do maintenance requirements; the opposite is true when intake is restricted (Clark et al., 2007). Therefore, a decrease in intake should result in reduced maintenance requirements (Clark et al., 2007). Trubenbach et al. (2014a) reported that non-lactating cows which were limit-fed a high-energy diet achieved maintenance at NE_m = 0.062 Mcal/$EBW^{0.75}$ compared with the NRC (2000) estimated NE_m of 0.077 Mcal/$EBW^{0.75}$. In a 2x2 factorial experiment comparing high and low density diets fed at 120% or 80% estimated NRC (2000) NE_m requirements, cows fed the higher energy diet had decreased maintenance energy requirements (9.9%) than cows on a low-energy dense diet (Trubenbach et al., 2014b). Likewise, limit-fed cows had reduced maintenance requirements of 29.1% compared to cows receiving 120% requirements (Trubenbach et al., 2014b).

Creep Feed

<u>Consumption and Capacity</u>

Ruminoreticular volume of calves is approximately 44, 300, and 230-360 ml/kg EBW for newborns (36 kg), 13 wk-olds (94 kg), and 542 kg calves, respectively (Jenkins, 2014). Lusby et al. (1976) reported a decrease in calf creep intake (Miller et al., 1999) and digestibility as milk intake increased. Likewise, Wyatt et al. (1977) and Boggs et al. (1980) found that at higher milk intakes, calves consumed less forage. Contrary to earlier data, Wyatt et al. (1977) found that milk intake was not significantly affected by the calf's growth-rate potential. Miller et al. (1999) also found no relationship between milk yield and total energy intake of cow-calf pairs. A calf begins consuming grass alongside its dam before 3 wk of age and by 3 mon it is estimated that calves will consume about 1% BW in forage DM (Jenkins, 2014). Newborn calves are preruminants, therefore, their diet other than milk (which bypasses the rumen) is necessary for ruminoreticular growth and development (Church, 1988). For these reasons, it is necessary for the calves to have access to high-quality creep feed early on if pairs are kept in a drylot to replace growing forage.

Work reviewed by Arthington et al. (2008) showed that creep intake and BW increased over time as calves had longer access to the creep. This is to be expected based on behavioral and physiological reasoning. Behaviorally, as calves learn where the creep area is and how to use it, their creep intake will increase over time. Physiologically, as their feed intake increases, their rumen will adapt and develop to the creep feed diet, also allowing ration intake to increase.

Calf Performance on Creep

Creep-feeding has been shown to increase calf gain during the suckling phase (Stricker et al., 1979; Faulkner et al., 1994; Tarr et al., 1994). Some studies have shown the efficiency of supplemental feed has been low (Stricker et al., 1979). Decreased efficiency has been proposed to be due to higher grain intakes, which lowers ruminal pH and, therefore, has a negative-associative effect on forage intake (Tarr et al., 1994). Assuming this is true, ways to improve efficiency are warranted for creep feeding to be a viable technique for improving calf gains.

Conventionally, when creep feed is fed, it is offered *ad libitum* to nursing calves. However, excessive creep can lead to fleshy calves at weaning, which is not a desirable trait to buyers (Taylor et al., 1938). Some researchers suggest that limit-feeding creep can be done in order to improve performance and efficiency without producing overly-fleshy calves. Calves can be limited to a certain amount of feed per feeding period, or to a certain time of day, or creep feeding can be limited to a period of time before weaning.

Calves with limited creep intakes have been shown to gain 39% more BW during the suckling phase than calves without supplemental feed; furthermore, calves with unlimited access to creep outperformed the limited calves by an additional 13% gain (Faulkner et al., 1994). Unlike previous research (Stricker et al., 1979), Faulkner et al. (1994) found no supplemental feed efficiency differences between limit-fed and *ad libitum*-fed calves.

Calves that had access to creep for 28 d did not perform better than those without in the suckling phase, whereas creep feeding for 56- and 84-d periods improved gain (Tarr et al., 1994). In that study, 56 d of creep feeding showed to be the most efficient.

Another technique to improve efficiency of creep feeding is using commodities with positive-associative effects on forage consumption for calves on pasture. Intuitively, as creep feed intake increases, forage consumption is expected to decrease (Faulkner et al., 1994). Faulkner et al. (1994) reported no difference in fescue intake between creep feeds of different sources (corn- or soybean hull-based). However, calves with access to soybean hulls had significantly greater NDF and ADF digestibilities of fescue than calves with corn-based creep (Faulkner et al., 1994). These results indicate the importance of the type of creep feed on pre-weaning efficiency.

Conflicting reports exist regarding the effects of creep feeding on feedlot performance. Control calves (no creep) outperformed creep-fed calves in the feedlot in one year, while no differences existed in the other years (Tarr et al., 1994). Calves with access to creep feed beginning at 45 d before shipping had improved feedlot gains (Arthington et al., 2008). Conversely, another study reports creep-fed calves (limit-fed and unlimited creep) had lower gains and reduced F:G ratios compared with non-creep-fed calves (Faulkner et al., 1994). However, the improved F:G efficiency in the suckling phase of creep-fed calves combined with the feedlot ratios generated no difference in lifetime efficiency (Faulkner et al., 1994). Calves fed corn-based creep had an improved feedlot F:G ratio over soybean hull-fed calves, most likely due to ruminal adaptation to a higher concentrate diet (Faulkner et al., 1994). Decisions would need to be made to determine what to use as creep depending upon the marketing technique (retaining ownership or selling calves for finishing).

It is not recommended to creep replacement heifers as any BW advantage at weaning is lost by 1 yr of age (Martin et al., 1981). Excessive fat in the pelvic area and mammary gland is also detrimental to reproductive performance when replacement heifers become fleshy. Martin et al. (1981) showed creep-fed heifers weaned fewer calves that were lighter at birth, 120-d old, and 210-d old. However, the correct amount of feed can add saleable BW and also condition calves to eat grain during the finishing phase. Cattle that were creep fed had higher quality grades, but they gained less BW after weaning than non-creep-fed calves (Martin et al., 1981). Steers receiving creep out-gained those that did not during the suckling phase, but ADG was not different during finishing in a 2-yr study by Myers et al. (1999). In that study, overall ADG tended to favor steers that had access to creep, although harvest BW was not different. Additionally, there were no differences in yield grade, marbling score, or longissimus muscle area in 1 of 2 yr, where yr 2 returned a higher yield grade in creep-fed steers (Myers et al., 1999).

There are also effects on the cows of calves consuming creep. Studies have shown significantly higher conception rates for cows with creep-fed calves (Stricker et al., 1979). The authors of that study did not understand the reason for this and speculated it could be due to increased energy consumption from eating spilled creep or old creep orts that were discarded in the pasture. It is reasonable to believe that calves consuming creep would nurse less and the reduced suckling stimulus therefore caused a more rapid decline in milk production. This would effectively reduce maintenance plus lactation energy requirements. It was reported that cows whose calves consume creep also gained BW and BCS (Tarr et al., 1994). These authors speculate this is due to greater forage availability to the cow due to decreased forage consumption of the calf. It is also reasonable in this case to believe decreased milk also effected BW and BCS for reasons just described. Increased condition, to an extent, is also important for improved conception rates (Selk, 2008).

Suckling Steer Calf Performance

Milk is the primary source of nutrients for young calves, hence, lactation is paramount to the calf's performance (Rodrigues et al., 2014). Clutter and Nielsen (1987) found that calves from low milking cows utilized 66% less milk in order to have the same BW gain as calves from medium and high milking dams, thus having a lower maintenance energy requirement. These calves better utilized available milk and relied more heavily and at an earlier age on feed sources other than milk. However, calves from high milking dams were significantly heavier at weaning and maintained much of that advantage through the feedlot period (Clutter and Nielsen, 1987), which is in agreement with Miller et al. (1999) and Mondragon et al. (1983).

Beal et al. (1990) reported a high correlation (r = .76) between calf gain in the suckling phase and milk production. Two separate studies with similar results report that milk production explains 60 or 65% of the variation in WW (Willham, 1972). A different study concluded that composition did not explain a significant amount of variation in WW (Mondragon et al., 1983). These results indicate that milk production is still the largest contributing affecter of WW(Beal et al., 1990).

Jenkins and Ferrell (1994) found a linear decrease in conversion of feed to calf BW as DMI of the cow increased. In a similar study, Jenkins et al. (2000) showed that low cow energy intakes produced maximum efficiency, however, their lowest energy intake was at 100% recommended requirements (NRC, 2000).

Past literature has indicated over half of the calf's energy intake is sourced from feeds other than milk by the third month of lactation (Boggs et al., 1980). Boggs et al. (1980) reported a suckling-phase ADG of 0.69 kg/d and that for each extra kg of milk taken in, calves gained an extra 7.20 kg of 205-d adjusted WW, on average. Conversely, they found that grass intake was negatively correlated with ADG in early lactation and forage consumption only showed a tendency to improve ADG during mid to late lactation at 0.02 kg/d.

Cows that produce more milk raised calves that gained more during the suckling phase were heavier upon feedlot entry and had heavier carcasses, although they did not have an advantage in post-weaning growth (Miller et al., 1999). It has been found that calves with access to higher levels of milk were less efficient in the feedlot (Willham, 1972) or tended to be less efficient (Miller et al., 1999) possibly due to excess fat accumulation in the suckling phase. Miller et al. (1999) calculated calf efficiency as the final carcass BW of the calf divided by total feed intake of the cow and calf.

LITERATURE CITED

Albertini, T. Z., S. R. Medeiros, R. A. A. Torres, S. S. Zocchi, J. W. Oltjen, A. B. Strathe, and D. P. D. Lanna. 2012. A methodological approach to estimate the lactation curve and net energy and protein requirements of beef cows using nonlinear mixed-effects modeling. J. Anim. Sci. 90:3867–3878.

Arthington, J. D., X. Qiu, R. F. Cooke, J. M. B. Vendramini, D. B. Araujo, C. C. Chase, and S. W. Coleman. 2008. Effects of preshipping management on measures of stress and performance of beef steers during feedlot receiving. J. Anim. Sci. 86:2016–2023.

Bartle, S. J., J. R. Males, and R. L. Preston. 1984. Effect of energy intake on the postpartum interval in beef cows and the adequacy of the cow's milk production for calf growth. J. Anim. Sci. 58:1068–1074.

Beal, W. E., D. R. Notter, and R. M. Akers. 1990. Techniques for estimation of milk yield in beef cows and relationships of milk yield to calf weight gain and postpartum reproduction. J. Anim. Sci. 68:937–943.

Boggs, D. L., E. F. Smith, R. R. Schalles, B. E. Brent, L. R. Corah, and R. J. Pruitt. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51:550–553.

Bond, J., and J. N. Wiltbank. 1970. Effect of energy and protein on estrus, conception rate, growth, and milk production of beef females. J. Anim. Sci. 30:438–444.

Broderick, G. A. 2003. Effects of varying dietary protein and energy levels on the production of lactating dairy cows. J. Dairy Sci. 86:1370–1381.

Church, D. C., ed. 1988. The ruminant animal: Digestive physiology and nutrition. Prentice Hall, Englewood Cliffs, NJ.

Clark, J. H., K. C. Olson, T. B. Schmidt, M. L. Linville, D. O. Alkire, D. L. Meyer, G. K. Rentfrow, C. C. Carr, and E. P. Berg. 2007. Effects of dry matter intake restriction on diet digestion, energy partitioning, phosphorus retention, and ruminal fermentation by beef steers. J. Anim. Sci. 85:3383–3390.

Clutter, A. C., and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 64:1313–1322.

Cochran, R. C., and M. L. Galyean. 1994. Measurement of in vivo forage digestion by ruminants. In: G. C. Fahey, M. Collins, D. R. Mertens, and L. Moser, editors. Forage quality, evaluation and utilization. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. p. 613–631.

Colucci, P. E., L. E. Chase, and P. J. Van Soest. 1982. Feed intake, apparent diet digestibility, and rate of particulate passage in dairy cattle. J. Dairy Sci. 65:1445–1456. Available from: http://dx.doi.org/10.3168/jds.S0022-0302(82)82367-9

CSIRO. 1990. Feeding standards for Australian livestock: Ruminants. Commonwealth Scientific and Industrial Research Organisation Publications, East Melbourne, Victoria, Australia.

Du, M., J. Tong, J. Zhao, K. R. Underwood, M. Zhu, S. P. Ford, and P. W. Nathanielsz. 2010. Fetal programming of skeletal muscle development in ruminant animals. J. Anim. Sci. 88.

Evans, B. J. L., B. L. Golden, and B. L. Hough. 2000. A new genetic prediction for cow maintenance energy. Beef Improv. Fed. Symp. Proc., Oklahoma State University, Stillwater OK. p. 79–88.

Faulkner, D. B., D. F. Hummel, D. D. Buskirk, L. L. Berger, D. F. Parrett, and G. F. Cmarik. 1994. Performance and nutrient metabolism by nursing calves supplemented with limited or unlimited corn or soyhulls. J. Anim. Sci. 72:470–477.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: nutritional aspects. J. Anim. Sci. 61:725–741.

Ford, S. P., and N. M. Long. 2012. Evidence for similar changes in offspring phenotype following either maternal undernutrition or overnutrition: Potential impact on fetal epigenetic mechanisms. Reprod. Fertil. Dev. 24:105–111.

Herd, D. B., and L. R. Sprott. 1998. Body condition, nutrition and reproduction of beef cows. College Station, TX. Available from: http://hdl.handle.net/1969.1/87723.

Hudson, M. D., J. P. Banta, D. S. Buchanan, and D. L. Lalman. 2010. Effect of weaning date (normal vs. late) on performance of young and mature beef cows and their progeny in a fall calving system in the Southern Great Plains. J. Anim. Sci. 88:1577–87. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19966151.

Jenkins, K. H. 2014. Limit feeding production cows in confinement. In: Dr. Kenneth and Caroline McDonald Eng Foundation Symposium. San Antonio, TX. p. 29–34.

Jenkins, T. G., L. V Cundiff, and C. L. Ferrell. 1991. Differences among breed crosses of cattle in the conversion of food energy to calf weight during the preweaning interval. J. Anim. Sci. 69:2762–2769.

Jenkins, T. G., C. L. Ferrell, and A. J. Roberts. 2000. Lactation and calf weight traits of mature crossbred cows fed varying daily levels of metabolizable energy. J. Anim. Sci. 78:7–14.

Jenkins, T. G., and C. L. Ferrell. 1994. Productivity through weaning of nine breeds of cattle under varying feed availabilities: I. Initial evaluation. J. Anim. Sci. 72:2787–97. Available from: http://www.ncbi.nlm.nih.gov/pubmed/7730170.

Johnson, C. R., D. L. Lalman, M. a Brown, L. a Appeddu, D. S. Buchanan, and R. P. Wettemann. 2003. Influence of milk production potential on forage dry matter intake by multiparous and primiparous Brangus females. J. Anim. Sci. 81:1837–1846.

Kropp, J. R. 1970. I. The performance on range and in drylot of two-year-old hereford, holstein and hereford x holstein females as influenced by level of winter supplementation. Oklahoma State University, Stillwater, OK. MS Thesis.

Linneen, S. K. 2014. Application of feed additive technologies to enhance health and performance of range beef cows. Oklahoma State University, Stillwater, OK. Ph.D. Dissertation.

Lusby, K. S., D. F. Stephens, and R. Totusek. 1976. Effects of milk intake by nursing calves on forage intake on range and creep intake and digestibility in drylot. J. Anim. Sci. 43:1066–1071.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in angus and simmental cow-calf pairs. J. Anim. Sci. 70:3304–3310.

Martin, T. G., R. P. Lemenager, G. Srinivasan, and R. Alenda. 1981. Creep feed as a factor influencing performance of cows and calves. J. Anim. Sci. 53:33–39.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64:1548–1558.

Miller, S. P., J. W. Wilton, and W. C. Pfeiffer. 1999. Effects of milk yield on biological efficiency and profit of beef production from birth to slaughter. J. Anim. Sci. 77:344–352.

Moe, P. W., J. T. Reid, and H. F. Tyrrell. 1965. Effect of level of intake on digestibility of dietary energy by high-producing cows. J. Dairy Sci. 48:1053–1061.

Mondragon, I., J. W. Wilton, O. B. Allen, and H. Song. 1983. Stage of lactation effects, repeatabilities and influences on weaning weights of yield and composition of milk in beef cattle. Can. J. Anim. Sci. 63:751–761.

Montano-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2279–2288.

Montano-Bermudez, M., and M. K. Nielsen. 1990. Biological efficiency to weaning and to slaughter of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2297–2309.

Myers, S. E., D. B. Faulkner, F. A. Ireland, L. L. Berger, and D. F. Parrett. 1999. Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. J. Anim. Sci. 77:300–310.

NRC. 2000. Nutrient Requirements of Beef Cattle. Seventh Revised Edition: Update 2000. National Academy Press, Washington, DC.

van Oijen, M., M. Montano-Bermudez, and M. K. Nielsen. 1993. Economical and biological efficiencies of beef cattle differing in level of milk production. J. Anim. Sci. 71:44–50.

Okine, E. K., and G. W. Mathison. 1991. Effects of feed intake on particle distribution, passage of digesta, and extent of digestion in the gastrointestinal tract of cattle. J. Anim. Sci. 69:3435–3445.

Petit, M., and D. Micol. 1981. Evaluation of energy requirements of beef cows during early lactation. Livest. Prod. Sci. 8:139–153.

Rodrigues, P. F., L. M. Menezes, R. C. C. Azambuja, R. W. Sune, I. D. Barbosa Silveira, and F. F. Cardoso. 2014. Milk yield and composition from Angus and Angus-cross beef cows raised in southern Brazil. J. Anim. Sci. 92:2668–2676.

Schroder, U. J., and R. Staufenbiel. 2006. Invited Review: Methods to determine body fat reserves in the dairy cow with special regard to ultrasonographic measurement of backfat thickness. J. Dairy Sci. 89:1–14.

Selk, G. 2008. Body condition scoring of cows. In: D. L. Lalman and D. Doye, editors. Beef Cattle Manual. 6th ed. Oklahoma State University Cooperative Extension, Stillwater, OK. p. 141–144.

Shaver, R. D., A. J. Nytes, L. D. Satter, and N. A. Jorgensen. 1986. Influence of amount of feed intake and forage physical form on digestion and passage of prebloom alfalfa hay in dairy cows. J. Dairy Sci. 69:1545–1559.

Stricker, J. A., A. G. Matches, G. B. Thompson, V. E. Jacobs, F. A. Martz, H. N. Wheaton, H. D. Currence, and G. F. Krause. 1979. Cow-calf production on tall fescue-ladino clover pastures with and without nitrogen fertilization or creep feeding: spring calves. J. Anim. Sci. 48:13–25.

Tarr, S. L., D. B. Faulkner, D. D. Buskirk, F. A. Ireland, D. F. Parrett, and L. L. Berger. 1994. The value of creep feeding during the last 84, 56, or 28 days prior to weaning on growth performance of nursing calves grazing endophyte-infected tall fescue. J. Anim. Sci. 72:1084–1094.

Taylor, B. R., L. E. Hawkins, and O. S. Willham. 1938. Creep-feeding March and April calves that are to be finished in dry lot after weaning. J. Anim. Sci.:110–112.

Trubenbach, L. A., T. A. Wickersham, G. E. Carstens, and J. E. Sawyer. 2014a. Managing energy requirements in confined cows. In: Dr. Kenneth and Caroline McDonald Eng Foundation Symposium. San Antonio, TX. p. 19-25.

Trubenbach, L. A., T. A. Wickersham, and J. E. Sawyer. 2014b. The effects of dietary energy density and intake restriction on apparent maintenance energy requirements of beef cows. In: JAM. Amer. Soc. Anim. Sci. Kansas City, MO.

Tyrrell, H. F., and P. W. Moe. 1975. Effect of intake on digestive efficiency. J. Dairy Sci. 58:1151–1163.

Willham, R. L. 1972. Beef milk production for maximum efficiency. J. Anim. Sci. 34:864–869.

Winterholler, S. J., C. P. McMurphy, G. L. Mourer, C. R. Krehbiel, G. W. Horn, and D. L. Lalman. 2012. Supplementation of dried distillers grains with solubles to beef cows consuming low-quality forage during late gestation and early lactation. J. Anim. Sci. 90:2014–2025.

Wyatt, R. D., M. B. Gould, J. V. Whiteman, and R. Totusek. 1977. Effect of milk level and biological type on calf growth and performance. J. Anim. Sci. 45:1138–1145.

CHAPTER II

ENERGY REQUIREMENTS AND PRODUCTION EFFICIENCY OF LACTATING BEEF COWS IN A DRYLOT SYSTEM

INTRODUCTION

There are many challenges and opportunities for beef production. Increased population leads to more demand for beef and more competition for resources. Alternative uses of agricultural lands along with adverse weather conditions decrease forage availability and grazing capacity. It is becoming increasingly necessary for producers to raise more beef with less land. There are also empty drylot pens that were former small dairies or feedlots, which give producers in the southern Great Plains the ability to place cow-calf pairs in a confinement or semi-confinement drylot setting (controlled environment, **CE**). This allows producers to fill facility vacancies as a potential buffer to market risk and volatility as well as a way to correctly manage their pastures without liquidating the herd. There is also an opportunity to increase ranch carrying capacity without harm to pasture resources, thereby increasing cow numbers and satisfying beef demand. In the northern Great Plains, CE systems are more common due to the close vicinity to cropland, grain, and co-products and more extreme weather. In the southern Great Plains, differing resources, conditions, and management styles present challenges in implementing CE, but many producers are already adopting variations of year-round or short-term confinement systems. A distinct advantage of CE systems is the ability to control intake. Limit-feeding is a key management tool, which is a fairly new concept in the management of mother cows (Jenkins, 2014). Benefits to limit-feeding moderate energy rations include: decreased feed cost and land area requirement, improved digestibility of feedstuffs, and decreased gut size, thereby reducing basal metabolic requirements. The current accepted estimation of NE_m required for maintenance of beef cattle is 0.077 Mcal/**EBW**$^{0.75}$ (NRC, 2000), where $EBW^{0.75}$ = empty metabolic body weight. Due to increased apparent digestibility from limit-feeding (Trubenbach et al., 2014) and limited activity in the drylot (CSIRO, 1990), it is hypothesized that maintenance energy requirements for cows would decrease, therefore the current Beef Cattle NRC (2016) model may not be applicable to cows in CE. Additionally, cow size and milk production has increased dramatically in the past few decades (Lalman et al., 2013), therefore, data used in NRC (2016) to estimate energy requirements and milk production may not be applicable to the current U.S. population of beef cows. The objectives of this study were to determine: 1) the energy intake necessary to maintain BW and body composition of lactating beef cows and, 2) the efficiency of energy intake of cows to calf growth in a CE system.

MATERIALS AND METHODS

Animals

All protocols were approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP AG-15-8). A total of 40 lactating beef cows (6 ± 2.0 yr, 539 ± 46 kg BW) along with their suckling steer calves (60 ± 9.4 d, 107 ± 13 kg

BW) were utilized. The cows were Angus and Angus x Hereford and the calves were sired by Angus bulls. Average calving date was March 15, 2015. Steers were castrated at birth by banding and received an anabolic implant (Ralgro, Merck Animal Health, Madison, NJ) at approximately 2 mo of age. Pairs were stratified by calf age and milk yield (determined on May 13, 2015 by methods described later), then assigned to 1 of 5 pen groups (experimental unit) in a completely randomized design. Each group was fed the same moderate-energy diet (Table 1) in varying amounts (limit-fed; Table 2) in order to achieve 135, 159, 176, 200, and 223 kcal (NE_m)·(kg $BW^{0.75}$)$^{-1}$·d^{-1}. Although no pen effects were expected, pen groups were rotated among the physical pens approximately every 28 d in order to minimize any potential pen effect bias.

Facilities

The experiment was performed at the Range Cow Research Center, South Lake Carl Blackwell Range Unit located West of Stillwater, Oklahoma. Pairs were offered increasing levels of the experimental ration for 11 d before trial initiation as a warm-up period. Experimental treatments were initiated on June 10 and continued through weaning on September 29, 2015 for a total of 111 days. Average monthly temperature and precipitation for months during the trial and long-term averages for those months is shown in Table 3.

Each pen contained concrete, fence-line feed bunks with 0.9 m of linear bunk space per cow and a creep area with 0.3 m of linear bunk space per calf. Cows and calves did not have access to each other’s feed. Calves were penned up under shade until cows consumed their ration. Calves had unrestricted to the creep area access (except when penned away from cow feed) via a creep gate, which the cows could not access. All animals had access to a source of 65% shade (4.18 m per cow) as well as an automatic waterer. Feeding occurred at approximately 0800 h once daily.

Diet

The diet was a total mixed ration (**TMR**) that was formulated to contain 1.59 Mcal NE_m/kg, 14.7% CP, 27.3% ADF, and 52.9% NDF (Table 1). Dietary total digestible nutrients (**TDN**) was determined using *in vitro* neutral detergent fiber digestibility (NRC, 2001) and an equation from Weiss (2000):

$$TDN = (CP \times e^{-1.2 \times ADIN}) + (0.98 \times [100 - NDF_{CP} - CP - Ash - EE]) +$$

$$([EE - 1] \times 2.7) + (.75 \times [NDF_{CP} \times \frac{IVNDF}{100}] \text{ -7}$$

where CP = crude protein, ADIN = acid detergent insoluble nitrogen (& of total N), NDF_{CP} = crude protein-free neutral detergent fiber, and IVNDF = in vitro digestible neutral detergent fiber. Calves were fed the same TMR diet as their dams in daily amounts to insure *ad libitum* intake with minimal refusal. Calf orts were removed and sampled approximately once weekly, or when adverse weather (especially precipitation) occurred. A vitamin and mineral supplement (11.7% Ca, 10.29% P, 1.2% Mg, 1,047 ppm Cu, and 7,631 ppm Fe) was top-dressed, which also contained Altosid IGR (Central Life Sciences, Schaumburg, IL 60007) for insect control and chlortetracycline (Aureomycin, Zoetis Services, LLC, Florham Park, NJ 07932) for the prevention of anaplasmosis. Protein supplement (cottonseed meal) was provided at 0.23 kg/cow for cows offered the low energy ration (135 kcal NE_m/kg) as that group was in a negative protein balance for their given ration.

Preventative Medicine

On May 19, 2015 steer calves received a clostridial vaccine (Covexin 8, Merck Animal Health, Madison, NJ), and pour-on dewormer (Normectin, Norbrook Inc., Lenexa, KS), while cows received a pour-on dewormer (Ivermectin, Durvet Inc., Blue Springs, MO). Cows and calves were poured with an insecticide (Synergized Permethrin, Durvet Inc., Blue Springs, MO), and drenched with a dewormer (Valbazen, Zoetis Inc., Florham Park, NJ) on June 6. Cows were given another dose of pour-on Permethrin for fly control 26 d later. Approximately 1 month later, insecticide ear tags (XP820, Y-Tex Corporation, Cody, WY) were deployed in the cows. On September 23, steers were revaccinated with Covexin 8 and BoviShield Gold 5 (Zoetis Inc., Florham Park, NJ) 1 week prior to weaning. All incidences of morbidity were documented and addressed according to standard operating procedures.

Milk Production

Cows were milked (described below) 28 d before study initiation on May 13 for pre-trial analysis and treatment allocation. During the study they were milked every 28 d beginning on June 30 (d-21) and ending on September 22 (d-105). The milking procedure was adapted from Marston et al. (1992). A portable milking machine (Portable Vacuum System, Springville, UT 84663) was used. The day before milking, pairs were separated at 1400 h. All animals had access to water, but calves were not allowed creep feed. At 2000 h, pairs were reunited for a 45 min nurse-out period. Calves were separated by 2100 h and milking began at 0500 h the following day, for an overnight separation of 8 h. Cows were combined into a large pen and brought randomly into the working facility.

Individuals were weighed on calibrated scales (Sooner Scale Inc., Oklahoma City, Oklahoma 73108) and sent to 1 of 2 chutes, allowing 2 animals to be milked simultaneously. Upon entering the chute, cows were injected intramuscularly with 1 ml oxytocin (Oxoject, Henry Schein Animal Health, Dublin, OH 43017) for milk let-down. Udders were washed with soapy water, dipped with an antibacterial solution, dried, and stripped before the claw was applied. Milking claws were removed when milk flow ceased and each quarter was stripped by hand to insure complete udder evacuation. After milking, teats were re-dipped with the antibacterial solution and the cow was returned to her calf. Hand stripped and machine milk were combined, weighed on a calibrated platform scale (Defender 5000, Ohaus Corp., Parsippany, New Jersey 07054), and a sample was taken in a vial containing 2-bromo-2-nitropropane-1,3-diol for preservation and shipped to the Heart of America Dairy Herd Improvement Association laboratory (Manhattan, KS 66506) for composition analysis. Milk energy content for each sample was calculated using Eq. 4 – 17 (NRC, 2000):

$$E = (0.092 \times \%Fat) + (0.049 \times \%SNF) - 0.0569$$

where E = energy content (Mcal/kg milk) and SNF = solids-non-fat. Milking time for each cow was recorded and yields were adjusted to 8 h and multiplied by a coefficient corrected for overnight separation time to determine 24 h milk production.

Body Measurements

Cows were weighed in the morning before feeding and body condition scored (**BCS**; 1 – 9 scale) and calves were weighed every 28 d. Scales were calibrated. Ultrasonography was used to measure back fat (**BF**, 12th rib), rib eye area (**REA**), rump fat (**RF**), and intramuscular fat (**IMF**; marbling). Ultrasonography (Aloka 500, Hiachi Aloka Medical, Ltd., Wallingford, CT 06492) was performed by a certified technician (Ultrasound Technologies, Fletcher, OK 73541) at d 0 and 105. Images were interpreted with Beef Image Analysis Pro Plus software (Designer Genes Technologies Inc., Harrison, AR 72601).

Cow BCS and BW were used to calculate total body energy (**TBE**) for each energy level group (Eq. 19-70, 1971, 19-78, 19-79, and 19-80; NRC, 2016). Retained energy (**RE**) was calculated as the change in TBE from trial initiation to end (Trubenbach et al., 2014). The maternal tissue maintenance level (**MML**) of energy intake is the point at which RE = 0.

Digestibility

An apparent digestibility study was completed for cows and calves from d 90 through d 96 of the experiment using acid detergent insoluble ash (**ADIA**) as an internal marker (Cochran and Galyean, 1994; Kanani et al., 2014). Feed samples were collected from the feed bunks each morning d 90-95. Manure was collected by rectal palpation from cows ($n \geq 5$) and calves ($n \geq 5$) per pen in the morning and evening on d 91-96. Calf orts were collected from the bunks each morning before feeding on manure collection days. Feed samples were placed in paper sacks and dried in a forced air oven (50°C; 52 h). Fecal samples were immediately frozen (-80°C). At a later date, fecal samples were placed in a freeze dryer (Virtis 213521, SP Scientific, Gardiner, NY 12525) until all moisture was extracted. Samples (feed and fecal) were then passed through a 1mm screen of a Wiley Mill (Thomas Scientific, Swedesboro, NJ 08085). Samples were pooled within sample type with equal amounts of sample from each sample. Acid detergent fiber was determined utilizing an ANKOM 2000 Automated Fiber Analyzer (ANKOM Technology, Macedon, NY 14502) according to the manufacturer's protocols. The ADF bags were then ashed (500°C; 8 h) to obtain ADIA. Retrospective energy supply to each pen was calculated using dry matter (**DM**) intake and apparent digestibility using equations from the NRC (2016) and Weiss et al (1992).

Breeding

Estrus was synchronized for timed artificial insemination using a co-synch program (Selk, 2008). A controlled internal drug-release (**CIDR**; Zoestis Inc., Florham Park, NJ) device containing progesterone was inserted into the vagina and Factrel (gonadorelin hydrochloride, Zoetis Inc., Florham Park, NJ) was injected IM. The CIDR was removed after 7 d and lutalyse (dinoprost tromethamine, Zoetis Inc., Florham Park, NJ) was administered IM. Artificial insemination (**AI**) was performed approximately 60 h later along with a second Factrel injection. Semen straws are stored in liquid nitrogen until use. At the time of breeding, semen straws are thawed for 45 seconds before being inserted into the AI syringe and covered with an aseptic sleeve. Rectal palpation was performed to locate the cervix and the syringe was inserted through the vagina and the cervix. The semen was deposited just beyond the cervix in the body of the uterus. Cows were monitored by Heatwatch Estrus Detection System (CowChips, LLC, Manalapan, NJ 07726) for an additional 45-d period to determine if AI was successful. If a cow came into estrus during this period, she was artificially inseminated 12 h after standing.

Statistical Analysis

For each animal, daily changes in BW and BCS were determined by regressing BW and BCS on d of the experiment. Dependent variables included measures of production, body composition, and energetic efficiency. Dependent variables were regressed on the linear and quadratic terms of energy intake in R software (R Core Team, 2015). Data from one cow and calf in the 200 pen group were removed from the study due to bovine traumatic reticuloperitonitis of the dam.

RESULTS AND DISCUSSION

Cow Performance

Cow and calf BW and cow BCS are presented as raw means in Table 4 for key dates throughout the experimental treatment period. Data are shown for June 18 because this date represents the maximum shrink (lowest BW) recorded for cows in each treatment after the limit-feeding strategy was initiated. Average cow BW within treatment group declined dramatically from June 10 to June 18. Some BW loss was expected due to the decreased gut fill associated with the limit-feeding strategy. Feed DM offered to cows differed by a maximum of about 7 kg per day between the 135 and 223 pen groups. Therefore, differences in cow BW and calculated weight change could be partially due to differences in gut fill.

Cow BW ($P < 0.05$) and BCS ($P < 0.01$) were positively and quadratically associated with increasing cow energy supply (Table 6). As expected, body composition components were not different ($P > 0.5$; Table 5) at the initiation of the experiment. Changes in REA/BW, IMF, BF and RF over the experimental period were sensitive to cow dietary energy intake ($P < 0.05$; Table 6). Interestingly, there was little change in RF and no change in BF for cows in the lowest energy intake group (135 kcal NE_m·(kg $BW^{0.75})^{-1}$), even though RE was negative ($P < 0.02$) for this group. A possible explanation for this phenomenon could be due to a loss in visceral organ mass or a loss in body protein, as REA per kg BW was reduced over the span of the study in the 2 lowest energy intake groups.

The calculated MML from the RE equation (Table 6; Figure 1) where RE = 0 is 157 kcal NE_m·(kg $BW^{0.75})^{-1}$. This calculation utilizes the energy fed in the feed and translates to be 87.4% of the NRC (2016)–recommended energy requirement for this herd. Increased digestibility due to limit feeding (Trubenbach et al., 2014), a potential reduction in visceral organ mass (Evans et al., 2000), and restricted activity in a CE (CSIRO, 1990) are all likely contributing factors to the reduction in MML requirement. Comparing the June 10^{th} and June 18^{th} BW of the pen group receiving 159 kcal NE_m·(kg $BW^{0.75})^{-1}$, maintenance energy requirement plus lactation is reduced by 11.1% in the later date due to organ shrink.

Angus and Angus crossbred cows in this study produced more milk, on average, than beef cows from much of the literature (Bond and Wiltbank, 1970; Bartle et al., 1984; Jenkins et al., 1991; Marston et al., 1992; NRC, 2000; Johnson et al., 2003; Hudson et al., 2010; Winterholler et al., 2012; Rodrigues et al., 2014). Milk yield was positively and linearly ($P < 0.01$) related to cow energy supply. These results are similar to those from Miller et al. (1999), where milk yield was associated with feed intake. Using the milk yield equation from Table 6 and solving for milk yield at 157 kcal NE_m·(kg $BW^{0.75})^{-1}$ resulted in milk yield of 8.4 kg·d^{-1} at MML.

Few studies in the literature have analyzed for composition of beef milk. Those that have (Mondragon et al., 1983; Marston et al., 1992; NRC, 2000; Hudson et al., 2010; Winterholler et al., 2012; Rodrigues et al., 2014) report similar values to these findings. Milk fat percent increased ($P < 0.05$) in a linear fashion, whereas milk protein percent tended to increase ($.05 < P < 0.1$) linearly as cow energy intake increased. There was not a significant relationship ($P > 0.1$) between energy intake and percent milk lactose. The variance in milk constituents accounted for by energy intake was greatest for milk fat ($R^2 = 0.703$), followed by milk protein ($R^2 = 0.586$) and the least sensitive milk component measured was lactose ($R^2 = 0.464$). Linear coefficients for milk protein and lactose were not significant ($P > 0.08$). Other work with beef (Bartle et al., 1984) and dairy (Moe et al., 1965; Broderick, 2003) cows indicates that increased energy intake can result in a linear increase in cow BW gain and milk yield. Increased energy intake has also been shown to increase milk component density (protein, lactose, and SNF; Broderick, 2003).

Cow DM and ADF digestibility decreased linearly ($P < 0.03$) as cow energy intake increased (Table 6; Figure 2; Figure 3). Similarly, Clark et al. (2007) reported a 6.9 percentage unit improvement in DM digestibility when cows were limited to 80% of their estimated nutrient requirements. More recent data for non-lactating beef cows indicated a 7.5% increase in organic matter digestibility when feed intake of a high-energy diet was restricted to 80% of maintenance requirements (Trubenbach et al., 2014).

Observed cow energy intake was estimated by multiplying DMI by true digestibility (Weiss et al., 1992) and converting digestible DMI to NE_m intake (NRC, 2016). The relationship of observed energy intake to the original calculated feed energy intake is shown in Figure 4. Improved DM digestibility when cow energy intake was restricted resulted in a curvilinear (P < 0.001) relationship between calculated and observed energy intake. Declining energy availability with incremental increases in feed intake is likely the major factor that explains the declining cow BW and cow BCS change response with increasing feed intake.

The relationship of RE to grams of DMI per kilogram of $BW^{.75}$ is shown in Figure 5. The RE response to level of feed intake was curvilinear (P = .011, R^2 = 0.988) and similar to the observed energy intake (calculated from feed intake and digestibility data) shown in Figure 4. Maternal tissue stasis was achieved at 96.9 g of feed intake per kilogram $BW^{0.75}$ or 157 kcal $NE_m \cdot (kg\ BW^{.75})^{-1}$. This value represents the feed intake required for the cows to neither gain nor lose body energy plus that required for milk production (MML).

Furthermore, maintenance requirement for these cows (using feed energy values) was estimated to be 84.7 kcal $NE_m \cdot (kg\ BW^{.75})^{-1}$, compared to the 77 kcal $NE_m \cdot (kg\ BW^{.75})^{-1}$suggested by NRC (2016). This calculation was accomplished by subtracting the energy required for milk production at 157 kcal $NE_m \cdot (kg\ BW^{.75})^{-1}$ and then subtracting 20% of the remaining feed energy assumed to be associated with increased maintenance energy requirement due to lactation (NRC, 2016). Using digestibility data (rather than the feed energy offered), observed maintenance energy requirement plus lactation is 108 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1}$. This compares to the NRC (2016) –estimate of 92.4 kcal $NE_m \cdot (kg\ BW^{0.75})^{-1}$. For a 545 kg beef cow, the NRC (2016) estimates peak milk yield to be 9 $kg \cdot d^{-1}$, whereas cows on this study produced 13.6 kg (shrunk BW = 519 kg). Perhaps a portion of the increase in energy requirement at maintenance can be attributed to increased maintenance associated with greater genetic capacity for milk production (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Lalman et al., 2013).

The NRC (2016) model assumes no change in energy use for milk as energy intake increases or declines. However, data from this experiment demonstrates that milk yield can be increased by at least 28.8% if energy intake is increased beyond maintenance requirements. Ferrell and Jenkins (1985), Montano-Bermudez et al. (1990), and Lalman et al. (2013) recognize a relationship between the genetic potential for milk production and year-round maintenance energy requirements of the cow.

A primary concern in utilizing CE and limit-feeding strategies is long-term effects on the cows, especially reproductive performance. Obviously, we do not have adequate data in this relatively small, single-year experiment to evaluate the influence of energy intake on reproductive performance. They are reported in this thesis for future use in the event of more years of replication and/or for meta-analysis. Pregnancy checks were performed on December 10, 2016. There was 1 open cow in each of the pen groups being offered 135, 159, and 200 Kcal NE_m / kg $BW^{.75}$ and 2 open cows in the 176 and 223 Kcal NE_m / kg $BW^{.75}$ pen groups.

Steer Calf Performance

Milk availability (P < 0.01) and milk fat (P < 0.05) percent increased and percent milk protein tended (P < 0.1) to increase as cow energy intake increased. Greater milk intakes that are more nutrient-dense should produce calves that gain significantly more BW. Calf BW gain had a strong tendency to increase (linear P = 0.058) as cow energy intake increased. We anticipated calves compensating for less milk energy (as cow feed intake declined) by consuming more energy from creep feed. However, the relationship of cow feed intake to calf creep energy consumed was not significant (quadratic P = 0.111). As a result, total calf energy intake (milk plus creep energy) increased (P < 0.001; Table 7) with increasing cow energy intake. Therefore, calf efficiency (P < 0.05) as well as cow-calf pair efficiency (P < 0.02) declined with increasing cow feed intake. It should be noted that these efficiency calculations reflect calf gain and do not consider BW or BCS gain or loss by the cows.

Steer calf BF increased as cow energy intake increased (P < 0.05). Intramuscular fat and REA of calves tended (0.05 < P < 0.1) to increase as cow energy intake increased. Rump fat and REA/BW were not sensitive to cow energy intake level (P > 0.1). The significant increase in BF, along with the tendency of BW and REA to increase indicates that calves whose dams consume more energy gain more weight in subcutaneous fat and put less growth into lean muscle. Lean muscle growth is desired in calves over fleshiness.

Neither DM, nor ADF digestibility by calves were significantly influenced (P > 0.12) by cow energy intake. A limitation of this data is that only creep feed intake was included in this model, whereas milk intake could influence the digestibility estimates. Milk nutrients in the feces are not accounted for by creep feed samples (intake), thus the apparent digestibility measurement is almost certainly lower than true digestibility.

As expected, calf DMI increased over time within each treatment group (Table 8). Work reviewed by Arthington et al. (2008) found that creep intake and BW increased over time as calves had access to the creep. Mean feeding BW (calculated as the average initial and final BW [June 10 and September 29]) and average DMI/d were used to calculate creep feed intake as a percent of BW for each treatment. Creep feed intakes were 1.83, 1.82, 1.78, 1.75, and 1.61 %BW (DM) for 135, 159, 176, 200, and 223, pen groups respectively. Faulkner et al. (1994) observed an intake of 1.18 % BW for calves receiving *ad libitum* creep feed on fescue pasture for an 84-d period. Creep intakes from the current study were expected to be greater, because calves did not have access to growing forage.

The nutrient-dense diet used in this experiment resulted in relatively great steer creep feed intake, rapid calf BW gain, and increased fat deposition in steers (Table 5). Consequently, earlier weaning may result in more efficient overall nutrient utilization and steer calves that perform better during later stages of production due to less fat accumulation. In a study comparing early and normal weaning, early weaned steers consumed less feed and had improved feed to gain efficiency in the feedlot and had increased IMF and heavier carcass weights (Myers et al., 1999).

SUMMARY AND CONCLUSIONS

Compared to NRC (2016) maintenance energy requirement for these cows was estimated to be substantially greater (77 vs 84.7 kcal NE_m·(kg $BW^{.75})^{-1}$. However, maternal tissue maintenance of lactating cows being limit-fed in a CE was calculated to be substantially lower (157 Kcal NE_m·(kg $BW^{0.75})^{-1}$) or 87.4% of the NRC (2016) recommended requirement for these cows.

It is clear that cow BW, energy reserves, milk yield, and milk composition are dynamic and sensitive to energy intake. Energy is partitioned to both maternal tissue as well as milk production. Increasing cow energy intake beyond MML produces excess milk, excessive cow BCS, and fleshy calves. Furthermore, when calves had *ad libitum* access to the high-quality diet, additional nutrient intake from increased milk production was not efficiently utilized. More work is needed to determine the optimal amount of creep feed to offer calves and the best time to wean in a CE.

LITERATURE CITED

Bartle, S. J., J. R. Males, and R. L. Preston. 1984. Effect of energy intake on the postpartum interval in beef cows and the adequacy of the cow's milk production for calf growth. J. Anim. Sci. 58:1068–1074.

Bond, J., and J. N. Wiltbank. 1970. Effect of energy and protein on estrus, conception rate, growth, and milk production of beef females. J. Anim. Sci. 30:438–444.

Broderick, G. A. 2003. Effects of varying dietary protein and energy levels on the production of lactating dairy cows. J. Dairy Sci. 86:1370–1381.

Clark, J. H., K. C. Olson, T. B. Schmidt, M. L. Linville, D. O. Alkire, D. L. Meyer, G. K. Rentfrow, C. C. Carr, and E. P. Berg. 2007. Effects of dry matter intake restriction on diet digestion, energy partitioning, phosphorus retention, and ruminal fermentation by beef steers. J. Anim. Sci. 85:3383–3390.

Cochran, R. C., and M. L. Galyean. 1994. Measurement of in vivo forage digestion by ruminants. In: G. C. Fahey, M. Collins, D. R. Mertens, and L. Moser, editors. Forage quality, evaluation and utilization. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. p. 613–631.

CSIRO. 1990. Feeding standards for Australian livestock: Ruminants. Commonwealth Scientific and Industrial Research Organisation Publications, East Melbourne, Victoria, Australia.

Evans, B. J. L., B. L. Golden, and B. L. Hough. 2000. A new genetic prediction for cow maintenance energy. Beef Improv. Fed. Symp. Proc., Oklahoma State University, Stillwater, OK. p. 79–88.

Faulkner, D. B., D. F. Hummel, D. D. Buskirk, L. L. Berger, D. F. Parrett, and G. F. Cmarik. 1994. Performance and nutrient metabolism by nursing calves supplemented with limited or unlimited corn or soyhulls. J. Anim. Sci. 72:470–477.

Ferrell, C L, Jenkins, T. 1985. Cow Type and the Nutritional Environment: Nutritional Aspects: 725–741.

Hudson, M. D., J. P. Banta, D. S. Buchanan, and D. L. Lalman. 2010. Effect of weaning date (normal vs. late) on performance of young and mature beef cows and their progeny in a fall calving system in the Southern Great Plains. J. Anim. Sci. 88:1577–87.

Jenkins, K. H. 2014. Limit feeding production cows in confinement. In: Dr. Kenneth and Caroline McDonald Eng Foundation Symposium. San Antonio, TX. p. 29–34.

Jenkins, T. G., L. V Cundiff, and C. L. Ferrell. 1991. Differences among breed crosses of cattle in the conversion of food energy to calf weight during the preweaning interval. J. Anim. Sci. 69:2762–2769.

Johnson, C. R., D. L. Lalman, M. A. Brown, L. A. Appeddu, D. S. Buchanan, and R. P. Wettemann. 2003. Influence of milk production potential on forage dry matter intake by multiparous and primiparous Brangus females. J. Anim. Sci. 81:1837–1846.

Kanani, J., D. Philipp, K. P. Coffey, E. B. Kegley, C. P. West, S. Gadberry, J. Jennings, A. N. Young, and R. T. Rhein. 2014. Comparison of acid-detergent lignin, alkaline-peroxide lignin, and acid-detergent insoluble ash as internal markers for predicting fecal output and digestibility by cattle offered bermudagrass hays of varying nutrient composition. J. Anim. Sci. Biotechnol. 5:1–8.

Lalman, D., M. Rolf, R. Kropp, M. Brown, D. Sparks, and S. Linneen. 2013. Addressing cowherd efficiency in a world of mixed messages for producers: matching production levels to environmental conditions. In: Beef Improvement Federation. Oklahoma City, OK. p. 78–87.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and Simmental cow-calf pairs. J. Anim. Sci. 70:3304–3310.

Miller, S. P., J. W. Wilton, and W. C. Pfeiffer. 1999. Effects of milk yield on biological efficiency and profit of beef production from birth to slaughter. J. Anim. Sci. 77:344–352.

Moe, P. W., J. T. Reid, and H. F. Tyrrell. 1965. Effect of level of intake on digestibility of dietary energy by high-producing cows. J. Dairy Sci. 48:1053–1061.

Mondragon, I., J. W. Wilton, O. B. Allen, and H. Song. 1983. Stage of lactation effects, repeatabilities and influences on weaning weights of yield and composition of milk in beef cattle. Can. J. Anim. Sci. 63:751–761.

Montano-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2279–2288.

Myers, S. E., D. B. Faulkner, F. A. Ireland, L. L. Berger, and D. F. Parrett. 1999. Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. J. Anim. Sci. 77:300–310.

NRC. 2000. Nutrient Requirements of Beef Cattle. Seventh Revised Edition: Update 2000. National Academy Press, Washington, DC.

NRC. 2001. Nutrient requirements of dairy cattle. 7th ed. National Academy Press, Washington, D.C.

NRC. 2016. Nutrient requirements of beef cattle. Eighth. National Academy Press, Washington, D.C.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: https://www.r-project.org/

Rodrigues, P. F., L. M. Menezes, R. C. C. Azambuja, R. W. Sune, I. D. Barbosa Silveira, and F. F. Cardoso. 2014. Milk yield and composition from Angus and Angus-cross beef cows raised in southern Brazil. J. Anim. Sci. 92:2668–2676.

Selk, G. 2008. Synchronizing heats in beef cows and heifers. In: D. L. Lalman and D. Doye, editors. Beef Cattle Manual. 6th ed. Oklahoma State University Cooperative Extension, Stillwater, OK. p. 219–226.

Trubenbach, L. A., T. A. Wickersham, G. E. Carstens, and J. E. Sawyer. 2014. Managing energy requirements in confined cows. In: Dr. Kenneth and Caroline McDonald Eng Foundation Symposium. San Antonio, TX. p. 19-25.

Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39:95–110.

Weiss, W. P. 2000. Mathematical methods to estimate feed energy. In: Pacific Northwest Animal Nutrition Conference and Alltech, Inc. Pre-Conference Symposium. Spokane, WA. p. 155–164.

Winterholler, S. J., C. P. McMurphy, G. L. Mourer, C. R. Krehbiel, G. W. Horn, and D. L. Lalman. 2012. Supplementation of dried distillers grains with solubles to beef cows consuming low-quality forage during late gestation and early lactation. J. Anim. Sci. 90:2014–2025.

Table 1. Total mixed ration ingredient formulation and chemical composition (DM-basis)

Commodity	Amount (%)
Corn gluten feed[1]	54.8
Prairie hay	30.0
Corn, cracked	12.7
Limestone, 38%	2.5
Composition component	**Amount**
DM, %	72.70
NE_m, Mcal/kg[2]	1.59
Crude Protein, %	14.70
ADF, %	27.30
aNDF, %	52.90
Ash, %	7.99
TDN, %[2]	68.80

[1]Sweet Bran (Cargill, Inc., Minneapolis, MN 55440).

[2]Estimated using summative equation with 48-hr neutral detergent fiber *in vitro* digestibility (NRC, 2001) and equations from Weiss (2000).

Table 2. Amount of ration fed to each pen group and the corresponding percent of estimated NRC (2000) energy requirements per cow

Kcal NE_m· (kg $BW^{0.75})^{-1}$·d^{-1}	Ration, kg (DM)·d^{-1}	Percent of NRC (2000)
135	8.7	73.8
159	10.8	88.5
176	12.5	101.6
200	14.1	113.2
223	15.2	119.8

[1]Feed energy offered to each group calculated using *in vitro* neutral detergent fiber and equations from (Weiss, 2000; NRC, 2001).

Table 3. Monthly 2015 and long-term temperature and precipitation averages

	Temperature, °C		Precipitation, cm[1]	
Month	2015 avg[2]	Long-term avg[3]	2015 total	Long-term avg
June	26.0	24.6	9.75	12.34
July	27.6	27.5	9.57	7.75
August	25.6	27.2	3.30	7.87
September	24.3	22.3	6.60	9.55

[1]Total 2015 and average long-term (1981-2010) monthly precipitation for Lake Carl Blackwell Mesonet Station.
[2]Average 2015 monthly temperature for Lake Carl Blackwell Mesonet Station.
[3]Average long-term (1981-2010) monthly temperature for Payne Co. OK (OK Climatological Survey).

Table 4. Raw means for cow and steer BW (kg) and BCS (1-9 scale) on key dates[1]

	Pen group[2]				
	135	159	176	200	223
Cow BW					
June 10	528.3	568.5	586.2	584.9	566.2
June 18	479.8	512.8	545.9	539.9	518.1
Sept. 29	484.0	535.0	573.9	580.6	572.1
Oct. 6	476.9	532.5	571.1	571.5	553.3
Cow BCS					
June 11	5.21	5.51	5.18	5.31	5.21
Sept. 29	3.94	5.50	6.13	6.29	6.50
Steer BW					
June 10	129.1	135.3	135.6	127.8	134.6
Sept. 29	274.0	296.5	299.9	296.1	307.2
Oct. 6	280.2	295.9	295.0	287.4	303.2

[1]Key dates represent trial initiation (June 10), lowest recorded BW (shrunk BW; June 18), weaning (September 29), and 1 wk post-weaning (October 6)

[2]Pen group indicating daily energy provided expressed as 135, 159, 176, 200, and 223 Kcal $NE_m \cdot (\text{kg BW}^{0.75})^{-1} \cdot d^{-1}$ (Weiss, 2000; NRC, 2001).

Table 5. Mean body composition of cows and steers as determined by ultrasonography

	Pen Group[1]	REA[2], sq. cm	REA$\cdot$(kg BW)$^{-1}$	IMF[3], %	Back Fat[4], cm	Rump Fat, cm
Cows						
June 11	135	23.3	.044	3.38	.23	.23
	159	25.1	.043	3.69	.27	.26
	176	24.6	.043	3.53	.25	.20
	200	25.2	.043	3.48	.24	.28
	223	24.3	.044	3.52	.27	.28
Sept. 23	135	21.8	.044	3.71	.23	.19
	159	26.5	.041	4.08	.30	.31
	176	25.9	.045	4.29	.37	.40
	200	28.0	.044	4.44	.52	.60
	223	29.1	.048	4.37	.53	.64
Steers						
Sept. 23	135	24.7	.099	3.30	.48	.47
	159	25.0	.093	3.39	.53	.59
	176	24.8	.091	3.30	.50	.54
	200	26.6	.099	3.48	.53	.61
	223	26.0	.095	3.73	.57	.58

[1]Pen group indicating daily energy provided expressed as 135, 159, 176, 200, and 223 Kcal $NE_m\cdot$(kg $BW^{0.75}$)$^{-1}\cdot d^{-1}$ (Weiss, 2000; NRC, 2001).
[2]REA = Rib eye area.
[3]IMF = Intramuscular fat (marbling).
[4]Back fat measured between the 12th and 13th ribs.

Table 6. Regression equations depicting the relationship of daily cow energy intake to 111-d performance responses.[1]

Item[2]	Intercept		Linear Coefficient		Quadratic Coefficient	Adj. R^2	P-value (linear)[3]	P-value (quadratic)
Cow BW Δ, kg	-214.6	(62.75)	2.2031	(.33)	-5.32e-3 (9.1e-4)	.978	.04	.028
Cow BCS Δ	-5.5	(.497)	0.0487	(5.7e-3)	-9.78e-5 (1.57e-5)	.996	.003	.025
Milk Energy, Mcal[4]	-126.8	(67.9)	5.070	(.374)	-	.979	< .001	.417
Milk yield, kg	36.179	(131.95)	5.73	(.728)	-	.938	.004	.658
Milk fat, %	2.522	(.3489)	6.23e-3	(1.925e-3)	-	.703	.048	.491
Milk protein, %	2.482	(.2438)	3.474e-3	(1.35e-3)	-	.586	.082	.869
Milk lactose, %	4.723	(.088)	1.021e-3	(4.83e-4)	-	.464	.125	.502
Cow REA/BW Δ, cm^2/kg	-0.015	(3.47e-3)	9.29e-5	(1.91e-5)	-	.85	.017	.342
Cow IMF Δ, %	-0.6205	(.3957)	7.16e-3	(2.18e-3)	-	.709	.047	.492
Cow BF Δ, cm	-0.473	(.121)	3.42e-3	(6.66e-4)	-	.864	.014	.835
Cow RF Δ, cm	-0.698	(.103)	4.92e-3	(5.7e-4)	-	.948	.003	.380
Cow DM digestibility	108.87	(8.91)	-0.1873	(.0492)	-	.772	.032	.331
Cow ADF digestibility	94.62	(6.59)	-0.151	(0.036)	-	.803	.025	.211
Retained Energy, linear	-840.5	(173.1)	5.35	(.955)	-	.883	.011	.096
Retained Energy, quadratic	-2583.4	(589)	25.37	(6.71)	-0.0558 (.019)	.968	.011	.096

[1]Standard errors (SE) are shown in parentheses.
[2]BW = body weight, BCS = body condition score (1-9 scale), Δ = change (over the 111-d trial; ultrasound data was collected 105 d apart), REA = ribeye area, IMF = intramuscular fat, BF = back fat (between the 12th and 13th ribs), RF = rump fat DM = dry matter, ADF = acid detergent fiber.
[3]P-value from the linear model.
[4]Milk energy production over 111-d period (Mcal NE_m), calculated using NRC (2000) Eq. 4-17: (0.092 * %Fat) + (0.049 * (%SNF) – 0.0569.

Table 7. Regression equations depicting the relationship of daily cow energy intake to various 111-d calf performance and efficiency responses.[1]

Item[2]	Intercept		Linear Coefficient		Quadratic Coefficient	Adj. R^2	P-value (linear)[3]	P-value (quadratic)
Calf BW gain, kg	125.96	(7.997)	0.1325	(4.4e-2)	-	.667	.058	.826
Energy from creep, Mcal[4]	97.3	(247.3)	7.31	(2.82)	-0.0215 (7.83e-3)	.692	.372	.111
Total calf energy, Mcal[5]	640.8	(131.5)	4.68	(.725)	-	.910	< .001	.241
Calf REA , cm^2 [6]	21.83	(1.51)	0.0201	(8.33e-3)	-	.546	.095	.947
Calf REA/BW , cm^2/kg[6]	0.152	(.058)	-6.3e-4	(6.63e-4)	1.72e-6 (1.84e-6)	-.338	.439	.448
Calf IMF , %[6]	2.626	(.271)	4.54e-3	(1.5e-3)	-	.672	.056	.182
Calf BF , cm[6]	0.362	(.049e-2)	8.89e-4	(2.72e-4)	-	.708	.047	.879
Calf RF , cm[6]	0.342	(.114)	1.197e-3	(6.3e-4)	-	.394	.154	.369
Calf efficiency[7]	0.243	(1.77e-2)	-1.36e-3	(2.02e-4)	3.1e-6 (5.62e-7)	.987	.016	.031
Pair efficiency, linear[8]	0.095	(7.93e-3)	-2.2e-4	(4.38e-5)	-	.858	.015	.065
Pair efficiency, quadratic[8]	0.178	(2.25e-2)	-1.17e-3	(2.56e-4)	2.64e-6 (7.12e-7)	.973	.015	.065
Calf DM digestibility	124.74	(34.7)	-0.659	(.395)	1.97e-3 (1.098e-3)	.485	.311	.215
Calf ADF digestibility	99.45	(19.84)	-0.455	(.226)	1.42e-3 (6.28e-4)	.775	.124	.152

[1]Standard errors (SE) are shown in parentheses.

[2]BW = body weight, BCS = body condition score (1-9 scale), Δ = change (over the 111-d trial; ultrasound data was collected 105 d apart), REA = ribeye area, IMF = intramuscular fat, BF = back fat (between the 12^{th} and 13^{th} ribs), RF = rump fat DM = dry matter, ADF = acid detergent fiber.

[3]P-value from the linear model.

[4]Energy consumed from creep (Mcal NE_m) summed over 111 d.

[5]Total calf energy = the sum of milk and creep energy consumed by calves (Mcal NE_m).

[6]Calf body composition measurements were taken via ultrasound on September 23, 2015.

[7]Calf efficiency calculated as 111-d calf gain divided by the total energy consumed by the calf for the 111-d period.

[8]Pair efficiency calculated as 111-d calf gain divided by 111-d creep and cow energy intake.

Table 8. Mean steer-calf dry matter intakes (DMI) and average daily gain

	Group[1]				
	135	159	176	200	223
DMI (kg) by period:					
d 1-20	27.9	30.0	30.7	24.4	27.9
d 21-48	88.7	92.6	88.4	86.7	80.4
d 49-76	127.4	134.9	134.2	119.3	123.5
d 77-111	188.1	201.3	199.1	201.7	187.0
Total DMI, kg	432.1	458.8	452.4	432.1	418.9
DMI(kg)·$calf^{-1}$·d^{-1}	3.89	4.13	4.07	3.89	3.77
ADG[2], kg	1.29	1.43	1.45	1.46	1.53

[1]Pen group indicating daily energy provided expressed as 135, 159, 176, 200, and 223 Kcal NE_m·(kg $BW^{0.75}$)$^{-1}$·d^{-1} (Weiss, 2000; NRC, 2001).

[2]ADG = average daily gain, calculated as the total gain (kg) divided by 111 d.

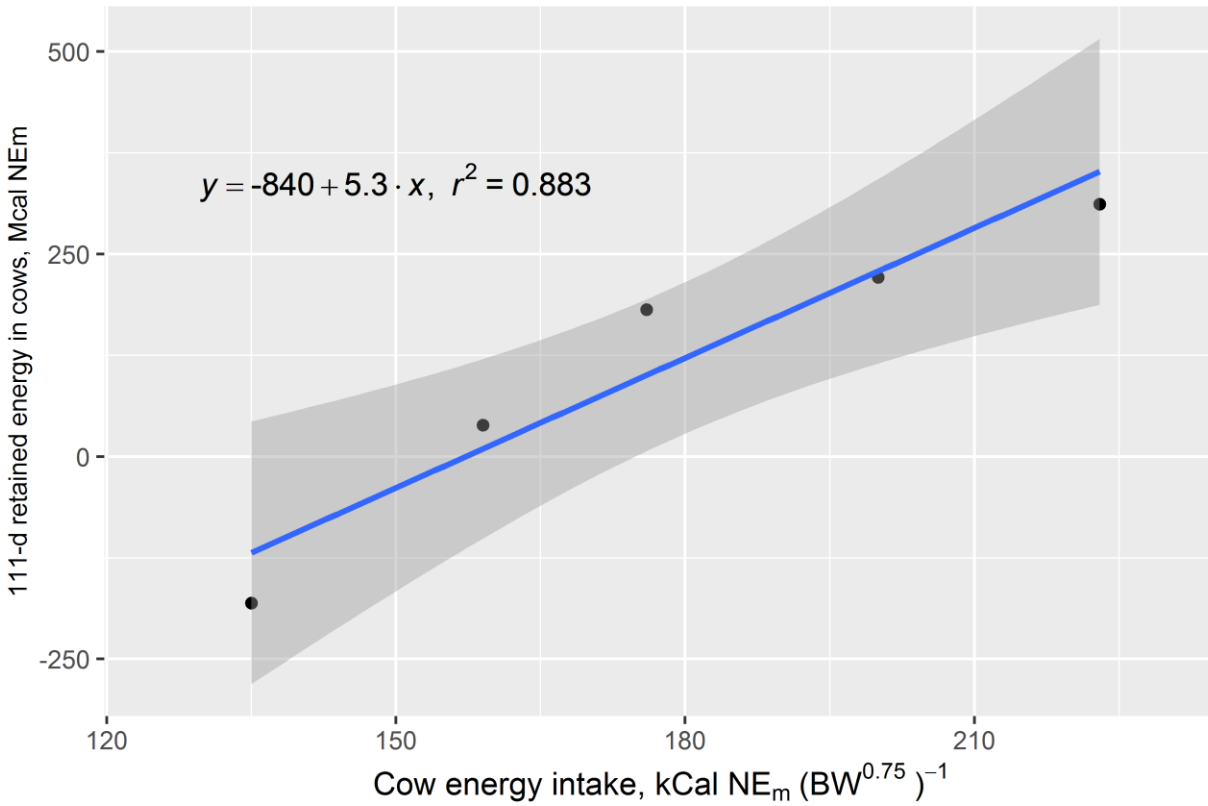

Figure 1. The relationship of retained energy (RE; Mcal NE_m) and cow energy intake (kcal $NE_m \cdot (kg\ BW^{0.75})^{-1}$).

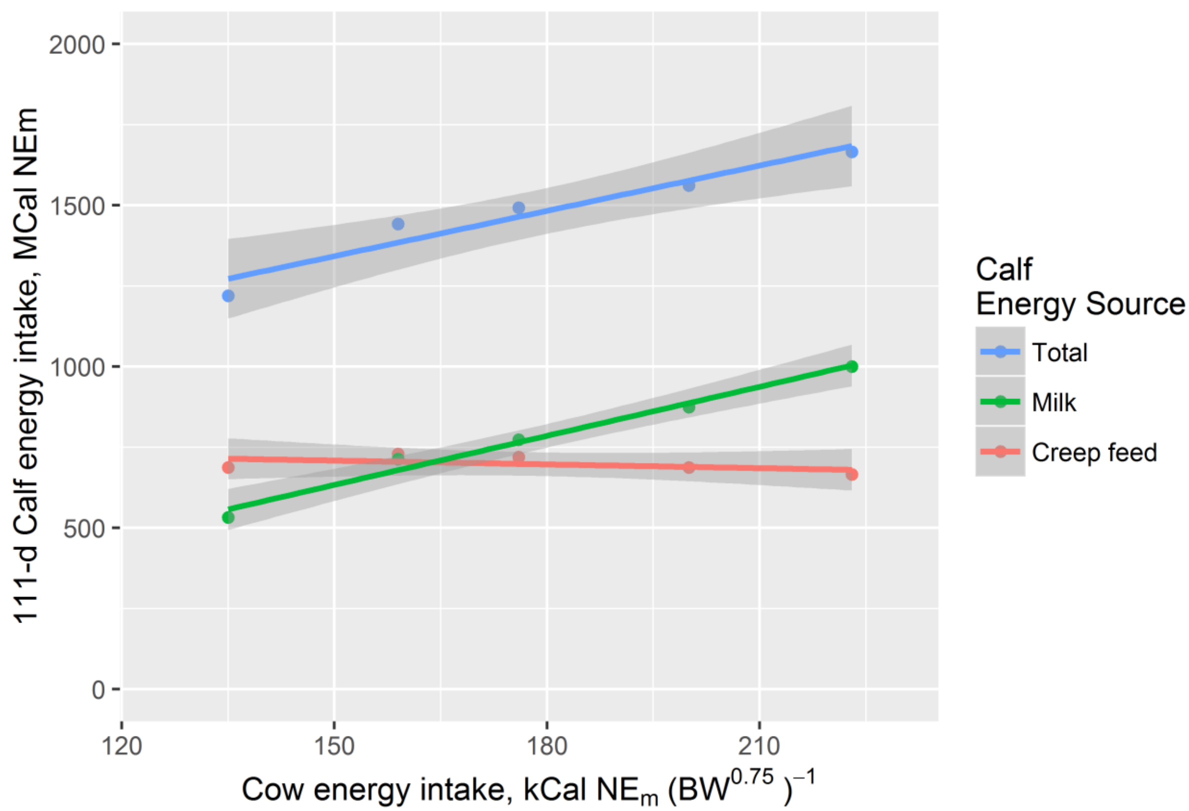

Figure 2. The relationship of calf energy intake from creep feed, milk, and the sum of both (Mcal NE_m) to cow energy intake (kcal NE_m·(kg $BW^{0.75}$)$^{-1}$).

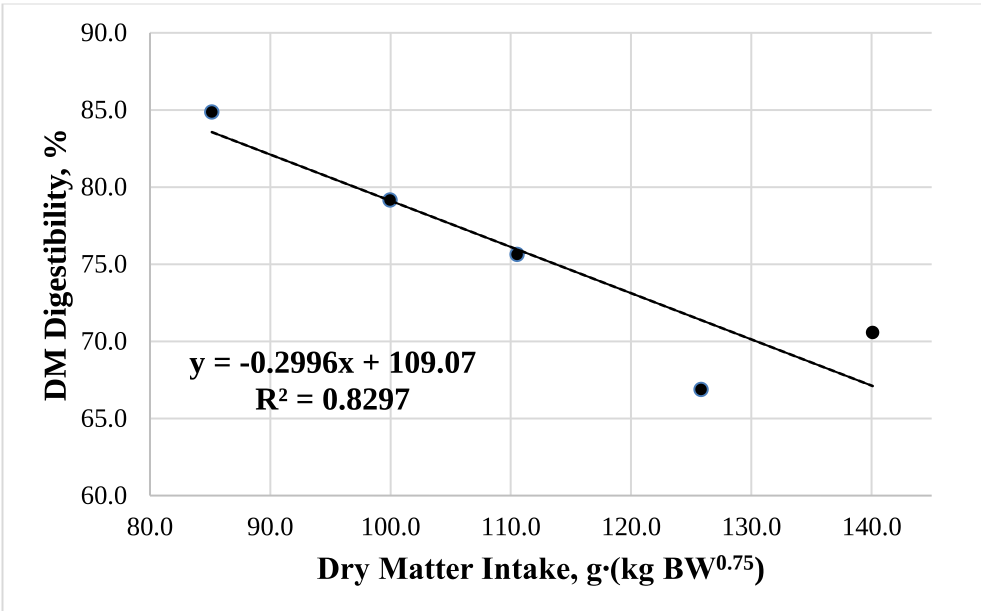

Figure 3. The effect of dry matter intake on dry matter digestibility (DMD). Dry matter digestibility was calculated as apparent DMD minus 7 to represent true DMD (NRC, 2001). Apparent DMD was determined using acid detergent insoluble ash (Kanani et al., 2014).

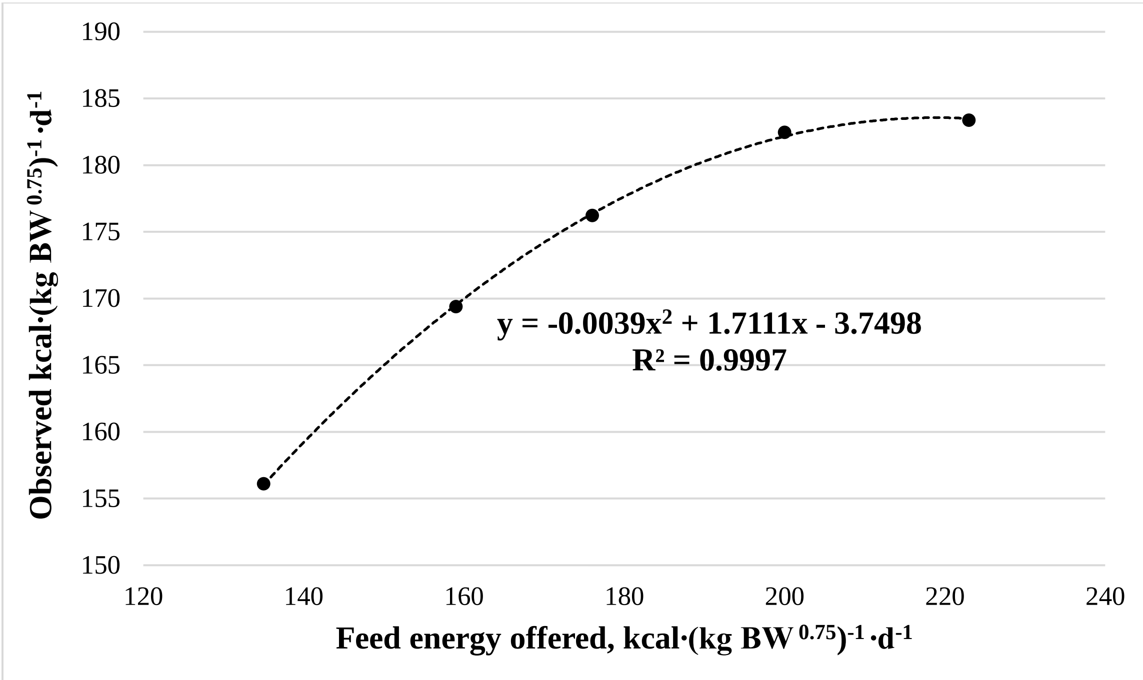

Figure 4. The relationship of observed cow energy intake to calculated feed energy intake. Feed energy offered = dry matter intake (DMI) * calculated NEm (calculated from Weiss et al., 2000 and NRC, 2001). Observed energy = DMI * observed NEm (calculated from observed true DMD determined using acid detergent insoluble ash as an internal marker (Kanani et al., 2014).

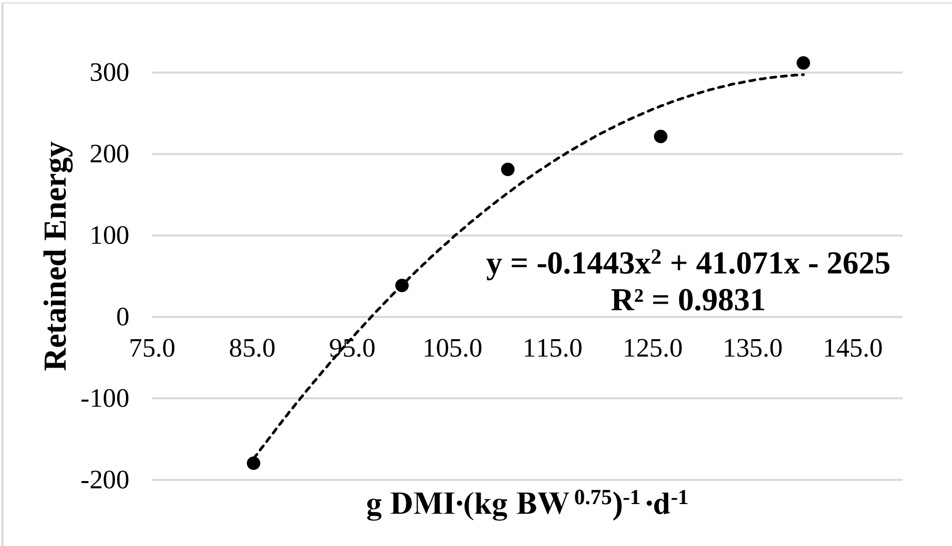

Figure 5. The relationship of retained energy (RE; calculated from the NRC, 2016 and Trubenbach et al., 2014) and dry matter intake (DMI).

APPENDICES

Appendix 1. Milk yield and composition least square means for cows that calved (on average) May 15, 2015 (± 9.6 d).

			Component					
Pen Group[1]	Date[2]	Yield, kg[3]	Fat, %	Protein, %	Lactose, %	SNF, %[4]	MUN, mg/dl[5]	E, Mcal/kg[6]
135	May 13	14.67	5.81	2.89	4.74	8.55	16.98	0.925
	June 30	8.53	3.17	2.79	4.94	8.68	11.24	0.676
	July 28	7.48	3.13	2.86	4.77	8.53	14.03	0.665
	August 25	6.78	3.61	3.16	4.87	8.88	12.06	0.728
	September 22	4.91	3.42	3.24	4.79	8.95	13.47	0.713
	SE	.79	.25	.08	.06	.09	.76	.03
159	May 13	13.32	5.74	2.85	4.90	8.68	18.86	0.925
	June 30	10.61	3.16	2.84	4.94	8.72	11.10	0.677
	July 28	10.14	3.40	2.81	4.88	8.59	12.27	0.694
	August 25	8.64	3.65	2.92	4.94	8.71	13.11	0.724
	September 22	7.32	3.43	3.06	4.91	8.89	13.22	0.712
	SE	.79	.25	.08	.06	.09	.76	.03
176	May 13	14.89	5.85	2.90	4.91	8.75	16.82	0.939
	June 30	10.68	3.81	2.94	4.92	8.79	10.87	0.743
	July 28	10.00	3.52	2.98	4.86	8.75	11.02	0.714
	August 25	9.30	3.65	3.21	4.90	8.95	11.57	0.774
	September 22	7.28	3.43	3.41	4.84	9.19	12.45	0.769
	SE	.79	.25	.08	.06	.09	.76	.03
200	May 13	15.30	5.11	2.91	4.79	8.64	16.00	0.862
	June 30	10.91	3.53	3.06	5.02	9.03	9.12	0.727
	July 28	12.26	3.36	3.06	4.91	8.89	10.37	0.705
	August 25	10.47	3.78	3.25	5.01	9.13	11.00	0.757
	September 22	7.98	4.38	3.56	4.90	9.46	13.15	0.832
	SE	.91	.27	.09	.06	0.1	.81	.03
223	May 13	16.08	5.42	2.99	4.84	8.78	15.99	0.899
	June 30	12.60	3.52	3.05	4.97	8.96	8.92	0.723
	July 28	12.44	4.19	3.11	4.89	8.92	11.48	0.787
	August 25	11.90	3.73	3.26	4.94	9.04	10.77	0.748
	September 22	10.49	3.96	3.51	4.91	9.36	12.76	0.786
	SE	.79	.25	.08	.06	.09	.76	.03

[1]Pen group indicating daily energy provided expressed as 135, 159, 176, 200, and 223 Kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$ (Weiss, 2000; NRC, 2001).

[2]Standard errors (SE) were calculated for dates within the trial period and do not include May 13 dates.

[3] Milk yield was corrected for the time of separation from calf to obtain a 24-h estimate.

4SNF = solids-non-fat percent.

[5]MUN = milk urea nitrogen (mg / dl).

[6]E = milk energy (Mcal NE_m / kg), calculated using NRC (2000) Eq. 4-17: (0.092 * %Fat) + (0.049 * (%SNF) – 0.0569.

Appendix 2. Calf feed intake and total feed intake per unit of calf body weight gain by period.

	Group[1]				
	135	159	176	200	223
Calf feed/calf gain:					
d 1-20	1.10	0.96	0.93	1.01	0.82
d 21-48	2.21	2.34	2.37	2.02	1.96
d 49-76	2.72	2.86	2.57	2.33	2.52
d 77-111	5.93	4.93	5.12	4.61	4.02
Total feed/calf gain[2]:					
d 1-20	8.84	8.14	8.35	12.70	9.91
d 21-48	8.19	9.90	11.73	11.17	12.29
d 49-76	7.71	9.16	9.31	10.03	11.14
d 77-111	15.34	14.08	16.43	15.90	15.49

[1]Pen group indicating daily energy provided expressed as 135, 159, 176, 200, and 223 Kcal $NE_m \cdot (kg\ BW^{0.75})^{-1} \cdot d^{-1}$ (Weiss, 2000; NRC, 2001).
[2]Total feed = calf creep feed and cow feed.

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