# THE RELATIONSHIP OF MATERNAL DIETARY ENERGY INTAKE TO MILK PRODUCTION, BODY COMPOSITION, AND EFFICIENCY OF CALF GROWTH


By

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# THE RELATIONSHIP OF MATERNAL DIETARY ENERGY INTAKE TO MILK PRODUCTION, BODY COMPOSITION, AND EFFICIENCY OF CALF GROWTH

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Abstract: The purpose of this research is to define cow and calf production responses and overall pair efficiency to a range of feed energy intakes provided to lactating beef cows. Two experiments were conducted in consecutive years using a total of 80 beef cow/calf pairs (40 per year). Each year, 8 cow/calf pairs were assigned to one of 5 intake levels (8.7, 10.8, 12.5, 14.1, 15.2 kg DM $\cdot$hd $\cdot d^{-1}$ for 111 d until weaning in yr 1 and 8.6, 9.5, 10.5, 11.4, 12.6 kg DM $\cdot$hd $\cdot d^{-1}$ for 125 d until weaning in yr 2). Each pen of 8 cows and their steer calves were managed together as contemporaries and group fed. While the cows were fed the range of feed energy intakes, the calves had ad libitum access to the same diet in a creep area. Calves did not have access to the cows' feed. Cow and calf BW were recorded every 28 d in yr 1 and every 14 d in yr 2. Cows were assigned a BCS every 28 d. Milk yield and composition were also measured at 28 d intervals. A digestibility trial was conducted each year to determine the relationship of energy intake on DM digestibility and acid detergent fiber (**ADF**) digestibility in both cows and calves. Dependent variables were regressed on linear and quadratic terms of energy intake. The mixed model included year as random and treatment energy level as a fixed effect, with pen as experimental unit. Cow DM digestibility ($P < 0.01$) and ADF digestibility ($P = 0.03$) decreased linearly with increasing cow energy intake. Increasing cow energy intake resulted in increased cow BW ($P < 0.01$), increased cow BCS ($P < 0.01$), increased milk yield ($P < 0.01$), and increased retained energy in cows (*quadratic* $P = 0.05$; **RE**). Calf efficiency ($P = 0.03$) and pair efficiency ($P < 0.01$) decreased with increasing cow energy intake.

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## Format of Thesis

This Thesis is presented in Journal of Animal Science style and format. Use of this format allows the individual chapters to be suitable for submission to scientific journals. Two papers have been prepared from the data collected and each one includes an abstract, introduction, materials and methods, results and discussion, and literature cited section. These two papers are chapters II and III.

# CHAPTER I

# REVIEW OF LITERATURE

## Energy Requirements of Beef Cows

### *Maintenance Energy*

Maintenance energy requirements are defined as the amount of feed energy intake that results in zero net gain of energy from tissues in the animal's body (NASEM, 2016). This requirement accounts for 70-75% of the total energy required by a cow (Ferrell and Jenkins, 1985). Maintenance energy requirements differ between animals, with a large portion of this variation being attributed to differences in energy expenditure of the visceral organs (heart, lungs, liver, kidney; Ferrell and Jenkins, 1985). Ferrell and Jenkins (1985) also found that visceral organ mass weighed more in cows fed ad libitum as compared to limit fed cows. More specifically, protein synthesis and turnover in the liver and gastrointestinal tract are believed to be directly related to the energy expenditure of those tissues (Ferrell and Jenkins, 1985). Chilliard et al. (1998) further supported this idea by noting that the liver and gastrointestinal tract account for only 6-9% of the normal body weight, but are responsible for 40-50% of the protein synthesis and oxygen consumption. Thus, an increase in energy intake will increase the energy expenditure of these organs and tissues, which contributes to differences in maintenance energy between animals at differing levels of intake.

Lofgreen and Garrett (1968) determined that fasting heat production (maintenance requirement) of cattle ranges from 72 to 82 Kcal/BW$^{0.75}$, with an average value of 77 Kcal/BW$^{0.75}$. The authors also found no difference in maintenance energy requirement between heifers and steers. Therefore, the current beef cattle NRC (NASEM, 2016) defines the NEm requirement of beef cattle to be 0.077 Mcal/SBW$^{0.75}$, where SBW$^{0.75}$ = shrunk metabolic BW in kg. The NRC also denoted that efficiency of ME use for lactation and maintenance was similar for beef cattle, thus requirements for lactation are also expressed in NEm units (NASEM, 2016). Requirements during lactation were found to be 20% greater than an animal's requirements for maintenance (NASEM, 2016).

Several authors have found that cattle with a greater genetic requirement for production parameters, such as milk or growth have an increased maintenance requirement (Ferrell and Jenkins, 1985; Jenkins and Ferrell, 2007). Greater production potential, and thus maintenance requirement, can lead to negative implications in reproductive performance of cows when feed energy availability does not meet the animals' requirement (Jenkins and Ferrell, 2007). Moreover, any limitations in feed energy intake can reduce milk production, as energy is directed away from the production of milk, which ultimately reduces the saleable product in the calf.

*Energy Partitioning*

In terms of energy partitioning, the dairy cattle NRC determined that efficiencies of use of ME for milk production and BW gain in lactating cows were 0.64 and 0.75 respectively (NRC, 2001). Efficiencies of ME use by non-lactating cows were determined to be 0.64 for milk production and 0.60 for BW gain. The lower efficiency estimate for BW gain in a non-lactating dairy cow reflects the increased digestibility of the diet during this production phase (NRC, 2001). Furthermore, Moe and Tyrrell (1972) determined the efficiency of ME use above maintenance to be 60% and below maintenance to be 84% for pregnant dairy cows.

*Implications of Underfeeding*

Underfeeding occurs when animals are subjected to periods of nutrient restriction, which results in a level of feeding below maintenance. Underfeeding gestating cows can lead to detrimental effects in the progeny. Du et al. (2010) described these effects to include a decrease in muscle fibers and overall muscle mass as well as reduction in the development of adipocytes, resulting in slower growing and lower preforming progeny. The reproductive performance of cows has also been shown to be affected. Buskirk et al. (1992) reported a tendency for reduced luteal activity and lower cycling rates in lactating Angus cows fed below the level of maintenance. Furthermore, Chilliard et al. (1998) noted that underfeeding can disrupt all reproductive regulatory functions, resulting in delayed puberty in heifers, suppression of ovulation, increased embryonic mortality, and increased post-partum interval.

Long term nutrient restriction lead to mobilization of body tissues, primarily fat, followed by muscle and bone in more extreme cases (Chilliard et al., 1998). Use of body protein to support production parameters such as milk is fairly limited as the use of protein to support structural and functional roles is prioritized over supporting milk production (Chilliard et al., 1998). The efficiency of this mobilization of body energy to support maintenance in times of nutrient restriction is found to be 80% (NASEM, 2016).

*Energy Requirements of Beef Cows Summary*

To avoid negative implications from underfeeding, animals should be fed at maintenance level. Maintenance energy is affected by many factors such as physiological state and genetic potential for production. The partitioning of energy for maintenance and retention (growth and lactation) further explains how the energy is utilized.

## Lifetime Cow Efficiency

Identification of cows that produce the greatest amount of calf weight gain (saleable product) on the lowest level of feed input will lead to maximization of cow efficiency. Matching the size and production potential of the cow to the size of the sire, the size of calf, and the production environment will also aid in the maximization of lifetime cow efficiency and profitability of the cow herd (Davis et al., 1983b; Ferrell and Jenkins, 1985; Jenkins and Ferrell, 1994).

Efficiency work conducted by Davis et al. (1983a, 1983b) determined that providing cows in excess of the energy requirement was not economically beneficial as the increased calf weight gain was not enough to offset the increased input expense. These authors also found crossbred dams to be slightly more efficient in conversion of digestible energy to calf weaning weight over straightbred dams. Furthermore, it was determined that the amount of feed consumed by the dam was the most important factor influencing overall lifetime efficiency. The dam accounted for 90% of the feed inputs of the cow/calf pair and was negatively correlated with lifetime efficiency, whereas the calf intake represented only 10% and was only slightly associated with efficiency (Davis et al, 1983b). In an experiment with differing breed crosses to represent high, medium, and low milk production, Van Oijen et al. (1993) reported that the low production potential group required the least amount of energy (14% and 12% less than the medium and high groups respectively) for production of calves to weaning and slaughter. The medium and high production groups produced 6% and 5% greater outputs in terms of calf weaning weight, but these higher outputs were offset by increased inputs. In this case, feed energy input was a larger contributor to efficiency than output (Van Oijen et al., 1992). Parity can also influence the efficiency of a cow, as shown by Johnson et al. (2003), where multiparous cows were 40% more efficient in early and late lactation than primiparous cows. The authors attributed this increased efficiency to potential differences in maintenance requirements, energy utilization for growth in the primiparous cows, or differences in fat mobilization to support milk production.

## Milk Production

*Genetic Selection*

Milk production is highly heritable ($h^2$ = 0.44; Dillard et al., 1978), therefore selection for greater milk EPD during sire selection will increase milk production in the daughters of those sires (Diaz et al., 1992; Marston et al., 1992; Johnson et al., 2003). Marston et al. (1992) noted a 1 kg change in the EPD of the dam lead to a 42.1 kg increase in total milk yield in Angus cows and a 69.3 kg increase in Simmental cows. Furthermore, these authors found that milk EPD was positively correlated with adjusted WW, where an additional 1 kg in milk EPD led to a 4.85 kg change in WW for Angus calves and a 3.74 kg change in Simmental calves (Marston et al., 1992).

In addition to selection for milk production through EPD selection, heterosis has been found to affect milk yield and the production of certain milk components (Willham, 1976; Holloway et al, 1985; Brown et al., 2001; Albertini et al., 2012; Rodrigues et al., 2014). Albertini et al. (2012) showed an increase in milk yield, milk protein, and solids non-fat content in crossbred cows over non-crossbred cows. Rodrigues et al. (2014) also demonstrated a positive effect of crossbreeding on milk yield. Furthermore, these authors reported that crossbred calves were more aggressive in suckling habits and suckled for a longer length of time, which could lead to stimulation of additional milk yield from the dam.

*Effect of Calf Sex*

Previous literature is inconsistent in determining the effects of suckling calf sex on subsequent dam milk yield. Several have found that cows with suckling male calves tended to produce a greater amount of milk (McCuskey et al., 1986; Albertini et al., 2012). More specifically, Albertini et al. (2012) demonstrated an 11.7% and an 11.9% increase in milk yield and milk protein respectively in dams with suckling male calves as compared to suckling heifer calves. Others showed no effect of calf sex on dam milk production (Marston et al., 1992; Rodrigues et al., 2014).

*Costs to Production*

Increased milk yield can inhibit the future productivity of the cow. Several studies reported reduced reproductive performance (Willham, 1976; Jenkins and Ferrell, 1992), in the form of increased postpartum interval (Boggs et al., 1980; Bartle et al., 1984; **PPI**) and reduced response to timed artificial insemination (**AI**; Edwards et al., 2017). Boggs et al. (1980) indicated a 1.4 d increase in PPI per additional kg of milk per day, while Bartle et al. (1984) showed a 3.3 d increase per kg of additional daily milk yield. In terms of AI, cows with a high genetic potential for milk yield had 11% and 13% lower AI pregnancy rates when compared with cows with a moderate and low genetic potential for milk yield respectively (Edwards et al., 2017). Overall, it is believed the decreased reproductive performance is a result of the competition between reproduction and lactation for the energy provided to the animal (Edwards et al., 2017). However, Fiss and Wilton (1992) found no negative effects of milk production on the reproductive performance of the cows and Beal et al. (1990) showed no effect of level of milk production on PPI.

Selection for cows with a greater potential for milk yield leads to cows with increased maintenance requirements (Montano-Bermudez et al., 1990a; Jenkins et al., 1991; Jenkins and Ferrell, 1992). Cows with moderate and high genetic potentials for milk yield had a 7% increase in maintenance energy requirements over cows with a low genetic potential for milk yield (Montano-Bermudez et al., 1990a). Further determination of the effects of milk production on maintenance requirements by Montano-Bermudez (1990b) showed that variation in milk production explained 23% of the variance in maintenance energy requirements. Montano-Bermudez (1990b) also determined gestation maintenance requirements to be 18% less than requirements of lactating cows with varying genetic potentials for milk yield.

While selection for increased milk yield can lead to greater weaning weights in a calf crop (Clutter and Nielsen, 1987; Van Oijen et al., 1993), the additional input costs needed to sustain the higher level of production are not always recovered by sale of the progeny. Van Oijen et al. (1993) noted that differences in energy input to sustain certain levels of production influenced the differences in herd efficiency and even outweighed differences in calf output. Furthermore, Davis et al. (1983b) reported that increased milk production only improves cow efficiency if the increased yield leads to increased calf weight gain. The work of Montano-Bermudez et al. (1990a) showed that calves of cows with a high and moderate genetic potential for milk yield received 54% and 52% of the preweaning energy intake from milk respectively, as opposed to 43% by the calves of cows with a low genetic potential for milk. This leads to a 3% and 13% increase in non-milk energy sources for calves of moderate and low milk producing cows.

Peak milk yield and time of peak are dependent on many factors, including breed composition, feed energy intake, and genetic potential for production. In addition to these factors, increased selection pressure on milk yield and an increasing supply of energy intake have been found to prolong the occurrence of peak milk yield (Jenkins and Ferrell, 1992). Lifecycle production efficiency studies by Jenkins and Ferrell (1992) estimated that an additional 40 Kcal/$BW^{0.75}$ of ME supplied to the cow resulted in a 2.6 wk delay in peak milk production. In addition to the potential delay in peak production, Johnson et al. (2003) indicated a faster decline in overall yield after peak milk for cows that produced a greater amount of milk. Various peak milk times and yields are reported throughout the literature, thus a comprehensive look at peak milk times and yields within the beef literature is presented in Table 1.

*Effects of Energy Intake on Milk Yield*

Increasing the energy supplied to the cow has been reported to increase peak and total milk yield (Moe et al., 1965; Miller et al., 1999; Jenkins et al., 2000; Lalman et al., 2000). When feeding cows 4 levels of energy intake to support ranges in milk production potential, Buskirk et al. (1992) noted an increase in not only BCS, BW, body energy, but also tendencies for increased milk production at higher energy intake levels. Moe et al. (1965) proposed the idea of diminishing milk output with increasing energy intake because increasing energy intake eventually leads to increases in lipogenesis, an energetically inefficient process as compared to the utilization of feed energy for maintenance and milk. The authors also noted that at inadequate levels of energy intake, body tissues will be mobilized to support the level of milk production. Petit and Micol (1981) fed 3 levels of energy to support a similar milk output in beef cows and found that cows fed 80-85% of the energy requirements lost BW and had decreased milk production during the experimental period as compared to those fed 100% and 115-120% of maintenance.

*Milk Composition*

Many studies in the literature have determined milk composition of various breeds and types of beef cattle. A comprehensive view of those estimates can be found in Table 2. These composition estimates can vary with stage of lactation (Mondragon et al., 1983; Albertini et al., 2012; Rodrigues et al., 2014), breed (Marston et al., 1992), or level of nutrition (Broderick et al., 2003; Winterholler et al., 2012). Several determined that milk protein content increased with increasing days in lactation (Mondragon et al., 1983; Marston et al., 1992; Albertini et al., 2012; Rodrigues et al., 2014). Other authors noted a similar relationship between milk fat content and increasing days in lactation (Albertini et al., 2012; Rodrigues et al., 2014). Conversely, Mondragon et al. (1983) found milk fat to be highest during early lactation and reported a 5.7%, 8.6%, and 13.7% depression in milk fat from 6 to 22 wks in lactation for first parity, second parity, and third parity cows respectively. Lactose concentrations within milk are reported to remain constant during lactation (Mondragon et al., 1983), decreased significantly (Rodrigues et al., 2014), or increased throughout lactation (Marston et al., 1992). The dairy cattle NRC (NRC, 2001) noted lactose concentrations to be the least variable and considers the concentration to be a constant 4.85% of milk. Any variation in lactose could be due to breed of cow or the milk protein content (NRC, 2001). Reports on total solids content are also variable, where total solids increased with increasing stage of lactation (Rodrigues et al., 2014) or decreased in Angus, but not Simmental cattle (Marston et al., 1992).

In terms of energy supply, Broderick et al. (2003) showed a linear increase in concentrations of protein, lactose, and solids non-fat with increasing supply of energy to Holstein cows. Contrary to the other milk components, milk fat content quadratically declined with increasing energy intake (Broderick et al., 2003). The work of Bowden (1981) also supported an increase in protein content with a 5.7% average increase in milk protein for beef cows fed 10% over the maintenance energy requirement as compared to cows fed at maintenance level. Average milk energy production also increased by 12% for the cows fed 10% over maintenance level. Winterholler et al. (2012) provided 3 levels of supplement, which supplied increasing levels of energy to beef cows consuming a low-quality forage. These authors found a linear decrease in milk fat with increased supplement provided and a linear increase in milk protein with increasing supplement. These findings support the idea that increased energy intake shifts nutrient metabolism to synthesize more milk protein over milk fat (Winterholler et al., 2012).

Fiss and Wilton (1992) expressed relationships between amount of milk yield and composition, where protein decreased with increasing yield, no change in lactose in response to yield, and a tendency for increased fat percentage with increasing yield.

*Milking Methods*

Machine milking (**MM**) and weigh suckle weigh (**WSW**) are the two main methods used to measure milk production in beef cattle. Removal of milk using the MM procedure allows for subsamples to be analyzed for milk components (Marston et al., 1992; Rodrigues et al., 2014). In MM methods within the literature, pairs were separated for a 4-7 h period (Marston et al., 1992) or for a 6 h period (Rodrigues et al., 2014), then reunited to allow the calf to nurse for 45 min on the day prior to milking. Following the 45-min nurse out period, pairs were once again separated and milking began 8 h later. On the day of milking, cows were administered 40 IU oxytocin (Marston et al., 1992) or 30 IU oxytocin (Rodrigues et al., 2014) to promote milk let down. After the administration of oxytocin, the milk claw was applied to the udder and remained on until milk flow ceased, at which point the claw was removed and the udder was hand stripped to remove any residual milk (Marston et al, 1992).

If a study does not aim to analyze milk samples for milk components, WSW could be utilized over MM procedures. The WSW procedure utilized by Rodrigues et al. (2014) used the same 6 h separation and 45 min nurse out period as their MM procedure. Twelve hours after the nurse out period, calves were weighed, allowed to suckle for 45 min and weighed again. The difference in the 2 weights was considered to be an estimate of 12 h milk production (Rodrigues et al., 2014). Separation times for WSW can vary from 4 h to 19 h, but Williams et al. (1979) showed a lower measurement error and higher correlation between milk production and calf ADG when an 8 h separation time is used as opposed to 4 h or 16 h.

Many in the literature indicated that MM lead to greater accuracy than WSW procedures (Mondragon et al., 1983; Beal et al., 1990; Albertini et al., 2012; Rodrigues et al., 2014). Albertini et al. (2012) determined a CV of 29% for MM estimates as opposed to a 45% CV for WSW estimates, indicating a greater ability to detect milk production differences when utilizing MM methods. Similarly, production estimates obtained from MM explained 25% of the variation in calf weaning weight (**WW**), while WSW only accounted for 13% of this variation (Rodrigues et al., 2014). Weigh suckle weigh estimates were consistently higher then MM estimates reported by Mondragon et al. (1983), but WSW estimates also had larger standard errors as compared to MM.

*Milk Production Summary*

Milk yield and composition are each affected by many factors including stage of lactation, dietary energy, breed, and parity. Changes in the diet can lead to shifts in the production of milk components and the absolute value of milk produced. While increased energy intake has proved to increase milk yield (Moe et al., 1965; Miller et al., 1999; Jenkins et al., 2000; Lalman et al., 2000), feed energy in excess of that needed to support production can lead to lipogenesis and a diminishing milk output (Moe et al., 1965).

## Cow Body Composition

Assessment of cow body composition can help to make adjustments to the nutritional program to ensure cows are in adequate condition for specific phases of production (Herd and Sprout, 1998; Lalman et al., 2015). Body condition scoring can be performed visually, utilizing a 1-9 scale, where 1 = emaciated and 9 = very obese (NASEM, 2016). Assessment of body condition within a cow herd is often more reliable then monitoring changes in live weight as BCS provides an idea of the cow's nutritional body reserves (Herd and Sprout, 1998). Improper condition (over or under the desired score) can lead to increases or decreases in the postpartum interval, milk yield, calf vigor, and even the occurrence of calving difficulty. Buskirk et al. (1992) showed that spring calving Angus cows in a thin BCS (BCS less than 3 on a 1-5 scale) had a 50% lower cycling rate at the end of the breeding season than contemporary cows in a BCS of 3 or greater.

A linear relationship between body weight change with change in BCS is well supported (Buskirk et al., 1992; Ferrell and Jenkins, 1996; Lalman et al., 1997). Buskirk et al. (1992) determined 37.8 kg of BW change per unit of BCS, while Ferrell and Jenkins (1996) reported 51 kg of EBW change was associated with one unit of BCS. For primiparous beef cattle, the beef cattle NRC determined an average BW change of 50.9 kg per unit of BCS (NASEM, 2016). Furthermore, the beef cattle NRC (NASEM, 2016) determined this linear relationship to be a 7.105% change in SBW per BCS.

Aside from the more traditional, subjective visual assessment of a BCS, ultrasound technology can be utilized to determine body composition (Schroder and Staufenbiel, 2006). Techniques outlined by Scroder and Staufenbiel (2006) indicated that the thickness of the skin of a cow is equivalent to 5 to 6 mm and is included in the ultrasound measurement, thus a measurement of 6 mm would indicate a complete loss of body reserves. A 1 mm change in ultrasound back fat thickness is associated with a 5-kg change in body fat and a change in 1 visual BCS is equal to a change in 10 mm of back fat. While differences in ultrasound technician and placement of the ultrasound transducer can lead to small margins of error, correlations of 0.91 to 0.95 have been reported between ultrasound back fat thickness and visual BCS (Schroder and Staufenbiel, 2006).

Ultrasound back fat measurements taken at 8 weeks post-calving and again at weaning by Bowden (1981) showed that cows fed at maintenance lost 0.6 mm of back fat during the lactation period, while cows fed 10% over the maintenance requirement maintained their back fat. The loss of back fat by those cows fed at maintenance indicated mobilization of body reserves to support the level of milk production. Similarly, Miller et al. (1999) reported that increasing milk yield led to a decrease in fat depth during the lactation period in beef cattle.

**Calf Growth and Performance**

Milk yield has historically been identified as the greatest influence on pre-weaning calf weight gain (Boggs et al., 1980; Beal et al., 1989; Edwards et al., 2017). More specifically, several authors have shown that 60-66% of the variation in weaning weight of calves can be attributed to milk production of the dam (Neville, 1962; Rutledge et al., 1971). Correlations between milk production and calf BW gain have been reported as a range of 0.12-0.88 (Ansotegui et al., 1991), or an intermediate value of 0.55 (Hudson et al., 2010). Marston et al.

(1992) reported correlations between total milk yield and calf WW to be 0.30 for Angus calves and 0.47 for Simmental calves, indicating a significant influence of milk production on not only calf BW gain, but also on calf WW. The calves of cows fed 10% over the maintenance level gained 0.06 additional kg per day and weaned an additional 11 kg over calves of dams fed at maintenance level (Bowden, 1981). These authors also noted that the energy intake from creep was similar among both groups of calves, thus the difference in weaning weights was attributed to the 7% greater milk energy available to calves of the dams fed 10% over maintenance (Bowden, 1981). Similarly, evaluation of low (<5.5 kg/d) and high (>9.8 kg/d) milk production Angus X Hereford dams showed a 20% increase in calf WW for calves of high milk producing dams in a range setting and a 19% increase in a drylot setting (Wyatt et al., 1977).

While the percentage of milk components was not correlated with adjusted WW, Marston et al. (1992) determined that the absolute quantities of milk fat and milk protein was significantly related to calf WW in Angus and Simmental calves. Brown and Brown (2002) also demonstrated an increase in preweaning weight gains with increased yields of milk protein, and milk fat.

While increased milk intake leads to increased weaning weights, many in the literature have presented the idea of a compensation mechanism, in which calves substitute forage for milk in low milk availability scenarios (Lusby et al., 1976; Wyatt et al., 1977; Ansotegui et al., 1991). The work of Wyatt et al. (1977) showed a 32% decrease in forage consumption from calves of high milk producing dams. Milk tends to be favored over forage, thus calves fed higher levels of milk consumed hardly any forage during the first 60 d (Tedeschi and Fox, 2009). Furthermore, at peak milk yield, forage consumption was reduced for calves consuming a greater amount of milk. Lusby et al. (1976) not only reported a substitution of non-milk feed sources when milk availability was lower for calves grazing forage, but also in a creep feeding scenario. In terms of creep feeding, calves with greater estimated milk intake consumed less creep feed (Davis et al., 1983a; Jenkins et al., 1991; Buskirk et al., 1992). Contrary to those that support a compensation mechanism, other authors reported no effect of creep intake on milk OM intake (Cremin et al., 1991; Soto-Navarro et al., 2004).

Differences in milk availability lead to differences in calf efficiencies and the efficiencies in which milk is utilized to produce weight gain. Wyatt et al. (1977) denoted a 63% decrease in milk utilization for gain in calves of high milk production Angus X Hereford dams, equating to an additional 27.6 kg of milk to produce an additional kg of gain above the calves receiving a low level of milk. These authors attribute differences in milk utilization to be the result of substitution of milk for forage. Bond and Wiltbank (1970) reported similar findings, where calves of cows consuming a low energy diet required 3.6 kg of milk per kg of weight gain as compared to 3.9 and 4.4 kg of milk for calves of cows consuming a moderate and high level of energy. Calves of higher milk producing dams required 31.3 kg of milk per kg of weight gain as compared to 18.9 kg of milk for calves of lower milk producing dams (Clutter and Nielsen, 1987).

*Calf Growth and Performance Summary*

Increased milk availability is proven to increase calf WW (Wyatt et al., 1977; Bowden, 1981). While milk production is correlated with overall calf gain and WW, the absolute quantity of the milk fat and milk protein were also correlated with calf WW (Marston et al., 1992; Brown and Brown, 2002). Variable data is available to determine whether calves substitute milk intake for feed and forage when milk availability is lower. Potential substitutions of non-milk sources can influence the efficiency of which milk is utilized by the calf and ultimately the efficiency of the cow/calf pair.

## Creep Feeding

Several authors have discussed the importance of non-milk sources on calf performance (Boggs et al., 1980; Willham, 1980; Bartle et al., 1984). For the cattle utilized by Bartle et al. (1984), the milk production of the dam at 9 weeks into lactation (5 kg/d) was only sufficient to support calf maintenance, thus non-milk intake became necessary to support growth in the calves. Boggs et al. (1980) further suggested that by 3 wks of age, more than half of the energy intake of the calf is coming from non-milk sources. Willham (1980) also noted that once a calf is able to utilize creep or forage, milk production is not as important.

Taylor et al. (1938) outlined the decision process of whether or not to include creep feeding in the management of young calves. The authors believed the end marketing method dictated the decision of whether or not to creep feed. Calves sold at weaning would benefit from the extra gain produced from creep feed intake, but calves to be fed out for a longer period before being sold could get fleshy and ultimately experience reduced gains in the finishing period (Taylor et al., 1938).

One of the primary benefits of creep feeding is the increase in calf weight gain. Faulkner et al. (1994) reported a 39% greater ADG for calves with limited access to creep over non-creep fed calves and a 13% greater ADG for calves with unlimited access to creep over limited access to creep. Both Martin et al. (1981) and Stricker et al. (1979) reported similar findings, as creep fed calves were 15 kg and 32 kg heavier at weaning respectively than the non-creep fed contemporaries.

While creep feeding does lead to increased pre-weaning gains, it can have negative effects on the post-weaning performance. More specifically, Faulkner et al. (1994) observed a lower gain to feed conversion for creep fed calves over non-creep fed calves in the finishing period (0.13 vs. 0.16). Post weaning gains in the work of Martin et al. (1981) were 0.11 and 0.01 kg less for female and male calves that had been creep fed as compared to calves with no access to creep. Fluharty and Loerch (1996) also reported decreased post-weaning feed efficiency for creep fed calves over non-creep fed calves (0.25 vs. 0.23 kg gain/kg feed). Creep feeding heifers can lead to detrimental effects on lifetime productivity if not managed properly. Heifers that were creep fed weaned less calves per cow, had calves with a lower birth weight and WW, and had reduced milk production as compared to non-creep fed heifers (Martin et al., 1981). The potential for reduced milk production in cows that were creep fed or developed on a high concentrate diet is a result of excess fat deposition in the udder, which hindered tissue development.

*Creep Feeding Summary*

The end marketing method is often utilized to determine whether or not to creep feed. While creep feeding lead to increased ADG (Stricker et al., 1979; Martin et al., 1981; Faulkner et al., 1994), post weaning feed efficiency can be compromised (Fluharty and Loerch, 1996), and replacement heifer productivity and reproductive performance can be inhibited (Martin et al., 1981). An understanding of the risks and benefits associated with creep feeding is essential to determination of whether this management tool benefits the end marketing method.

## Diet Digestibility

Digestibility is the availability of food nutrients within a ration, which ultimately predicts the level of production that can be supported by that ration. The digestibility of a diet is primarily dependent upon level of intake and diet composition (Colucci et al., 1982). Previous literature greatly supports the idea that increasing feed intake leads to increased rate of passage and thus decreased diet digestibility (Moe et al., 1965; Colucci et al., 1982; Shaver et al., 1986; Okine and

Mathison, 1991). Colucci et al. (1982) determined a correlation of 0.92 between forage retention time and diet concentrate retention time, such that a unit increase in forage retention lead to an increase in concentrate retention by 0.46 units. A review by Moe et al. (1965) showed that for all diets and digestibility values evaluated, the TDN value of the diet decreased as the level of intake increased. More specifically, TDN values declined by 4.58, 6.22, and 3.41% for each unit increase of feed intake in growing steer diets encompassing varying forage and concentrate ratios. These authors also noted that increased levels of intake ultimately lead to increases in digestive, gas, and fecal losses. Okine and Mathison (1991) determined a 17% decrease in retention of a forage diet in the reticulorumen in response to an increase in feeding levels (maintenance and 1.7 times maintenance) for non-lactating dairy cows. The review by Tyrrell and Moe (1975) established that the TDN of a total mixed ration (**TMR**) tends to decline at an increasing rate as the intake of the TMR increases. They also denoted that this rate of depression in TDN increases as the portion of grain in the TMR increases. The digestion trials used in the review fed a ration containing 75, 62.5, 50, 37.5, or 25% grain. Digestive efficiency was shown to be maximized at 37.5% grain, which represented a feeding level of 3.2 times maintenance (Tyrrell and Moe 1975). When gestating beef cows were fed a high- and low-level energy diet, each at two levels of intake (80% and 120% of maintenance requirements), digestibility of diet OM was increased for the higher energy diet (Trubenbach et al., 2014). Furthermore, restriction of intake to 80% of maintenance requirements resulted in a 4.5-unit increase in OM digestibility for both diets.

Variable data is present to support the relationship of stage of production and diet digestibility. In dairy cows, diet digestibility for lactating cows fed a high energy diet to support peak milk was recorded as 66.6% compared to an estimate of 72.3% when cows were fed a maintenance level during the dry period (Tyrrell and Moe, 1975). The authors indicated that these estimates prove that tabular values of digestibility and digestive coefficients are not representative of all levels of production. When comparing lactating and non-lactating (first trimester of pregnancy) beef cows, Ovenell et al. (1991) reported a tendency for greater particulate passage rate for the lactating cows, but overall DM digestibility did not differ between the two groups (54.9% digestibility for lactating cows vs. 55.5% for non-lactating). Similarly, Linden et al. (2014) showed no influence of lactation on DM digestibility, but when comparing pregnant and non-pregnant cows and heifers, pregnant animals had a significantly greater DM digestibility. Age did not influence rate of digestibility (Linden et al., 2014).

*Diet Digestibility Summary*

Level of intake and diet composition are the primary factors influencing diet digestibility. Increased intake leads to decreased digestibility due to increased passage rate of the digesta (Moe et al., 1965; Colucci et al., 1982; Shaver et al., 1986; Okine and Mathison, 1991). Stage of production (lactating vs. non-lactating) has been documented to have varying effects, if any on overall diet digestibility.

## Conclusion

Determination of cow maintenance requirements is essential to ensuring the production potential of the animal is met. If the level of intake does not support the level of production, body reserves will be utilized in order to meet production demands. Assessment of body reserves is an essential management tool and can be utilized to determine the performance of the animal given the input resources. This assessment can be performed visually through the assignment of a BCS by a trained evaluator, or less subjectively through the use of ultrasound technology.

Milk production influences the maintenance requirement of the animal and can be greatly influenced by genetic selection and dietary energy. Increased selection pressure for milk production and increasing dietary energy leads to increased milk yields. Milk yield is highly correlated to calf WW and overall BW gain, thus an increase in milk yield will lead to increased calf WW. While the dam's level of milk production should support the calf for a period of time, non-milk sources such as forage or creep feed may become necessary if milk availability is low. There is a possibility for calves to substitute feed and forage for milk, although the research is variable.

While the feed intake of the dam is the major component affecting overall pair efficiency, calf utilization of milk energy for BW gain is also a contributing factor. Increasing cow inputs as a means to increase calf weight gain is inefficient as the sale of the calf rarely offsets the increased costs of the production system.

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**Table 1.** Time of peak milk and peak yield reported for beef cows in the literature

| Source | Time of Peak Milk (weeks) | Yield at Peak Milk (kg/d) |
|---|---|---|
| **NASEM, 2016** | | |
| Angus Cows | - | 8.00 |
| Hereford Cows | - | 7.00 |
| **Rodrigues et al., 2014** | | |
| Angus Cows | 8.70 ± 0.60 | 6.60 |
| Angus X Hereford Cows | 9.10 ± 0.40 | 6.30 |
| **Jenkins et al., 2000** | | |
| Sire Breed: | | |
| Angus/Hereford 1963-1970 | 5.00 ± 1.70 | 7.00 ± 1.50 |
| Angus/Hereford 1980's | 6.00 ± 1.40 | 8.00 ± 1.10 |
| **Jenkins and Ferrell, 1992** | | |
| Angus Cows | 10.40 ± 0.40 | 9.40 ± 0.30 |
| Hereford Cows | 8.80 ± 0.40 | 8.50 ± 0.30 |
| **Marston et al., 1992** | | |
| Angus Cows | 12.70 | 9.60 ± 0.30 |
| Simmental Cows | 11.40 | 11.40 ± 0.30 |
| **Clutter and Nielsen, 1987** | | |
| Angus X Hereford | 8.29 | 9.66 |
| Angus X Red Poll | 7.14 | 8.75 |
| Angus X Milking Shorthorn | 7.14 | 7.04 |

**Table 2.** Milk yield and composition estimates presented in the literature

| Source | Milk Yield, kg/d | Fat, % | Protein, % | Lactose, % | Solids Non-Fat, % |
|---|---|---|---|---|---|
| **Edwards et al., 2017**[1] | | | | | |
| d 58 | | | | | |
| Low Production Group | 6.80 | 2.33 | 2.71 | 5.13 | 11.47 |
| Moderate Production Group | 8.90 | 2.81 | 2.70 | 5.21 | 11.96 |
| High Production Group | 12.70 | 3.24 | 2.82 | 5.24 | 12.63 |
| d 129 | | | | | |
| Low Production Group | 6.00 | 2.01 | 3.01 | 4.46 | 10.40 |
| Moderate Production Group | 8.80 | 2.16 | 2.94 | 4.51 | 10.50 |
| High Production Group | 11.00 | 2.29 | 2.99 | 4.54 | 10.66 |
| **NASEM, 2016** | 8.00[1] | 4.03 ± 1.24 | 3.38 ± 0.27 | 4.75 ± 0.91 | 8.31 ± 1.38 |
| **Rodrigues et al., 2014** | | | | | |
| Angus Cows | 4.09 | 3.21± 0.11 | 2.90 ± 0.04 | 4.65 ± 0.03 | - |
| Hereford X Angus Cows | 4.00 | 3.43 ± 0.10 | 3.03 ± 0.04 | 4.61 ± 0.03 | - |
| **Winterholler et al., 2012**[2] | 8.28 | 2.11 | 3.05 | 4.97 | 8.94 |
| **Hudson et al., 2010**[1] | | | | | |
| Normal Weaned | 7.53 ± 3.31 | 3.56 ± 0.17 | 2.91 ± 0.06 | 5.00 ± 0.05 | 8.91 ± 0.10 |
| Late Weaned | 7.62 ± 3.31 | 3.68 ± 0.17 | 2.85 ± 0.06 | 4.96 ± 0.05 | 8.81 ± 0.10 |
| **Johnson et al., 2003**[3] | | | | | |
| Primiparous, Early Lactation | | | | | |
| High Sire MEPD[4] | 7.80 | - | - | - | - |
| Low Sire MEPD[4] | 2.70 | - | - | - | - |
| Mulitparous, Early Lactation | | | | | |
| High Sire MEPD[4] | 11.30 | - | - | - | - |
| Low Sire MEPD[4] | 10.50 | - | - | - | - |
| Primiparous, Late Lactation | | | | | |
| High Sire MEPD[4] | 5.40 | - | - | - | - |
| Low Sire MEPD[4] | 4.10 | - | - | - | - |

| | | | | | |
|---|---|---|---|---|---|
| Mulitparous, Late Lactation | | | | | |
| High Sire MEPD[4] | 8.70 | - | - | - | - |
| Low Sire MEPD[4] | 8.80 | - | - | - | - |
| **Lalman et al., 2000[5]** | | | | | |
| Low Energy | 5.14 | 3.50 | 2.90 | - | - |
| Maintenance Energy | 6.20 | 3.80 | 3.00 | - | - |
| Maintenance High Energy | 6.83 | 3.70 | 3.10 | - | - |
| High Energy | 6.34 | 3.30 | 3.40 | - | - |
| **Miller et al., 1999[6]** | | | | | |
| Days in Lactation | | | | | |
| 68 | 5.72 ± 2.29 | - | - | - | - |
| 117 | 5.15 ± 2.13 | - | - | - | - |
| 185 | 3.71 ± 1.70 | - | - | - | - |
| **Beal et al., 1990[1]** | | | | | |
| Weigh-Suckle-Weigh | 5.2 ± 0.50 | - | - | - | - |
| Machine Milking | 5.1 ± 0.20 | 4.10 ± 0.07 | 3.32 ± 0.02 | 4.70 ± 0.03 | 8.80 ± 0.04 |
| **Montaño-Bermudez et al., 1990b** | | | | | |
| Hereford X Angus cows | 8.50 ± 0.27 | - | - | - | - |
| Red Poll X Angus cows | 9.60 ± 0.20 | - | - | - | - |
| Milking Shorthorn X Angus cows | 10.50 ± 0.30 | - | - | - | - |
| **Bartle et al., 1984[7]** | | | | | |
| 100% NRC (1976) | 5.90 | - | - | - | - |
| 120% NRC (1976) | 6.10 | - | - | - | - |
| **Mondragon et al., 1983[8]** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Weigh-suckle-weigh | | | | | |
| 1st parity | 9.33 | - | - | - | - |
| 2nd parity | 11.00 | - | - | - | - |
| 3rd parity | 11.10 | - | - | - | - |
| Machine milking | | | | | |
| 1st parity | 6.23 | 3.30 | 3.43 | 5.07 | - |
| 2nd parity | 7.63 | 3.27 | 3.37 | 5.10 | - |
| 3rd parity | 7.70 | 3.27 | 3.40 | 5.20 | - |
| **Bowden, 1981**[9] | | | | | |
| Maintenance Energy | 5.90 | 4.13 | 3.30 | - | - |
| Maintenance + 10% Energy | 6.50 | 4.13 | 3.50 | - | - |

[1]Angus cows
[2]Angus cows, averaged across dietary treatment
[3]Brangus cows
[4]MEPD = predicted genetic merit for milk production
[5]Angus cows, values represent the mean from milk collections performed at d 30, d 60, and d 90 of lactation
[6]Purebred Hereford cows
[7]Hereford and Hereford X Angus cows
[8]British beef breeds and various dairy breeds, values represent the averages of 3 sampling collections
[9]Simmental X Angus, Charolais X Angus, Hereford X Angus, and Jersey X Angus cows, values represent average of values recorded at 6, 14, and 22 weeks into lactation

CHAPTER II

# I. The relationship of maternal dietary energy intake to diet digestibility, milk production, and feed intake of calves

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**ABSTRACT:** The objective of this research was to define cow milk composition, diet digestibility, and calf production responses to a range of feed energy provided to lactating beef cows. Two experiments were conducted in consecutive years using a total of 80 beef cow/calf pairs (40 per year). Each year, 8 cow/calf pairs were assigned to a pen and one of 5 energy intake levels (135, 159, 176, 200, and 223 kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ for 111 d until weaning in yr 1 and 142, 159, 177, 193, and 212 kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ for 125 d until weaning in yr 2). Each pen of 8 cows and their steer calves were managed together as contemporaries and group fed. The range of feed energy intakes was accomplished by varying the amount of feed provided to each pen of cows, while the calves had ad libitum access to the same diet in a creep area. Calves did not have access to the cows' feed. Milk yield and composition were measured at 28-d intervals. A digestibility experiment was conducted each year to determine the relationship of energy intake with DM and acid detergent fiber (**ADF**) digestibility in both cows and calves. Pen was the experimental unit and dependent variables were regressed on linear and quadratic terms of energy intake. The mixed model included year as a random effect and energy intake as the fixed effect. Cow DM digestibility ($P < 0.01$) and ADF digestibility ($P = 0.03$) decreased linearly with increasing cow energy. Increasing cow energy intake resulted in a linear increase in milk yield ($P < 0.01$), milk fat ($P = 0.01$), milk protein ($P < 0.01$), and milk solids non-fat ($P < 0.01$, **SNF**). Increases in milk fat, SNF, and overall milk yield lead to greater milk energy availability for the calves of cows fed greater levels of energy. While increasing energy intake stimulated increases in milk yield, this additional yield requires increased inputs and thus can be costly to produce. Continual selection for cows with increased genetic potential for milk yield can be detrimental to the efficiency of the cow/calf pair if the additional milk production is not efficiently utilized by the calf to produce BW gain.

**Keywords:** energy intake, digestibility, milk composition, milk yield

## INTRODUCTION

Characterization of production responses to feed energy availability is a critical element in designing beef production systems that optimize the efficiency of grazing resources or harvested feed utilization. In particular, accurate characterization of responses to varying feed energy intake in lactating beef cows is complex due to the impact that feed intake can have on diet digestibility (Trubenbach et al., 2014).

Similarly, the dynamic nature of partitioning of available nutrients to maintenance, maternal tissue, and lactation (Jenkins and Ferrell, 1992) adds complexity to the ability to accurately define or predict production responses. Increasing energy intake increases total milk yield in beef (Jenkins and Ferrell, 1992; Miller et al., 1999; Lalman et al., 2000) and dairy cows (Macleod et al., 1984; Coulon and Remond, 1991; Friggens et al., 1995; Broderick, 2003). While responses in milk chemical components vary, in general, milk energy concentrations increase with increasing feed energy intake in beef (Lalman et al., 2000; Winterholler et al., 2012) and dairy cattle (Coulon and Remond et al., 1991; Friggens et al., 1995; Broderick, 2003).

While the work of Ferrell and Jenkins (1992) documented a significant influence of breed and energy intake level on time of peak lactation, yield at peak lactation, and total 210-d milk yield, varying feed energy intake levels were based on calculated feed energy availability from tabular values.

Therefore, the objectives of this experiment were to determine the influence of energy intake in lactating beef cows on apparent diet digestibility, milk yield, and milk composition responses.

## MATERIALS AND METHODS

*Animals*

The Oklahoma State University Institutional Animal Care and Use Committee approved all animal protocols used in the 2-yr study. Eighty Angus and Angus x Hereford lactating beef cows (6 ± 2.0 yr, 534 ± 60 kg BW) were used (40 per year) along with their suckling steer calves (84 ± 8.7 d, 130 ± 15 kg BW). The steer calves were sired by Angus and Hereford sires. Average calving date was March 15, 2015 in yr 1 and March 8, 2016 in yr 2. Steers were castrated at birth by the application of a rubber ring (banding; Fell et al., 1986; Chase et al., 1995) and received an anabolic implant (Ralgro, Merck Animal Health, Madison, NJ) at approximately 2 mo of age. Cows were assigned to 1 of 5 pens (experimental unit) in a completely randomized design. Cows were ranked by days in milk, body weight, and early lactation milk yield and allocated so that each of these variables were similar across all pens. Differing levels of energy intake were provided to each pen by varying the amount of feed fed to the cows (Table 1) to achieve 135, 159, 176, 200, 223 kcal (NEm) · (kg $BW^{0.75})^{-1} \cdot d^{-1}$ kcal in yr 1 and 144, 160, 178, 193, 213 kcal NEm · (kg $BW^{0.75})^{-1} \cdot d^{-1}$ in yr 2. Animals were rotated among the physical pens every 28 d in an effort to minimize any pen effect.

*Facilities*

The experiment was performed at the Range Cow Research Center, South Range Unit located West of Stillwater, Oklahoma. Five outdoor, dirt floor pens were utilized that provided 89 square meters per cow-calf pair. Each pen contained concrete, fenceline feed bunks that provided 0.9 m of linear bunk space per cow and 0.3 m of linear bunk space in a creep area for the calves. Cows and calves had access to 4.18 square meters per cow of shade and each pen was equipped with an automatic waterer.

Experimental treatments began on June 10, 2015 in yr 1 and June 1, 2016 in yr 2 resulting in 111 d and 125 d of data collection in yr 1 and yr 2 respectively. Cow/calf pairs were acclimated to the experimental ration for 11 d prior to experiment initiation in both years. For the first 6 d during acclimation, pairs grazed Bermudagrass pasture and were delivered feed in the pasture. For the remaining 5 d, pairs were housed in the experimental pens and fed in the bunks that would be used for the duration of the experiment. Feed delivery amounts were increased daily until the approximate amount of feed to be delivered to the 200 kcal NEm ·(kg $BW^{0.75})^{-1}·d^{-1}$ and 193 kcal NEm ·(kg $BW^{0.75})^{-1}·d^{-1}$ groups in yr 1 and 2 respectively was reached for all cows.

*Diets and Feeding Procedures*

The diet was a total mixed ration (**TMR**) for both years (Table 2). In yr 1, 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 at a rate of 2 ounces per hd/d on cow and calf feed daily. The mineral also contained Altosid IGR (Central Life Sciences, Schaumburg, IL) for insect control and chlortetracycline (Aueromycin, Zoetis Services, LLC, Florham Park, NJ) for the prevention of anaplasmosis. Model level 1 (NRC, 2000) was used to estimate DIP and MP balance with a microbial efficiency of 12% (NASEM, 2016). To ensure adequate degradable intake protein (**DIP**), 0.23 kg of cottonseed meal per cow was top dressed on cow feed daily for the 135 kcal NEm· (kg $BW^{0.75})^{-1}·d^{-1}$ treatment group. Calculated DIP balance ranged from 191.2 to 217.3 g/d for the 135 and 223 kcal NEm· (kg $BW^{0.75})^{-1}·d^{-1}$ treatment groups respectively and MP balance ranged from 101.7 to 275.7 g/d. In yr 2, calculated DIP balance ranged from 23.9 to 35.1 g/d for the 144 and 213 kcal NEm· (kg $BW^{0.75})^{-1}·d^{-1}$ treatment groups respectively and calculated MP balance ranged from 14.1 to 452.8 g/d for the 144 and 213 kcal NEm· (kg $BW^{0.75})^{-1}·d^{-1}$ treatment groups.

TDN was calculated using *in vitro* neutral detergent fiber digestibility and summative equations provided in the dairy cattle NRC (2001):

$$TDN = \left(CP \times e^{-1.2\times(ADICP/CP)}\right) + (0.98\times[100 - NDF_{CP} - CP - Ash - EE]) + (0.90\times[EE - 1]\times 3) + (NDF_{CP}\times \frac{IVNDF}{100}) - 7$$

where CP = crude protein, ADICP = acid detergent fiber insoluble crude protein (& of total N), $NDF_{CP}$ = crude protein-free neutral detergent fiber, and IVNDF = in vitro digestible neutral detergent fiber.

Feeding occurred at approximately 0730 h each day. Prior to feed delivery, calves were gathered and penned in the shaded areas and remained penned until the cows consumed their ration. This ensured that calves did not have access to cow feed. Calves had unrestricted access to the creep area through a creep gate, which the cows could not access. Calves received the same TMR diet as the cows and daily amounts provided were increased as needed to ensure *ad libitum* intake. Orts from the creep areas were removed weekly during yr 1 and daily in yr 2, and sampled weekly both years. No orts were recorded from the cow feed bunks during either year.

*Digestibility*

An apparent diet digestibility study using acid detergent insoluble ash (**ADIA**) as the internal marker (Cochran and Galyean, 1994; Kanani et al., 2014) was conducted for cows and calves from d 90 through d 96 in yr 1 and d 68 through d 74 in yr 2. Feed samples were collected from the bunks each morning from d 90-95 and d 68-73 in yr 1 and yr 2 respectively. Manure collections from cows ($n \geq 5$) and calves ($n \geq 5$) were performed per pen each morning and night (12 hours apart) on d 91-96 and d 69-74. Orts from the calf bunks were collected prior to feeding on the days of manure collection. Feed samples from each collection were placed in paper bags and dried in a forced air oven (50°C; 52 h minimum). Manure samples were frozen immediately (-80°C) and placed in a freeze dryer at a later date (Virtis 213521, SP Scientific, Gardiner, NY) until all the moisture was extracted. Feed and manure samples were then ground through a

Wiley Mill (Thomas Scientific, Swedesboro, NJ) using a 1 mm screen. Equal amounts of ground sample from each day were pooled within animal treatment. ADF was determined using an ANKOM 2000 Automated Fiber Analyzer (ANKOM Technology, Macedon, NY) according to manufacturer's protocols. The ADF bags were ashed (500°C; 8 h) to obtain ADIA.

*Animal Health*

Prior to experiment initiation in year 1, the steer calves received a clostridial vaccine (Covexin 8, Merck Animal Health, Madison, NJ) and pour-on dewormer (Normectin, Norbrook Inc., Lenexa, KS). At experiment initiation in yr 1, cows and calves were treated with an insecticide (Synergized Permethrin, Durvet, Inc., Blue Springs, MO) and drenched with a dewormer (Valbazen, Zoetis Inc., Florham Park, NJ). On d 26, cows were given another dose of pour-on Permethrin for fly control. Approximately 1 mo later, the cows received insecticide ear tags (XP820, Y-Tex Corporation, Cody, WY). One week prior to weaning, steers were revaccinated with Covexin 8 and BoviShield Gold 5 (Zoetis Inc., Florham Park, NJ).

On d 0 in yr 2, all steers were administered a clostridial (Vision 7, Merck Animal Health, Madison, NJ) and respiratory vaccine (Titanium 5, Elanco Animal Health, Greenfield, IN) as well as administered a dewormer (Safegurad, Merck Animal Health, Madison, NJ). At this same time point, all cows were administered Safeguard and XP820 insecticide ear tags. On the last day of the experiment (d 125), steers were revaccinated with Titanium 5 and Vision 7.

*Breeding*

Prior to the experiment, all cows were synchronized for artificial insemination (**AI**) using a Co-Synch protocol (Stein et al., 2015). A controlled internal drug release (**CIDR**; Zoetis Inc., Parisppany, NJ) device containing progesterone was inserted into the vagina and Factrel® (gonadorelin hydrochloride, Zoetis Inc., Parisppany, NJ) was injected intramuscularly (**IM**). After 7 d, the CIDR was removed and Lutalyse® (dinoprost tromethamine, Zoetis Inc., Parisppany, NJ) was given IM. Approximately 60 h later AI was performed and a second Factrel® injection was administered. Following AI, cows in yr 1 were monitored by Heatwatch Estrus Detection System (CowChips, LLC, Manalapan, NJ) for 45 d. If estrus was detected, the cow was artificially inseminated 12 h after observation of standing heat.

In yr 2, blood samples were taken from the coccygeal vein 20 d after AI to determine pregnancy status. Heat detection patches (Estrotect, Estrotect Inc., Spring Valley, WI) were applied to those cows determined to be open. Morning and night visual heat checks were performed on those with heat detection patches. Cows were artificially inseminated 12 h following observation of standing heat. Palpation pregnancy checks were performed on December 10, 2015 in yr 1 and on October 26, 2016 in yr 2.

*Milk Sampling*

Milk yield was measured 28 d and 20 d prior to experiment initiation in yr 1 and 2 respectively to be used for treatment allotment. After experiment initiation, milk yield was determined every 28-d using a milking procedure adapted from Marston et al. (1992). All cows were machine milked using a portable milking machine (Portable Vacuum Systems, Springville, UT). On the day prior to milking, calves were separated from their dams at 1400 h. During this time they were allowed access to water, but did not have access to creep feed. Calves were reunited with their dams at 2000 h for a 45 min nurse out period. Following this period, calves were again separated at 2045 h. Milking began at 0500 h the following morning, resulting in an average separation time of 8 h. On the morning of milking, cows were combined into one pen and brought into the working facility in random order. After entering the working facility, cows were weighed on a calibrated scale (Sooner Scale Inc., Oklahoma City, OK) and sent to 1 of 2 working chutes, allowing 2 cows to be milked simultaneously. Once in the chute, cows were injected IM with 1 ml oxytocin (Oxoject, Henry Schein Animal Health, Dublin, OH) for milk let down. Udders were then washed with warm, soapy water, dipped with an antibacterial solution, dried, and hand stripped before application of the milking claw. The milking claw remained on the udder until milk flow ceased. Each quarter was then hand stripped to ensure complete udder evacuation. At the completion of milking, teats were again dipped with the antibacterial solution and the cow was returned to her calf. Any hand stripped milk obtained was combined with the machine milk and weighed on a calibrated platform scale (Defender 5000, Ohaus Corp., Parsippany, New Jersey). A sub sample was taken in a vial containing 2-bromo-2nitropropane-1,3-diol for preservation and shipped to the Heart of America Dairy Herd Improvement Association laboratory (Manhattan, KS) for composition analysis. Milk energy content of each sample was estimated utilizing the following equation (Eq. 4-17, NRC, 2000):

$$E = (0.092 \text{ X } \%Fat) + (0.049 \text{ X } \%SNF) - 0.0569$$

Where E = energy content (Mcal/kg of milk) and SNF = solids non-fat. Time of milking and milk yield was recorded for each cow. Yield was multiplied by a coefficient to adjust all yields to reflect an 8 h production, which was then multiplied by 3 as an estimate of 24 h milk yield.

*Statistical Analyses*

Pen was the experimental unit. Regression of the dependent variables on energy intake included year as a random effect and energy intake as the fixed effect (R Core Team, 2016). Year was considered a random effect because it is not repeatable due to differences in climate factors and availability of diet ingredients. Since the 2 experiments differed slightly in length, all dependent variables were adjusted to represent a 100-d period. Linear and quadratic terms were considered significant at $a = 0.05$ and trends were significant at $0.05 < P < 0.10$.

In yr 1, data from one cow and calf were omitted from the 200 Kcal treatment group due to bovine traumatic reticuloperitonitis of the dam. In yr 2, data from one cow and calf were omitted from the 144 Kcal treatment group due to death of the calf.

## RESULTS AND DISCUSSION

*Cow Diet Digestibility*

Cow diet DM digestibility ($P < 0.01$; Figure 1) decreased with increasing cow energy intake. A similar negative linear relationship was observed for cow ADF digestibility ($P = 0.03$; Table 3). Moe et al. (1965) reported a similar relationship in which the TDN value of the diet decreased with increasing levels of intake in lactating dairy cows consuming 1 to 5 times their maintenance requirement. Tyrrell and Moe (1975) also indicated that the TDN of a TMR declined at an increasing rate as the amount of TMR provided is increased.

Similar results in gestating beef cows fed a wheat straw based TMR indicated a 4.5 percentage unit improvement in OM digestibility when intake was restricted to 80% of maintenance requirement as opposed to 120% of the requirement (Trubenbach et al., 2014). The current experiment indicates a 6.9-unit improvement in DM digestibility for cows limit fed to 80% vs. 120% of their energy requirement when using the energy specifications of Trubenbach et al. (2014).

Broderick (2003) noted a similar linear decline in ADF digestibility with increasing dietary energy. This included a 3.1 percentage unit decrease in ADF digestibility in lactating Holstein cows fed a high energy diet as opposed to those fed a low energy diet. Utilization of these authors dietary energy specifications with the current experiment's model predicts a 3.5 percentage unit decrease, similar to the 3.1 percentage unit decrease reported by the authors. Although the dietary energy provided by Broderick (2003) was much greater than that supplied by the current experiment, the current model appeared to generate similar results for estimated ADF digestibility.

After determination of apparent digestibility, energy availability was determined by multiplying apparent digestibility by DMI (Weiss, 1992) and converting digestible DMI to NEm intake (NASEM, 2016). Increased DM digestibility when cows were limit-fed led to a curvilinear (quadratic $P < 0.01$) relationship between the calculated and apparent feed energy supplied to each treatment group (Figure 2). The regression model (Table 3) was then used to determine the apparent feed energy supplied to each treatment group (Table 1).

*Milk Yield and Composition*

The Angus and Angus crossbred cows in the current experiment produced an average of 12.3 kg of milk per day during peak lactation (61 ± 9 d post-partum). This peak production is greater than estimates from beef literature which range from 6.5 to 7.9 kg of milk production per day (Miller et al., 1999; Hudson et al., 2010; Rodrigues et al., 2014). During mid- to late-lactation, cows in the current experiment produced 9.8 kg of milk per day compared to 6.4 to 8.6 kg of milk production per day in previous literature for this stage of lactation (Miller et al., 1999; Winterholler et al., 2012; Edwards et al., 2017).

Milk yield was linearly and positively related to cow energy intake ($P < 0.01$, Figure 3, Table 4). Moe et al. (1965) reported that with increasing energy availability, a greater portion of the diet is available to support milk production and the portion of the diet partitioned to maintenance declines. Numerous reports observed an increase in milk yield with increased daily energy intake in beef cows (Moe et al., 1965; Coulon et al., 1991; Jenkins and Ferrell, 1992; Friggens et al., 1995; Miller, 1999; Broderick, 2003). Jenkins and Ferrell (1992) reported a linear increase in milk yield of Angus beef cows with increasing dietary energy (Figure 3). The dissociation of the Jenkins and Ferrell (1992) and the current experiment regression lines results in a difference of 175.6 kg of milk for the 100-d period at the greatest energy intake reported in the study of Jenkins and Ferrell (1992). We interpret these differences in milk yield in response to energy intake between the two experiments to reflect substantially greater genetic potential for milk yield in the Angus and Angus X Hereford cows in the current experiment as compared with those used by Jenkins and Ferrell (1992). Cows with an increased genetic potential for milk yield have been shown to require a greater amount of energy intake to sustain the increased level of production (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Jenkins et al., 1991).

Few studies are available to compare the influence of dietary energy on milk composition. Milk composition values in the current study were slightly lower than those presented in previous literature (Lalman et al., 2000; Hudson et al., 2010; Winterholler et al., 2012; Rodrigues et al., 2014, NASEM, 2016; Edwards et al., 2017). Milk fat was an exception to this as values yielded in the current study fell within the range of values reported in the literature. Milk fat ($P = 0.01$), milk protein percent ($P < 0.01$), and milk SNF ($P < 0.01$) increased linearly with increasing cow energy intake (Table 4). This aligns with the work of Broderick (2003), indicating an increase in concentrations of milk protein and SNF with increasing energy density of the diet in primiparous Holstein cows. Using primiparous beef cows, Lalman et al. (2000) also found similar responses in which milk protein increased linearly and milk fat increased in a curvilinear fashion with increasing levels of energy supplied. Additional work from Friggens et al. (1995) reported an increase in milk fat content with increasing dietary energy in Friesian dairy cows.

Conversely, no significant relationship was observed for milk lactose percentage or MUN ($P > 0.05$). Several reviews have indicated that unlike milk fat and milk protein, lactose concentration is rarely altered with dietary changes in dairy cows (Sutton, 1989; Sutton and Morant, 1989). However, Broderick (2003) demonstrated increasing lactose concentrations with increasing dietary energy in dairy cattle. Stage of lactation influence on lactose concentrations is inconsistent, where lactose concentration increased throughout the lactation period (Marston et al., 1992), did not differ with stage of lactation (Mondragon et al., 1983), or decreased with increasing stage of lactation (Rodrigues et al., 2014). From the standpoint of milk yield, Edwards et al. (2017) found no significant difference between level of milk production and lactose concentration.

Milk energy, a function of milk fat and SNF (NRC, 2000) increased with increasing dietary energy intake ($P < 0.01$, Table 4). Total milk energy yield, a function of milk energy and total milk yield also increased with increasing dietary energy ($P < 0.01$; Figure 4). Efficiency calculations indicate that an additional 0.3 Mcal/d of milk energy is produced for each additional Mcal of NEm supplied to the cow. The efficiency of milk energy production per unit of feed energy appears to be greater in dairy cattle (Broderick, 2003) over the cattle in the current experiment, but no comparable research is available for beef cattle.

*Steer Calf Diet Digestibility*

The regression for calf feed DMI per unit of cow NEm intake did not differ from zero ($P = 0.19$). Furthermore, neither calf DM nor ADF digestibility was sensitive to cow energy intake ($P > 0.25$, Table 3). These measures of digestibility only included creep feed intake and did not account for the consumption of milk. Previous literature indicated that the ADIA concentration within milk is assumed to be zero since there is no fiber present in milk (Abdelsamei et al., 2005). Additionally, Diaz et al. (2001) noted that the digestibility of milk should be equal to or greater then 95%. Since milk nutrients were not accounted for in the feces in the current experiment, the digestibility estimates are likely lower then true digestibility.

Milk intake has been shown to influence intake of grain and forages as well as digestibility of these feedstuffs. Milk is preferred over forage intake if milk production is not limited, but several studies demonstrated a substitution of forage and grain for milk during times of lower milk availability (Baker et al., 1976; Buskirk et al., 1992; Abdelsamei et al., 2005; Tedeschi and Fox, 2009). Abdelsamei et al. (2005) supplied 5 levels of peak milk production along with ad libitum alfalfa hay to Holstein steer calves. The results indicated a 43% decrease in forage consumption with a 22% increase in milk intake between the highest and lowest milk intake treatment groups. Despite the compensation of lower milk availability with increased forage intake, Abdelsamei et al. (2005) did not find a difference in DM digestibility among treatment groups, which supports the current experiment's findings.

Faulkner et al. (1994) noted a linear increase in DM digestibility with increasing level of creep feed intake. No comparisons between intake and digestibility can be determined in the current experiment since no differences in intake were observed.

In conclusion, an increase in cow dietary energy led to an increase in many production parameters, including milk yield, milk protein, milk fat and SNF content. The increase in milk fat and SNF content lead to an increased amount of milk energy supplied to the calf, but the overall conversion efficiency of feed energy to milk energy was fairly low compared to dairy literature. Additional research is needed to verify this efficiency of energy conversion in beef cattle.

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**Table 1.** Daily feed energy and amount of ration provided to each cow and the corresponding estimate of percent NASEM (2016) energy requirements

| Year | Calculated Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ | Calculated Percent of NASEM 2016[2] | Apparentl[1] Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ | Apparent Percent of NASEM 2016[2] | Ration, kg DM $\cdot d^{-1}$ |
|---|---|---|---|---|---|
| 2015 | 135 | 77.7 | 148 | 89.6 | 8.7 |
| | 159 | 88.8 | 162 | 94.7 | 10.8 |
| | 176 | 99.9 | 168 | 100.2 | 12.5 |
| | 200 | 111.1 | 174 | 101.3 | 14.1 |
| | 223 | 122.2 | 175 | 100.6 | 15.2 |
| 2016 | 144 | 83.3 | 153 | 95.5 | 8.6 |
| | 160 | 92.5 | 162 | 100.8 | 9.5 |
| | 178 | 101.8 | 169 | 104.4 | 10.5 |
| | 193 | 110.6 | 173 | 107.3 | 11.4 |
| | 213 | 122.1 | 175 | 109.4 | 12.6 |

[1]Apparent Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ was calculated using the regression model depicting the relationship between calculated and apparent feed energy intake

[2]NASEM requirements was calculated using the 2016 Beef Cattle Nutrient Requirements Model (NASEM, 2016)

**Table 2.** Total mixed ration formulation and chemical composition (DM-basis)

| | Amount (%) | |
|---|---|---|
| | Exp. 1 | Exp. 2 |
| Ingredient, % DM | | |
| Corn gluten feed[1] | 54.80 | - |
| Prairie hay, chopped | 30.00 | - |
| Corn, cracked | 12.70 | 21.00 |
| Limestone, 38% | 2.50 | 2.00 |
| Bermudagrass hay, chopped | - | 37.50 |
| Distillers grain | - | 29.00 |
| Liquid supplement[2] | - | 7.50 |
| Soybean meal | - | 2.50 |
| Salt | - | 0.50 |
| Composition, % DM | | |
| DM, % | 72.70 | 88.40 |
| NEm, Mcal/kg[3] | 1.59 | 1.58 |
| CP, % | 14.70 | 15.60 |
| ADF, % | 27.30 | 27.00 |
| NDF, % | 52.90 | 47.70 |
| Ash, % | 7.99 | 7.64 |
| TDN, %[3] | 68.80 | 68.40 |

[1]Sweet Bran (Cargill, Inc., Minneapolis, MN).
[2]Liquid supplement contained 0.8 % Ca, 0.84% P, 0.57% Mg, 416.2 ppm Cu, and 239.6 ppm Fe per lb. DM (Quality Liquid Feeds Inc., Dodgeville, WI).
[3]Estimated using a summative equation with 48-hr neutral detergent fiber *in vitro* digestibility (NRC, 2001).

**Table 3.** Regression models depicting the relationship between calculated cow energy intake and cow and calf digestibility parameters.[1]

| Item[2] | Intercept | | Linear Coefficient | | Quadratic Coefficient | | Conditional[3] $R^2$ | P-value (linear) | P-value (quadratic) |
|---|---|---|---|---|---|---|---|---|---|
| Cow DM digestibility, % | 79.42 | (0.99) | -0.19 | (0.03) | NS | | 0.81 | < 0.01 | 0.14 |
| Cow ADF digestibility, % | 69.29 | (1.52) | -0.22 | (0.07) | NS | | 0.86 | 0.03 | 0.15 |
| Calf creep DMI, kg | NS[4] | | NS | | NS | | 0.24 | 0.19 | 0.76 |
| Calf DM digestibility, % | NS | | NS | | NS | | 0.51 | 0.75 | 0.25 |
| Calf ADF digestibility, % | NS | | NS | | NS | | 0.97 | 0.66 | 0.25 |
| Apparent feed energy, Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ | 162.06 | (7.81) | 0.46 | (0.01) | -0.004 | (0.0002) | 0.99 | - | < 0.01 |

[1]Standard errors (SE) are shown in parentheses, energy intake (x-axis) = Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, models predict 100-d production, equations are centered at 160 Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, (y = a + b(x-160))
[2]DM = dry matter, ADF = acid detergent fiber, DMI = dry matter intake, Apparent feed energy = feed energy corrected for apparent digestibility
[3]Conditional $R^2$ = percent of variance explained by fixed and random factors
[4]NS = neither linear or quadratic term was significant (*P > 0.05)*

**Table 4.** Regression models representing the influence of calculated cow energy intake on milk production and milk composition[1]

| Item[2] | Intercept | | Linear Coefficient | | Conditional[3] $R^2$ | P-value (linear) | P-value (quadratic) |
|---|---|---|---|---|---|---|---|
| Milk yield, kg | 897.42 | (43.86) | 4.35 | (0.99) | 0.79 | < 0.01 | 0.26 |
| Milk fat, % | 2.79 | (0.38) | 0.01 | (0.002) | 0.94 | 0.01 | 0.67 |
| Milk protein, % | 2.57 | (0.17) | 0.003 | (0.001) | 0.95 | < 0.01 | 0.45 |
| Milk lactose, % | NS | | NS | | 0.99 | 0.11 | 0.59 |
| Milk SNF, % | 7.52 | (0.44) | 0.004 | (0.001) | 0.99 | < 0.01 | 0.69 |
| MUN, % | NS | | NS | | 0.99 | 0.06 | 0.21 |
| Milk energy, Mcal[5] | 0.57 | (0.05) | 0.001 | (0.0002) | 0.97 | < 0.01 | 0.65 |
| Total milk energy yield, Mcal[6] | 516.39 | (25.49) | 3.35 | (0.63) | 0.94 | < 0.01 | 0.38 |

[1]Standard errors (SE) are shown in parentheses, energy intake (x-axis) = Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, models predict 100-d production, equations are centered at 160 Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, (y = a + b(x-160))

[2]SNF = solids non-fat, MUN = milk urea nitrogen

[3]Conditional $R^2$ = percent of variance explained by fixed and random factors

[4]NS = neither linear or quadratic term was significant (*$P > 0.05$*)

[5]Milk energy production (Mcal NEm), calculated using (Eq. 4-17, NRC 2000): (0.092* %Fat) + (0.049 * %SNF) – 0.0569

[6]Total milk energy yield (Mcal NEm) = milk yield (kg) * milk energy production (Mcal NEm)

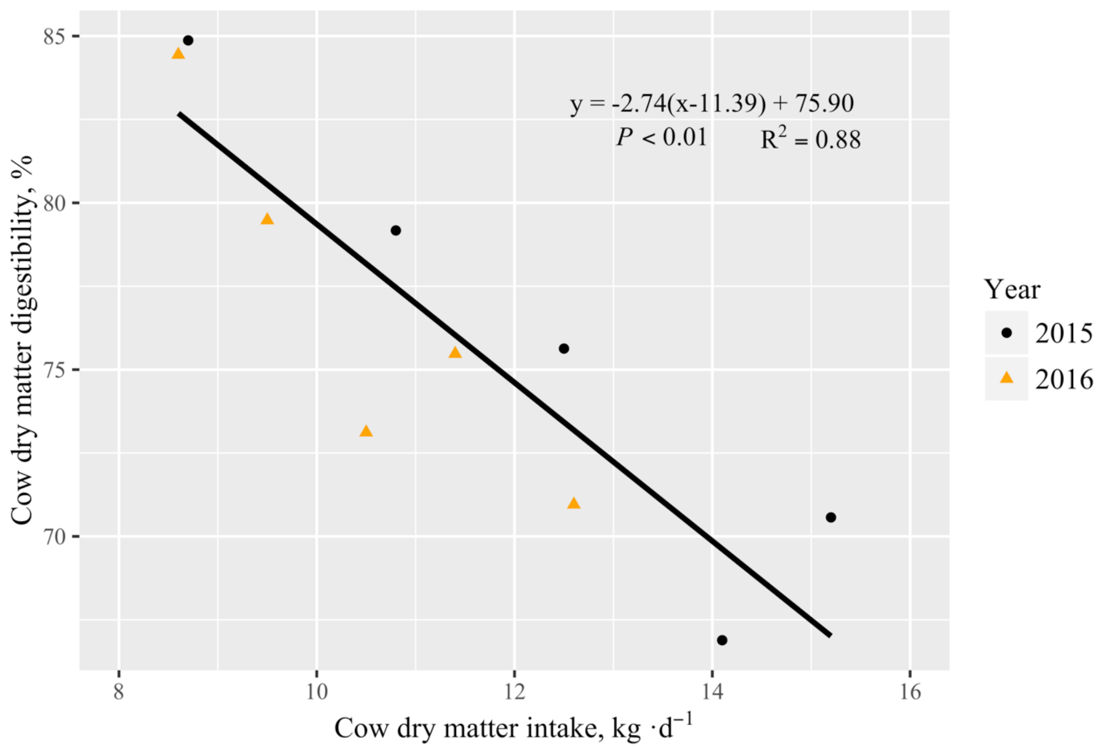


**Figure 1.** Cow dry matter digestibility decreased as daily dry matter intake increased. The model is centered at 11.39 kg DMI $\cdot$ $d^{-1}$.

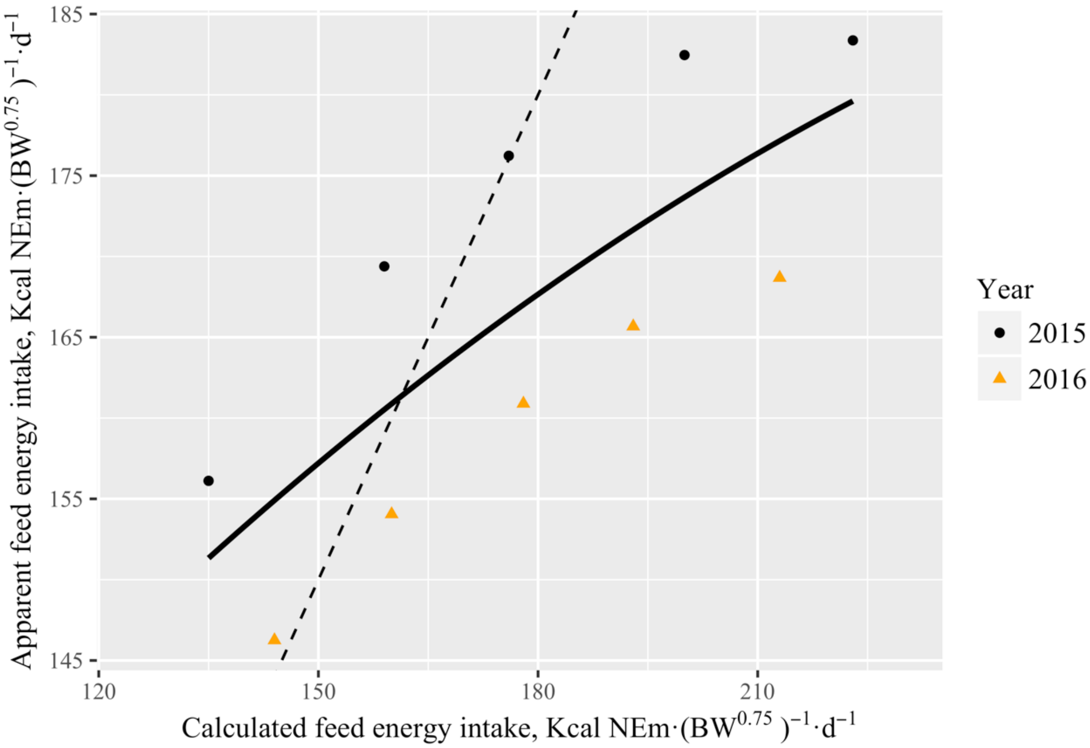


**Figure 2.** The relationship between calculated and apparent feed energy intake of the cow. Regression line is solid and unity line is dashed. Calculated feed energy intake = dry matter intake (DMI) * diet NEm (obtained from calculations from NRC, 2001). Apparent feed energy intake = DMI * observed NEm (calculated using true DM digestibility using acid detergent insoluble ash as an internal marker (Cochran and Galyean, 1994; Kanani et al., 2014)).


**Figure 3.** A comparison of the relationship of 100-d cow milk yield to calculated cow energy intake (Kcal NEm·kg BW$^{-0.75}$·d$^{-1}$) for the current experiment and Jenkins and Ferrell (1992). The Jenkins and Ferrell (1992) data were adjusted to represent mid to late lactation yields, to match the data collection times of the current experiment.

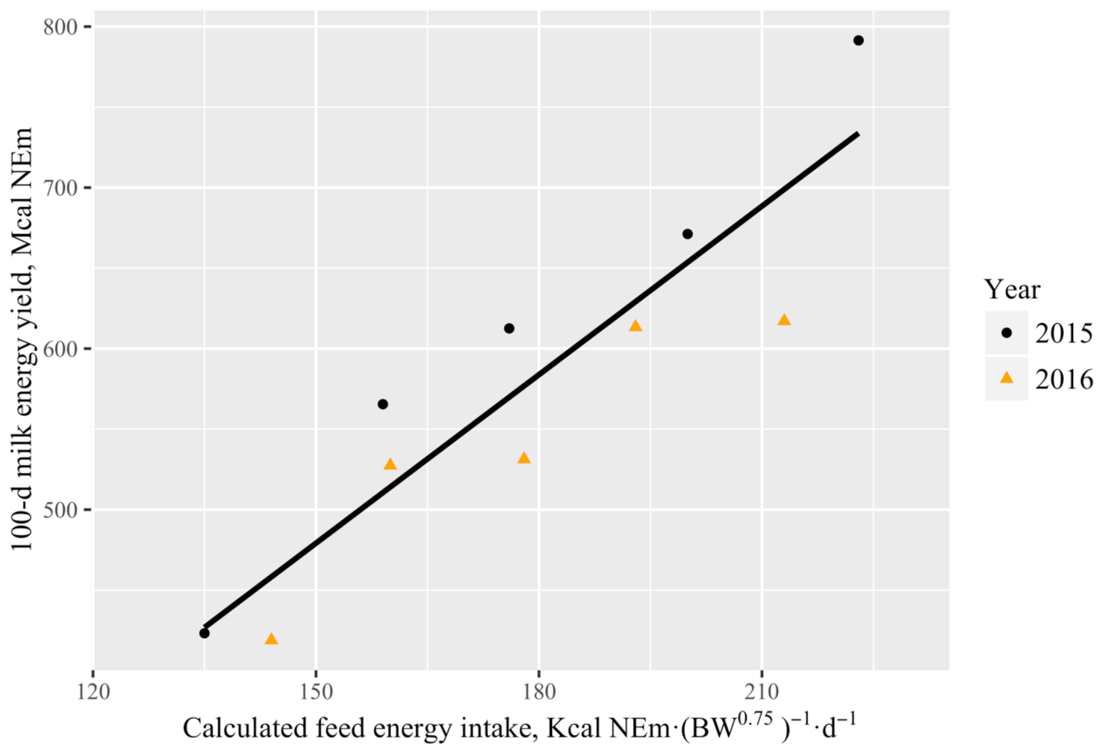


**Figure 4.** Total milk energy yield [milk energy (Mcal NEm) * 100-d milk yield (kg)] in response to calculated feed energy intake.

CHAPTER III

# II. The relationship of maternal dietary energy intake to body composition and efficiency of calf growth

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**ABSTRACT:** The purpose of this research is to define cow and calf production responses and overall pair efficiency to a range of feed energy provided to lactating beef cows. Two experiments were conducted in consecutive years using a total of 80 beef cow/calf pairs (40 per year). Each year, 8 cow/calf pairs were assigned to a pen and one of 5 intake levels (8.7, 10.8, 12.5, 14.1, 15.2 kg DM $\cdot$hd $\cdot d^{-1}$ for 111 d until weaning in yr 1 and 8.6, 9.5, 10.5, 11.4, 12.6 kg DM $\cdot$hd $\cdot d^{-1}$ for 125 d until weaning in yr 2). Each pen of 8 cows and their steer calves were managed together as contemporaries and group fed. While the cows were fed varying levels of intake, calves had ad libitum access to the same diet in a creep area. Calves did not have access to the cows' feed. Cow and calf BW were recorded every 28 d in year 1 and every 14 d in yr 2 and condition scores were assigned to the cows every 28 d. Body composition was determined by ultrasound at experiment initiation and conclusion for cows and experiment conclusion for the calves. Dependent variables were regressed on linear and quadratic terms of energy intake. The mixed model included year as a random effect and energy intake as the fixed effect with pen as experimental unit. Increasing cow energy intake resulted in increased cow BW ($P < 0.01$), increased cow BCS ($P < 0.01$), and increased retained energy (*quadratic* $P = 0.05$). Cow BF increased in a curvilinear manner with increasing cow energy intake (*quadratic* $P < 0.01$), indicating no mobilization of body reserves to support increased levels of production in the cows consuming greater levels of dietary energy. Calf BW gain also increased ($P = 0.03$) with increasing cow energy intake. Calf efficiency ($P =0.03$) and pair efficiency ($P < 0.01$) decreased with increasing cow energy intake. While increasing cow energy did improve calf performance, the gain in performance was biologically insignificant and was not achieved in a manner that promotes profitability of the production system.

**Keywords:** body composition, efficiency, energy intake

## INTRODUCTION

Forage and feed input costs account for a large portion of cow/calf enterprise expenses and profitability (Davis et al., 1994; Miller et al., 2001). Increased genetic potential for milk yield increases calf weaning weights (Marston et al., 1992; Edwards et al., 2017), while concomitantly increasing nutrient requirements for milk production (Ferrell and Jenkins, 1985) and maintenance energy requirements (Montano-Bermudez et al., 1990; Jenkins et al., 1991; Jenkins and Ferrell, 1992). Several reports indicated no benefit to providing feed energy to the cow above the level of maintenance because increased input costs were not offset by income from increased production (Davis et al., 1983a, 1983b; Van Oijen et al., 1992). It has been previously documented that feed energy is not exclusively partitioned to lactation or to maternal tissue (Lalman et al., 2000). Therefore, designing optimal feeding or supplementation programs in cow/calf systems requires an understanding of nutrient partitioning and the efficiency of feed energy utilization by both the cow and the calf.

Thus, the objectives of this 2-yr study were to determine: 1) the amount of feed energy required to maintain cow body composition, 2) maintenance energy requirements of the Angus X Hereford cows used in the experiment, and 3) the efficiency of feed and milk energy utilization to calf weight gain through weaning over a range of cow feed energy intake.

## MATERIALS AND METHODS

*Animals*

The Oklahoma State University Institutional Animal Care and Use Committee approved all animal protocols used in the 2-yr study. Eighty Angus and Angus x Hereford lactating beef cows (6 ± 2.0 yr, 534 ± 60 kg BW) were used (40 per year) along with their suckling steer calves (84 ± 8.7 d, 130 ± 15 kg BW). The steer calves were sired by Angus and Hereford sires. Average calving date was March 15, 2015 in yr 1 and March 8, 2016 in yr 2. Steers were castrated at birth by the application of a rubber ring (banding; Fell et al., 1986; Chase et al., 1995) and received an anabolic implant (Ralgro, Merck Animal Health, Madison, NJ) at approximately 2 mo of age. Cows were assigned to 1 of 5 pen groups (experimental unit) in a completely randomized design. Cows were ranked by days in milk, body weight, and early lactation milk yield and allocated so that each of these variables were similar across all treatments. Differing levels of energy intake were provided to each pen by varying the amount of feed fed to the cows (8.7, 10.8, 12.5, 14.1, 15.2 kg DM ·hd ·$d^{-1}$ in yr 1 and 8.6, 9.5, 10.5, 11.4, 12.6 kg DM ·hd ·$d^{-1}$ in yr 2; Table 1). Animals were rotated among the physical pens every 28 d in an effort to minimize the possibility of any pen effect.

*Facilities*

The experiment was performed at the Range Cow Research Center, South Range Unit located West of Stillwater, Oklahoma. Experimental treatments began on June 10, 2015 in yr 1 and June 1, 2016 in yr 2 leading to 111 d and 125 d of data collection in yr 1 and yr 2 respectively. Acclimation periods to experimental diet and detailed facility descriptions are provided in the companion (Spencer et al., 2018).

*Diets and Feeding Procedures*

The diet was a total mixed ration (**TMR**) for both experimental years (Spencer et al., 2018). In yr 1, 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 at a rate of 2 ounces per hd/d on cow and calf feed daily. The mineral also contained Altosid IGR (Central Life Sciences, Schaumburg, IL) for insect control and chlortetracycline (Aueromycin, Zoetis Services, LLC, Florham Park, NJ) for the prevention of anaplasmosis. Model level 1 (NRC, 2000) was used to estimate DIP and MP balance with a microbial efficiency of 12% (NASEM, 2016). To ensure adequate degradable intake protein (**DIP**), 0.23 kg of cottonseed meal per cow was top dressed on cow feed daily for the 148 kcal NEm· (kg $BW^{0.75})^{-1}$·$d^{-1}$ treatment group. Calculated DIP balance ranged from 191.2 to 217.3 g/d for the 148 and

175 kcal NEm· (kg $BW^{0.75})^{-1}\cdot d^{-1}$ treatment groups respectively and MP balance ranged from 101.7 to 275.7 g/d. In yr 2, calculated DIP balance ranged from 23.9 to 35.1 g/d for the 153 and 175 kcal NEm· (kg $BW^{0.75})^{-1}\cdot d^{-1}$ treatment groups respectively and calculated MP balance ranged from 14.1 to 452.8 g/d for the 148 and 163 kcal NEm· (kg $BW^{0.75})^{-1}\cdot d^{-1}$ treatment groups.

Feeding occurred at approximately 0730 h each day. Prior to feed delivery, calves were gathered and penned in the shaded areas and remained penned until the cows consumed their ration. This ensured that calves did not have access to cow feed. Calves had unrestricted access to the creep area through a creep gate, which the cows could not access. Calves received the same TMR diet as the cows and daily amounts provided were increased as needed to ensure *ad libitum* intake. Orts from the creep areas were removed weekly during yr 1 and daily in yr 2 and sampled weekly both years. No orts from the cow feed bunks were recorded during either year.

*Body Measurements*

Prior to feeding, cows and calves were weighed on d 0, d 7 and then every 28 d for the remainder of yr 1. In yr 2 animals were weighed every 7 d for the first 4 weeks, then every 14 d for the remainder of the experiment. Cows were assigned a BCS (1-9 scale) every 28 d by an experienced evaluator. Ultrasonography (Aloka 500, Hiachi Aloka Medical, Ltd., Wallingford, CT) was performed by a certified technician (Ultrasound Technologies, Fletcher, OK) on d 0 and 105 in yr 1 and d 0 and d 121 in yr 2. Ultrasonography was used to measure back fat (**BF**, $12^{th}$ rib), rib eye area (**REA**), rump fat (**RF**), and intramuscular fat (**IMF**; marbling). Images were interpreted using

Beef Image Analysis Pro Plus software (Designer Genes Technologies Inc., Harrison, AR).

*Breeding and Animal Health*

All cows were synchronized for artificial insemination (**AI**) using a co-synch protocol (Stein et al., 2015). Palpation pregnancy checks were performed on December 10, 2015 in yr 1 and on October 26, 2016 in yr 2. Details of synchronization and heat detection as well as vaccinations administered throughout the experiment are reported in Spencer et al. (2018).

*Statistical Analyses*

Pen was the experimental unit. Regression of the dependent variables on energy intake included year as a random effect and energy intake as the fixed effect (R Core Team, 2016). Year was considered a random effect because it is not repeatable due to differences in climate factors and availability of diet ingredients. Since the 2 experiments differed slightly in length, all dependent variables were adjusted to represent a 100-d period. Linear and quadratic terms were evaluated at $a = 0.05$ and trends were determined significant at $0.05 < P < 0.10$.

A linear regression of live BW and BCS over day of experiment was generated for each animal and utilized to predict final BW and BCS values to be used in the calculation of retained energy (**RE**; Ferrell and Jenkins, 1984). Retained energy was calculated using equations from NRC (2000):

$$RE = TBE_f - TBE_i$$

where $TBE_f$ = total body energy final (d 111 in yr 1, d125 in yr 2), $TBE_i$ = total body energy initial (d 0). Total body energy (final and initial) = 9.4 * total fat (kg) + 5.7 * total protein (kg), where total fat = proportion of empty body fat * EBW, proportion of empty body fat = 3.768 * BCS, and total protein = proportion of empty body protein * EBW, proportion of empty body protein = 20.09 – 0.668 * BCS.

In yr 1, data from one cow and calf were omitted from the 174 Kcal treatment group due to bovine traumatic reticuloperitonitis of the dam. In yr 2, data from one cow and calf were omitted from the 153 Kcal treatment group due to death of the calf.

## RESULTS AND DISCUSSION

*Cow Performance*

Cow BW ($P < 0.01$) change over the duration of the experiment increased linearly with increasing cow energy intake (Figure 1). A similar relationship was also observed for changes in BCS ($P < 0.01$) over the duration of the experiment (Table 2). The relationship of BW to BCS is an important component in the determination of RE. The current experiment determined a positive linear relationship between daily BCS change and daily BW change, with a 1 unit increase in BCS resulting in 33.9 kg of BW gain (Figure 2). This relationship is similar to that reported by the NASEM (2016) and falls within the range demonstrated in current literature. Lalman et al. (1997) reported a 33.0 kg change in BW with 1 unit of BCS change in primiparous Angus heifers, Houghton et al. (1990) denoted a 33.3 kg change in BW in mature Charolais X Angus cows, and Buskirk et al. (1992) showed a 37.8 kg change in BW in mature Angus cows.

At the start of the experiment, initial body composition did not differ ($P > 0.18$). Changes in cow RF and REA were not sensitive to cow energy intake ($P > 0.05$), while percent IMF ($P = 0.02$) and BF (quadratic $P < 0.01$) increased with increasing energy intake (Table 2).

While mobilization of lipids in response to underfeeding is well established, mobilization of body protein is less documented. Chilliard et al. (1998) suggests that changes in body protein do not follow changes in body fat and that protein reserves are used to support structural and functional roles rather than production parameters such as milk yield in times of underfeeding. This would support the current experiment in which no differences in REA were attributed to the level of energy supplied to the cow.

In an experiment utilizing 2-yr old beef cows fed a high energy diet at maintenance level or at 10 percent above maintenance, Bowden (1981) found that those fed only the maintenance level of energy lost backfat and those fed over the maintenance level maintained backfat throughout lactation. Furthermore, Miller et al. (1999) determined that increased milk production led to decreases in back fat during the lactation period for cows fed to maintain body condition. In the current experiment, increasing energy intake resulted in a simultaneous increase in milk yield, milk energy production, BF, and IMF (Spencer et al., 2018).

As expected, RE increased with increasing energy intake (quadratic $P = 0.05$; Figure 3; Table 2). Trubenbach et al. (2014) determined RE in cows fed a high energy (2.45 Mcal ME/kg) or low energy (1.94 Mcal ME/kg) diet, each at two levels of intake (80% or 120% of maintenance). Energy level (high or low) did not affect RE, but level of intake did significantly affect RE. Cows fed the low energy diet at 120% of maintenance retained significantly less energy than those on the high energy diet fed at the same level. Similarly, the cows on the low energy diet fed at 80% of maintenance retained significantly less energy than those on the high energy diet, also fed at 80% of maintenance.

*Cow Maintenance Requirements*

Currently, the beef cattle NRC (NASEM, 2016) estimates the daily NEm requirement of beef cattle to be 0.077 Mcal/ $SBW^{0.75}$, where SBW = shrunk BW in kg. A 20% increase in daily NEm requirement is recommended for cows in lactation, thus the NRC requirement for maintenance plus lactation is 0.0924 Mcal/ $SBW^{0.75}$. Maintenance requirements for the current experiment were estimated separately for each year. The calculated daily NEm requirement for maintenance plus lactation for cows in yr 1 and 2 were 0.0874 Mcal/ $SBW^{0.75}$ and 0.0873 Mcal/ $SBW^{0.75}$ respectively.

A series of experiments conducted with the same cow herd at the same location as the current experiment estimated the NEm requirement over 3 consecutive years for non-lactating cows, ranging 6-8 mo into gestation (Cooper-Prado et al., 2014). The authors determined average daily NEm requirements to be 0.0892 Mcal/ $SBW^{0.75}$, 0.093 Mcal/ $SBW^{0.75}$, and 0.094 Mcal/ $SBW^{0.75}$ for yr 1, 2, and 3 respectively. These estimates did not account for increases in fetal weight or maintenance required for gestation, thus estimates of true maintenance would likely be lower than those reported.

*Steer Calf Performance*

Calf BW gain increased linearly with increasing cow energy intake ($P = 0.03$; Table 3). In terms of body composition, calf IMF and BF were not sensitive to cow energy intake ($P > 0.05$), but calf RF increased linearly with increasing energy intake ($P = 0.02$; Table 3). While BW gain did significantly increase, the increase seems biologically insignificant when considering the range of energy intake (27 Kcal NEm·kg $BW^{-0.75}·d^{-1}$). A 27 Kcal NEm·kg $BW^{-0.75}·d^{-1}$ increase in cow energy intake results in 12.4 kg of additional calf BW gain and only a 0.11 cm increase in RF over a 100-d period.

We anticipated that calves of cows on the lower energy treatments would compensate for lower milk energy availability by consuming more energy from the creep feed. However, creep energy consumed relative to cow energy intake was not significant (*P = 0.32*; Table 3). This is consistent with previous literature that indicated no effect of non- milk feed sources on intake of milk by the calf (Cremin et al., 1991; Soto-Navarro et al., 2004). However, other literature supports the occurrence of a substitution effect in which calves will begin to offset lower milk availability with increased feed or forage intake (Ansotegui et al., 1991; Buskirk et al., 1992; Tedeschi and Fox, 2009). Lusby et al. (1976) found a depression in non-milk feed intake at increasing levels of milk production, while Willham (1972) noted that once creep feed or forage becomes available to a calf, milk availability is no longer a concern.

Calf efficiency, defined as calf weight gain divided by total energy consumed by the calf declined (*P = 0.03*; Figure 4) with increasing cow energy intake. This suggests that increasing milk energy was not efficiently utilized or that increasing milk energy availability had a negative impact on feed energy utilization. However, neither calf DM nor ADF digestibility were influenced by level of cow energy intake (Spencer et al., 2018). Calegare et al. (2007) determined the calf efficiency of various breeds of calves fed an ad libitum pelleted diet during early to late lactation. When corrected to represent a 100-d calf efficiency value, similar to that calculated in the current experiment, the authors found an efficiency of 0.45 kg of calf weight gain per unit of calf energy intake for Angus X Nellore X Canchim bull and heifer calves. The average efficiency value for the current experiment was 0.12 kg of calf weight gain per unit of calf energy intake. The cows in Calegare et al. (2007) were fed at maintenance, thus no effect of cow energy intake on calf efficiency can be determined and compared to the current experiment.

Similar to calf efficiency, overall pair efficiency (calf weight gain divided by creep and cow energy intake) declined linearly with increasing cow energy intake ($P < 0.01$; Figure 5). Average pair efficiency across all treatments for the current study were 0.061 kg of calf weight gain per unit of energy intake. This is slightly greater than the 0.044 kg of calf weight gain per unit of energy reported for Angus X Herford cows by Jenkins et al. (1991). Davis et al. (1983b) noted that cow feed intake represents roughly 90% of the inputs for a cow/calf pair. It was further determined that this cow intake was negatively correlated with overall production efficiency.

Consequently, from a biological efficiency standpoint, it would appear that optimal energy intake is the lowest value of energy that can be provided which supports milk production, but does not inhibit the future reproductive performance of the cow.

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**Table 1.** Amount of energy supplied to each pen and the subsequent amount provided.

| Year. | Calculated Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ | Apparent[1] Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ | Ration, kg (DM) $\cdot d^{-1}$ |
|---|---|---|---|
| 2015 | 135 | 148 | 8.7 |
| | 159 | 162 | 10.8 |
| | 176 | 168 | 12.5 |
| | 200 | 174 | 14.1 |
| | 223 | 175 | 15.2 |
| 2016 | 144 | 153 | 8.6 |
| | 160 | 162 | 9.5 |
| | 178 | 169 | 10.5 |
| | 193 | 173 | 11.4 |
| | 213 | 175 | 12.6 |

[1]Apparent Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$ was calculated using the regression model depicting the relationship between calculated and apparent feed energy offered (Spencer et al., 2018)

**Table 2.** Regression equations representing the relationship of daily energy intake to cow performance responses [1]

| Item [2] | Intercept | | Linear Coefficient | | Quadratic Coefficient | | Conditional[3] $R^2$ | P-value (linear) | P-value (quadratic) |
|---|---|---|---|---|---|---|---|---|---|
| BW Δ, kg | 9.79 | (5.63) | 1.68 | (0.22) | - | | 0.90 | < 0.01 | 0.08 |
| BCS Δ | -0.04 | (0.15) | 0.05 | (0.01) | - | | 0.91 | < 0.01 | 0.18 |
| IMF Δ, % | 0.38 | (0.09) | 0.02 | (0.01) | - | | 0.73 | 0.02 | 0.34 |
| BF Δ, cm, quadratic | -0.01 | (0.03) | 0.002 | (0.004) | 0.0005 | (0.0001) | 0.95 | - | < 0.01 |
| RF Δ, cm | NS[4] | | NS | | NS | | 0.86 | 0.14 | 0.06 |
| REA Δ, sq. cm | NS | | NS | | NS | | 0.80 | 0.70 | 0.76 |
| RE, Mcal[5], quadratic | 7.84 | (19.69) | 9.78 | (2.66) | 0.44 | (0.16) | 0.92 | - | 0.05 |

[1]Standard errors (SE) are shown in parentheses, energy intake (x-axis) = Kcal NEm·kg $BW^{-0.75}$·$d^{-1}$, models predict 100-d production, equations are centered at 160 Kcal NEm·kg $BW^{-0.75}$·$d^{-1}$, (y = a + b(x-160))

[2]BW= body weight, BCS= body condition score (1-9) scale, Δ= change over time, IMF= intramuscular fat, BF= back fat (between the 12th and 13th ribs), RF= rump fat, REA= ribeye area, RE = retained energy

[3]Conditional $R^2$ = percent of variance explained by fixed and random factors

[4]NS = term was not significant

[5]Retained energy, Mcal calculated using NRC 2000

**Table 3.** Regression equations representing the relationship of apparent cow energy intake to calf performance responses [1]

| Item [2] | Intercept | | Linear Coefficient | | Conditional[3] $R^2$ | P-value (linear) | P-value (quadratic) |
|---|---|---|---|---|---|---|---|
| BW gain, kg | 137.36 | (3.57) | 0.46 | (0.16) | 0.91 | 0.03 | 0.60 |
| IMF, %[4] | NS | | NS | | 0.48 | 0.76 | 0.76 |
| BF, cm[4] | NS[5] | | NS | | 0.28 | 0.15 | 0.73 |
| RF, cm[4] | 0.56 | (0.02) | 0.004 | (0.001) | 0.66 | 0.02 | 0.44 |
| Energy from Creep, Mcal[6] | NS | | NS | | 0.38 | 0.32 | 0.39 |
| Total Energy, Mcal[7] | 1122.08 | (34.55) | 8.47 | (2.96) | 0.86 | 0.04 | 0.75 |
| Calf Efficiency[8] | 0.12 | (0.01) | -0.0005 | (0.0002) | 0.90 | 0.03 | 0.70 |
| Pair Efficiency[9] | 0.06 | (0.004) | -0.0006 | ($4.72\ e^{-05}$) | 0.97 | < 0.01 | 0.08 |

[1]Standard errors (SE) are shown in parentheses, energy intake (x-axis) = Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, models predict 100-d production, equations are centered at 160 Kcal NEm·kg $BW^{-0.75}\cdot d^{-1}$, ($y = a + b(x-160)$)

[2]BW= body weight, IMF= intramuscular fat, BF= back fat (between the 12th and 13th ribs), RF= rump fat

[3]Conditional $R^2$ = percent of variance explained by fixed and random factors

[4]Calf body composition measurements were taken via ultrasound at the conclusion of the experiment in each year (September 23, 2015 in yr 1 and September 29, 2016 in yr 2)

[5]NS = neither quadratic or linear term was significant

[6]Energy consumed from creep (Mcal NEm) summed over the duration of the experiment

[7]Energy consumed from creep and milk (Mcal NEm) summed over the duration of the experiment

[8]Calf efficiency calculated as calf gain divided by total energy consumed by the calf

[9]Pair efficiency calculated as calf gain divided by creep and cow energy intake

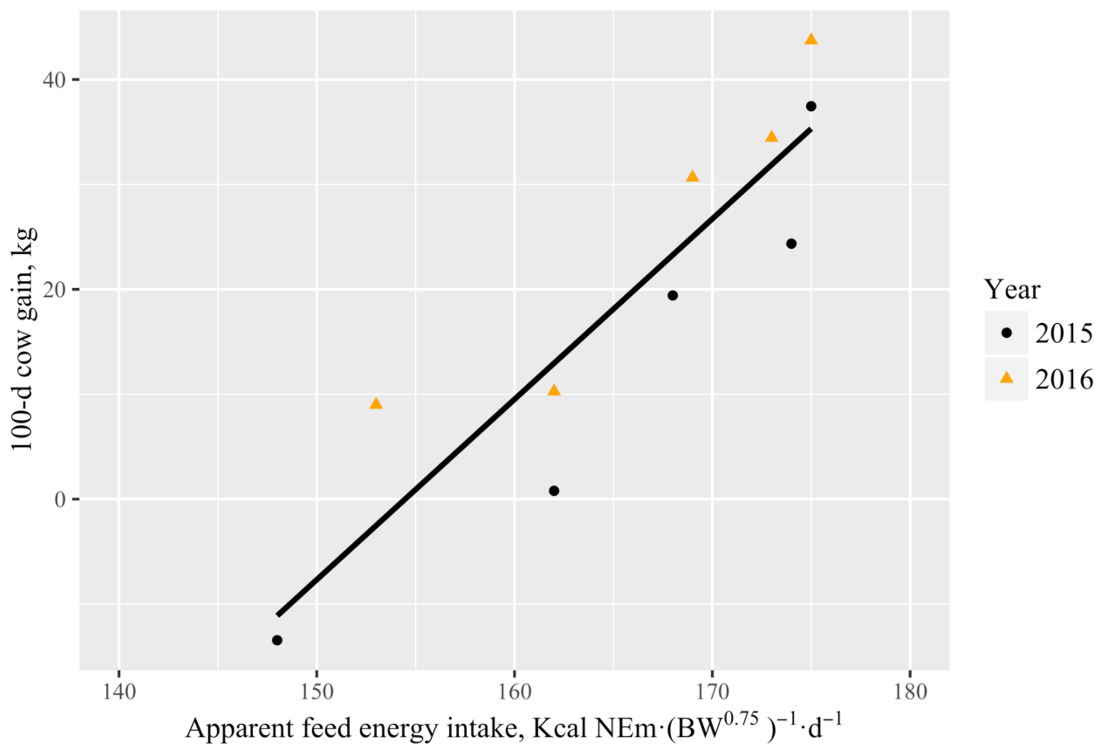



**Figure 1.** Change in cow BW in response to increasing energy intake.

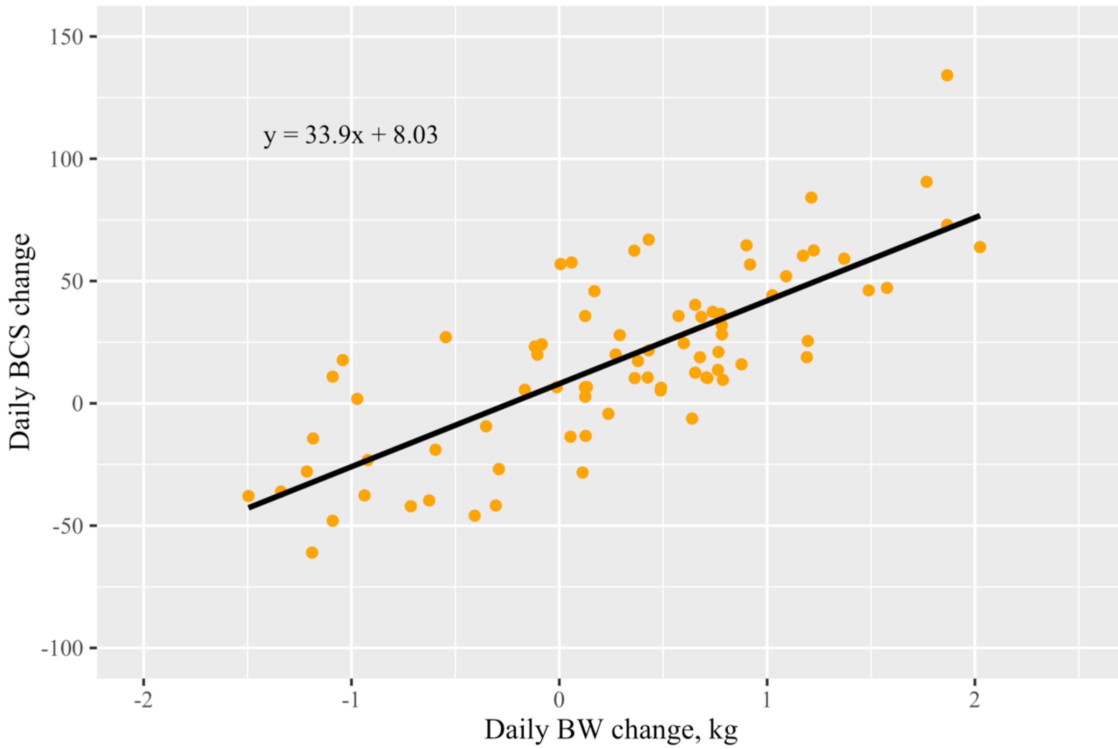



**Figure 2.** Relationship of daily BW change (kg) to daily BCS change.

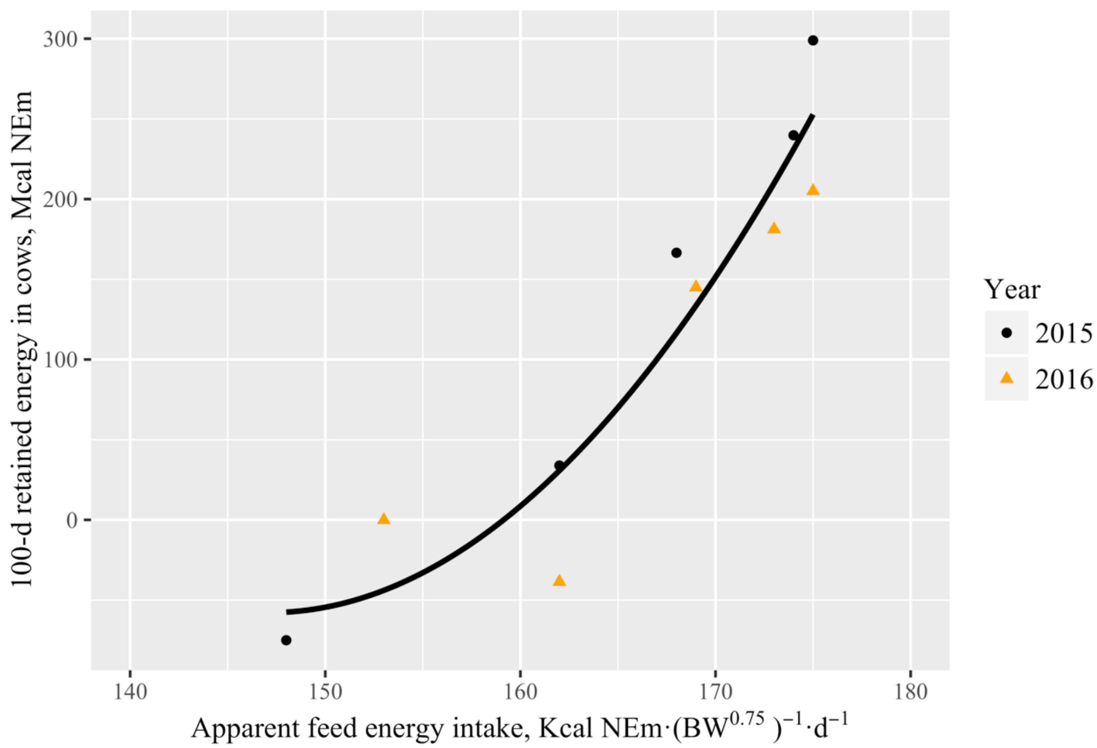



**Figure 3.** 100-d retained energy in cows fed increasing levels of dietary energy.

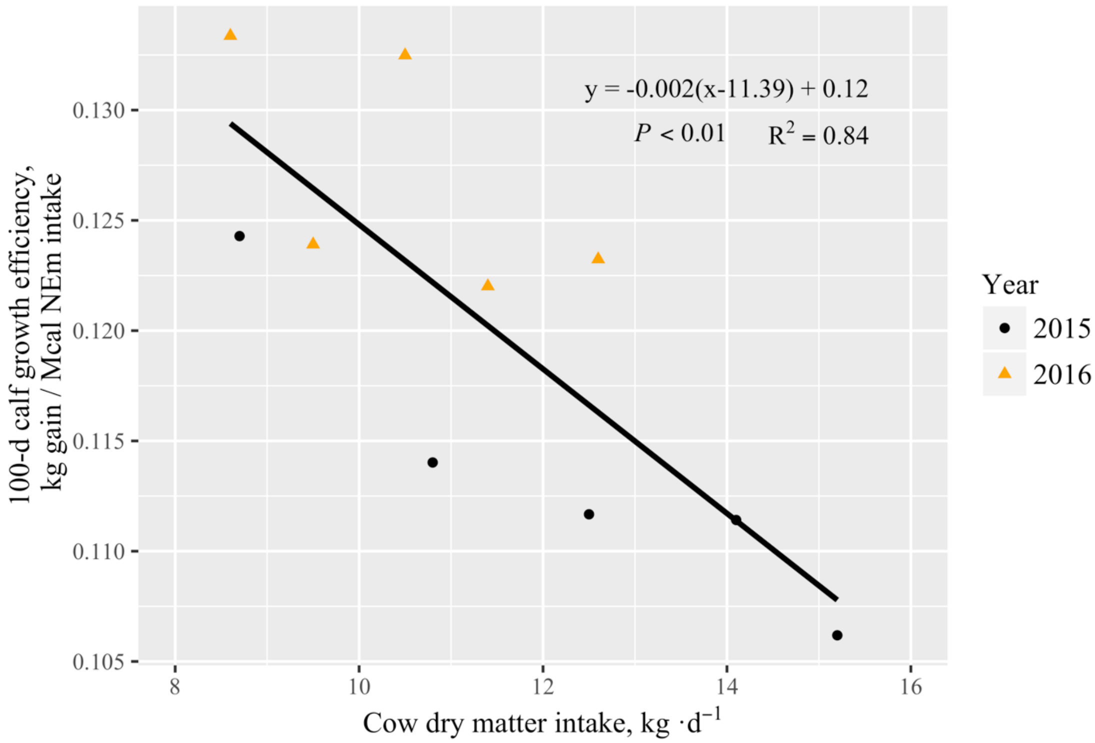



**Figure 4.** The effect of increasing cow dry matter intake on 100-d calf efficiency. The model is centered at 11.39 kg DMI · $d^{-1}$.

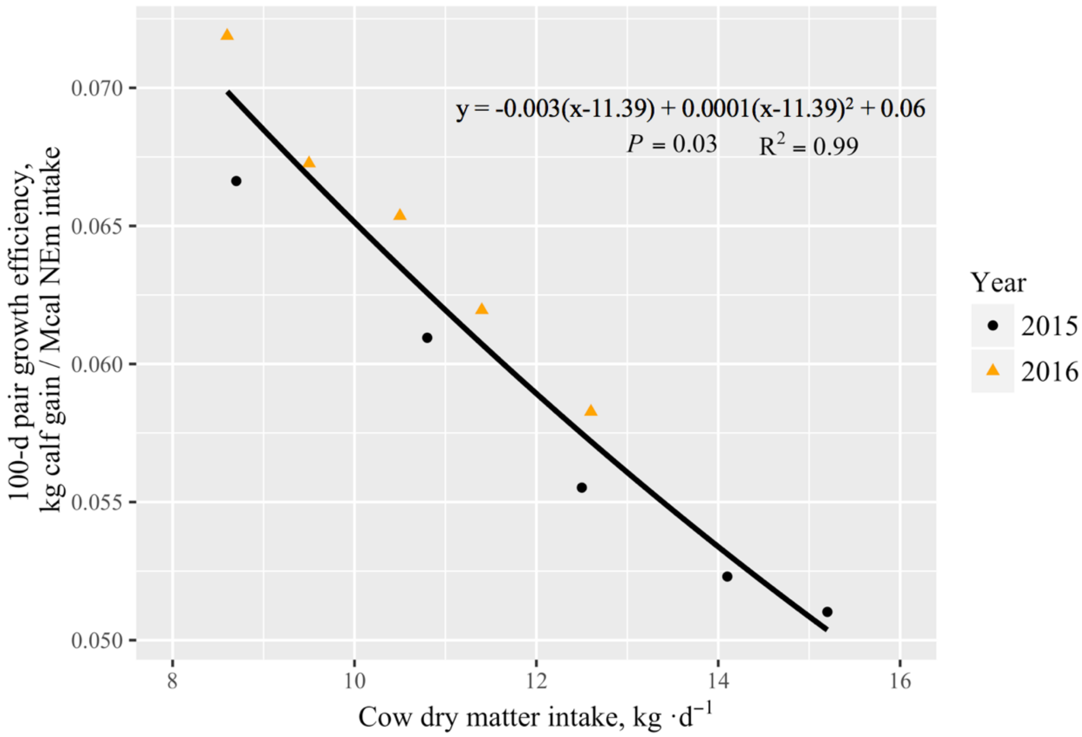



**Figure 5.** 100-d pair efficiency in response to increased cow dry matter intake. The model is centered at 11.39 kg DMI · $d^{-1}$.

APPENDICES

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

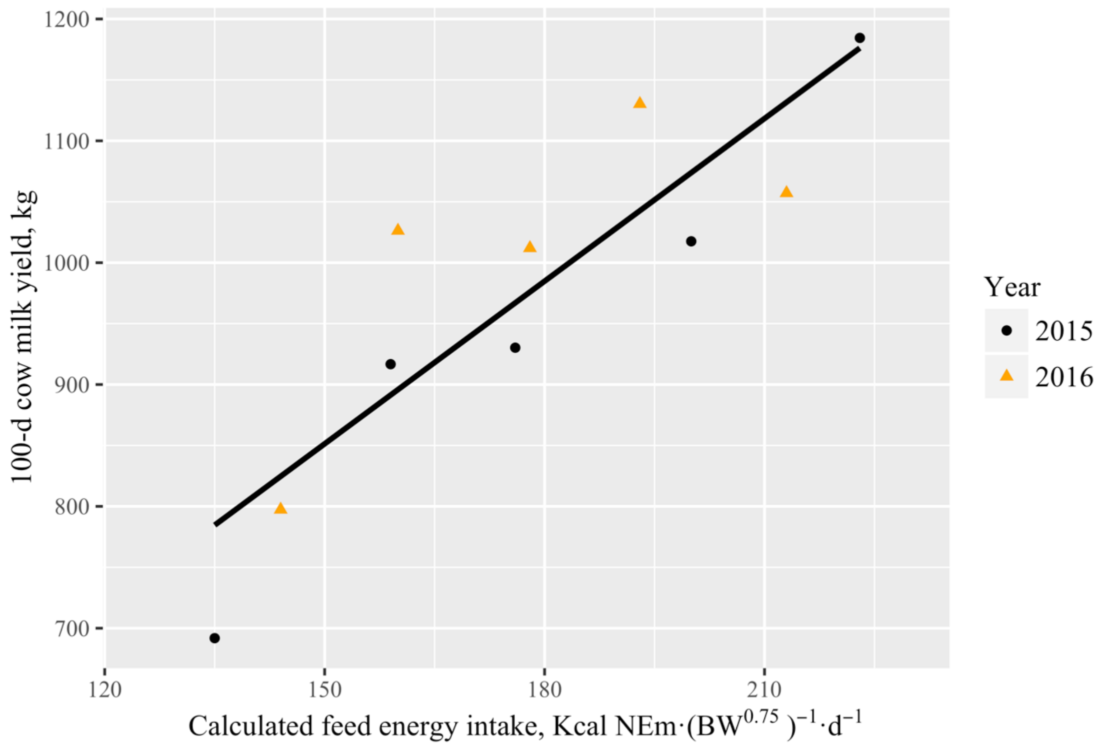
| | Year 1: Pen Group[2] | | | | |
|---|---|---|---|---|---|
| | 135 | 159 | 176 | 200 | 223 |
| Cow BW | | | | | |
| June 10, 2015 | 527.6 | 563.3 | 580.9 | 584.0 | 561.5 |
| June 18, 2015 | 479.8 | 512.8 | 545.9 | 544.3 | 518.1 |
| September 29, 2015 | 484.0 | 535.0 | 573.9 | 580.6 | 572.1 |
| Cow BCS | | | | | |
| June 11, 2015 | 5.20 | 5.50 | 5.20 | 5.40 | 5.23 |
| September 29, 2015 | 3.96 | 5.35 | 5.75 | 5.88 | 6.10 |
| Steer BW | | | | | |
| June 10, 2015 | 129.9 | 137.4 | 138.6 | 133.7 | 136.7 |
| September 29, 2015 | 274.0 | 296.5 | 299.9 | 296.1 | 307.2 |
| | Year 2: Pen Group[2] | | | | |
| | 144 | 160 | 178 | 193 | 213 |
| Cow BW | | | | | |
| June 1, 2016 | 507.1 | 508.9 | 502.3 | 501.0 | 502.0 |
| June 13, 2016 | 494.0 | 503.9 | 499.6 | 509.8 | 513.6 |
| October 3, 2016 | 537.7 | 517.3 | 561.9 | 553.2 | 568.2 |
| Cow BCS | | | | | |
| June 1, 2016 | 4.06 | 4.25 | 3.75 | 4.19 | 4.00 |
| October 10, 2016 | 4.79 | 4.19 | 4.38 | 5.19 | 4.94 |
| Steer BW | | | | | |
| June 1, 2016 | 128.2 | 125.6 | 116.4 | 128.9 | 122.0 |
| October 3, 2016 | 300.4 | 301.1 | 291.9 | 309.6 | 305.9 |

[1]Key dates represent trial initiation (June 10, 2015; June 1, 2016), shrunk BW (June 18, 2015; June 13, 2016), and weaning (September 29, 2015; October 3, 2016)
[2]Pen group indicating calculated daily energy intake for each experiment, expressed in Kcal NEm$\cdot$(kg BW$^{0.75}$)$^{-1}\cdot$d$^{-1}$

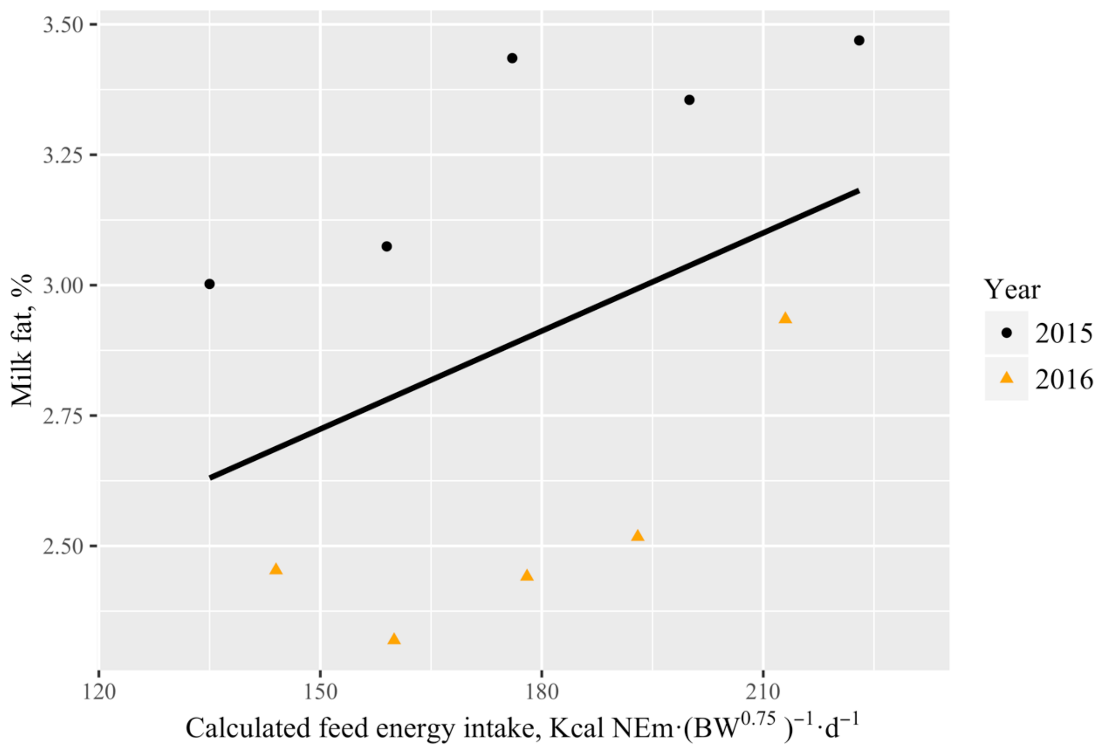
**Appendix 2.** Mean body composition values for cows and steers as determined by ultrasonography

| | Pen Group[1] | REA[2], sq. cm | IMF[3], % | Back Fat[4], cm | Rump Fat, cm |
|---|---|---|---|---|---|
| **Cows** | | | | | |
| June 11, 2015[5] | 135 | 59.1 | 3.37 | 0.23 | 0.23 |
| | 159 | 63.8 | 3.69 | 0.27 | 0.26 |
| | 176 | 62.4 | 3.53 | 0.25 | 0.20 |
| | 200 | 65.9 | 3.63 | 0.31 | 0.37 |
| | 213 | 61.6 | 3.52 | 0.27 | 0.28 |
| September 23, 2015[5] | 135 | 62.7 | 3.71 | 0.23 | 0.19 |
| | 159 | 63.6 | 4.08 | 0.30 | 0.32 |
| | 176 | 62.8 | 4.29 | 0.37 | 0.40 |
| | 200 | 67.5 | 4.44 | 0.52 | 0.60 |
| | 213 | 66.2 | 4.37 | 0.53 | 0.64 |
| May 31, 2016[6] | 144 | 58.1 | 3.47 | 0.19 | 0.20 |
| | 160 | 53.7 | 3.06 | 0.24 | 0.21 |
| | 178 | 53.0 | 3.39 | 0.23 | 0.23 |
| | 193 | 57.2 | 2.90 | 0.36 | 0.22 |
| | 213 | 56.5 | 3.31 | 0.22 | 0.18 |
| September 29, 2016[6] | 144 | 64.7 | 3.59 | 0.20 | 0.21 |
| | 160 | 67.6 | 3.60 | 0.19 | 0.19 |
| | 178 | 66.7 | 3.76 | 0.19 | 0.22 |
| | 193 | 68.7 | 3.95 | 0.33 | 0.35 |
| | 213 | 64.7 | 4.20 | 0.33 | 0.30 |
| **Steers** | | | | | |
| September 23, 2015[5] | 135 | 62.7 | 3.30 | 0.48 | 0.47 |
| | 159 | 63.6 | 3.39 | 0.53 | 0.59 |
| | 176 | 62.9 | 3.30 | 0.50 | 0.54 |
| | 200 | 67.5 | 3.48 | 0.53 | 0.61 |
| | 213 | 66.2 | 3.73 | 0.57 | 0.58 |
| September 29, 2016[6] | 144 | 64.7 | 3.36 | 0.49 | 0.55 |
| | 160 | 67.6 | 3.57 | 0.55 | 0.58 |
| | 178 | 66.7 | 3.30 | 0.50 | 0.61 |
| | 193 | 68.7 | 3.34 | 0.62 | 0.67 |
| | 213 | 64.7 | 3.14 | 0.51 | 0.59 |

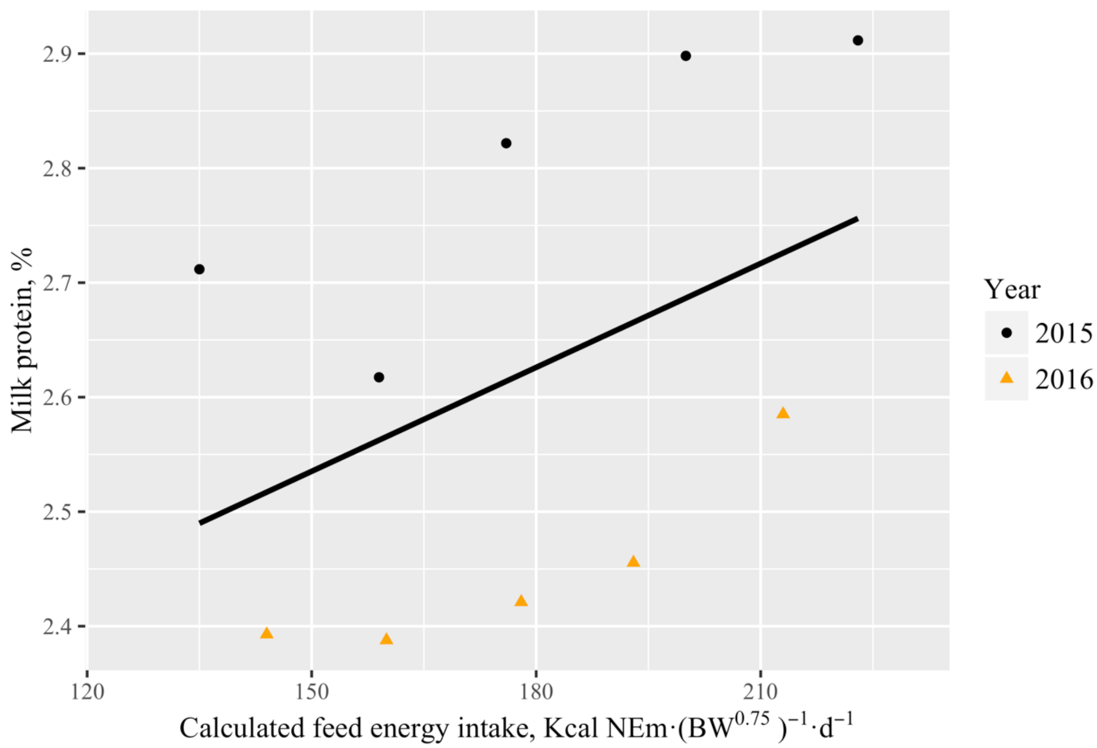
[1]Pen group indicating calculated daily energy intake expressed in Kcal NEm·(kg $BW^{0.75})^{-1}\cdot d^{-1}$.
[2]REA = Rib eye area.
[3]IMF = Intramuscular fat (marbling).
[4]Back fat measured between the $12^{th}$ and $13^{th}$ ribs.
[5]Ultrasound measurements dates in year 1
[6]Ultrasound measurements dates in year 2



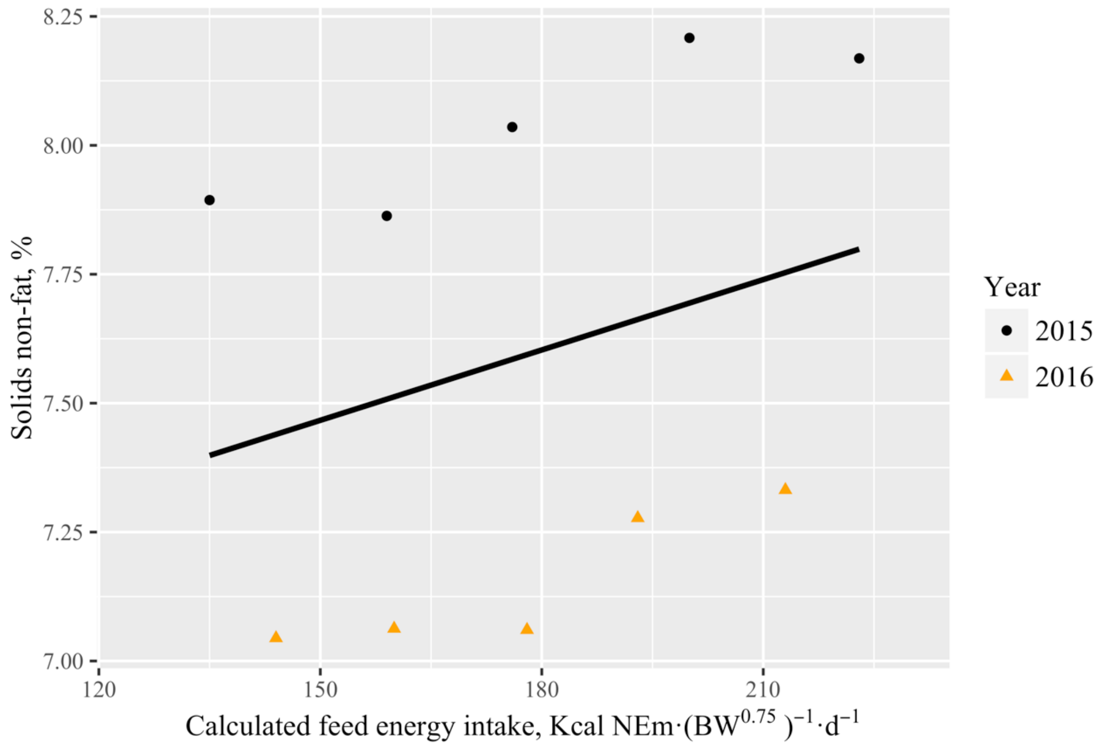

**Appendix 3.** Total milk yield (kg) increased with increasing calculated feed energy intake (Kcal).



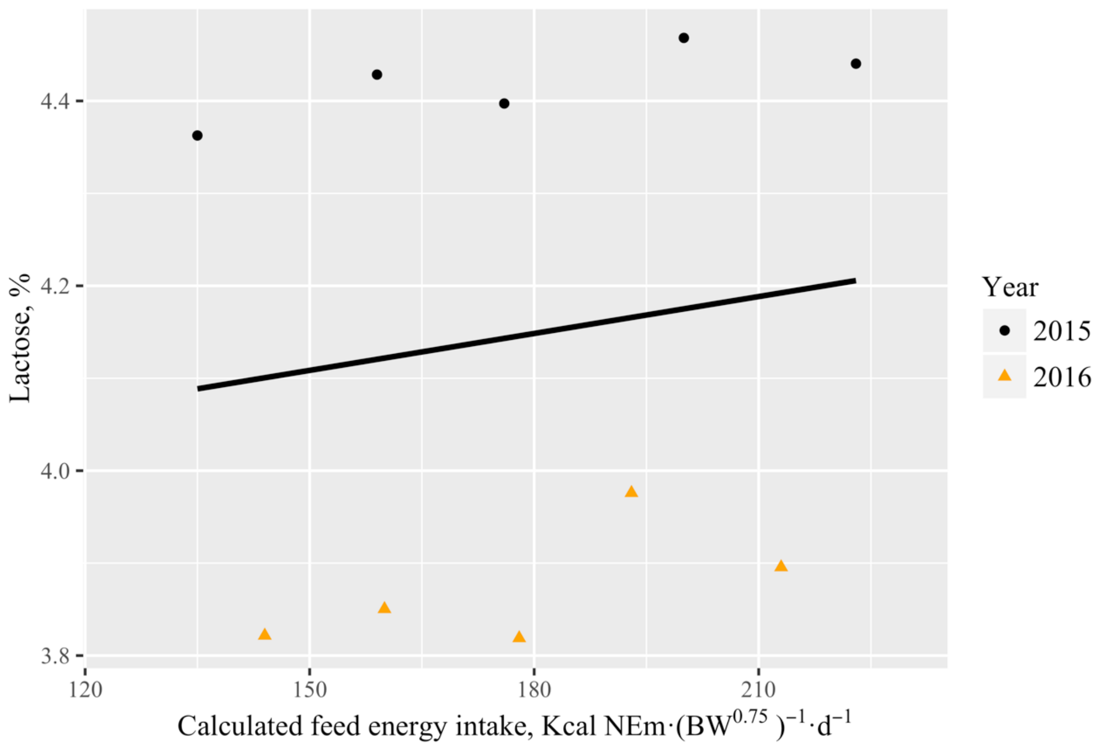

**Appendix 4.** The response of milk fat content to calculated feed energy intake.



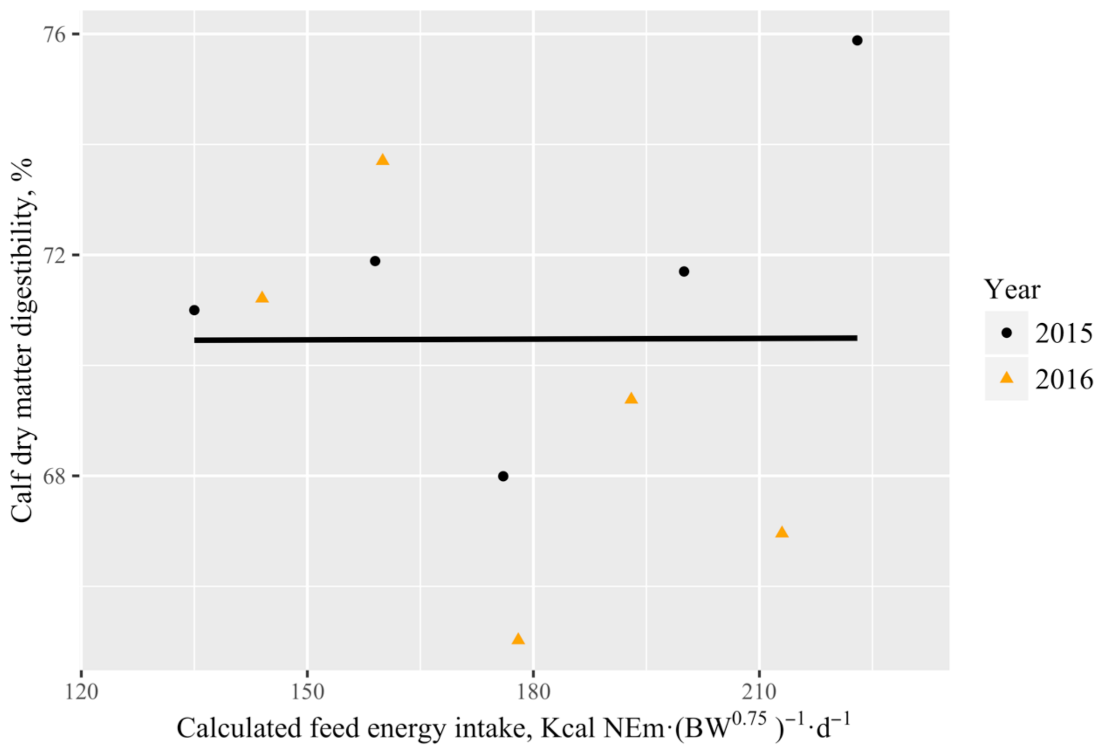

**Appendix 5.** Milk protein content in response to calculated feed energy intake.



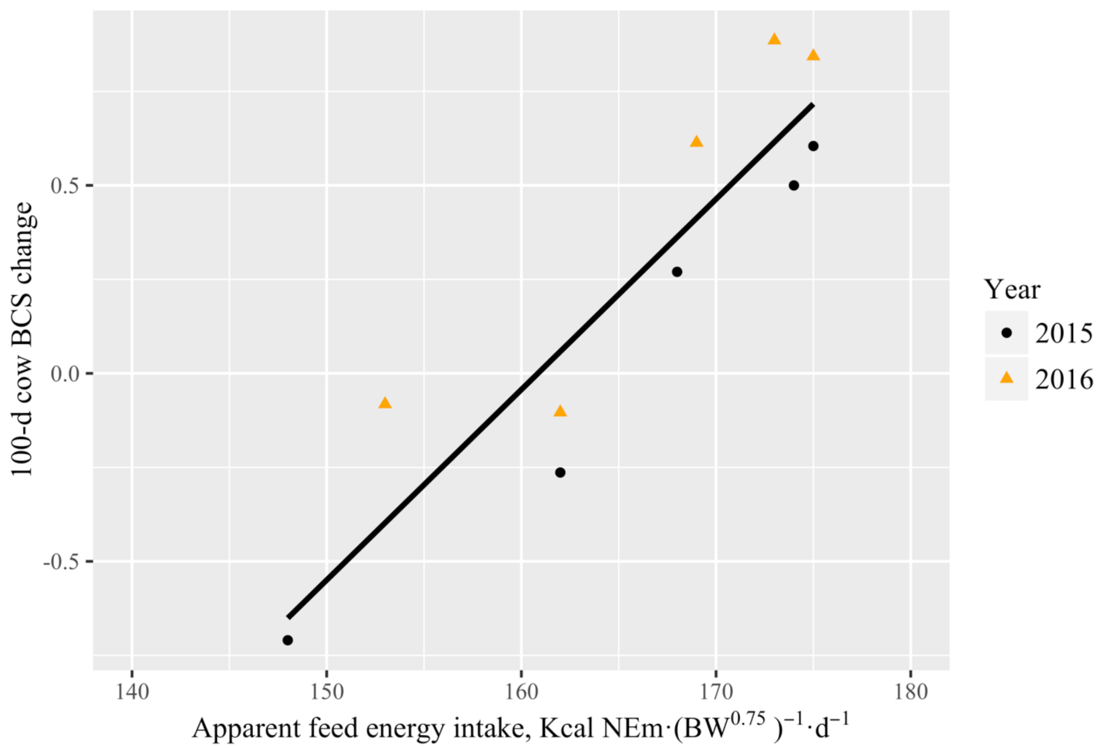

**Appendix 6.** Solids not-fat percentage relationship with calculated feed energy intake.



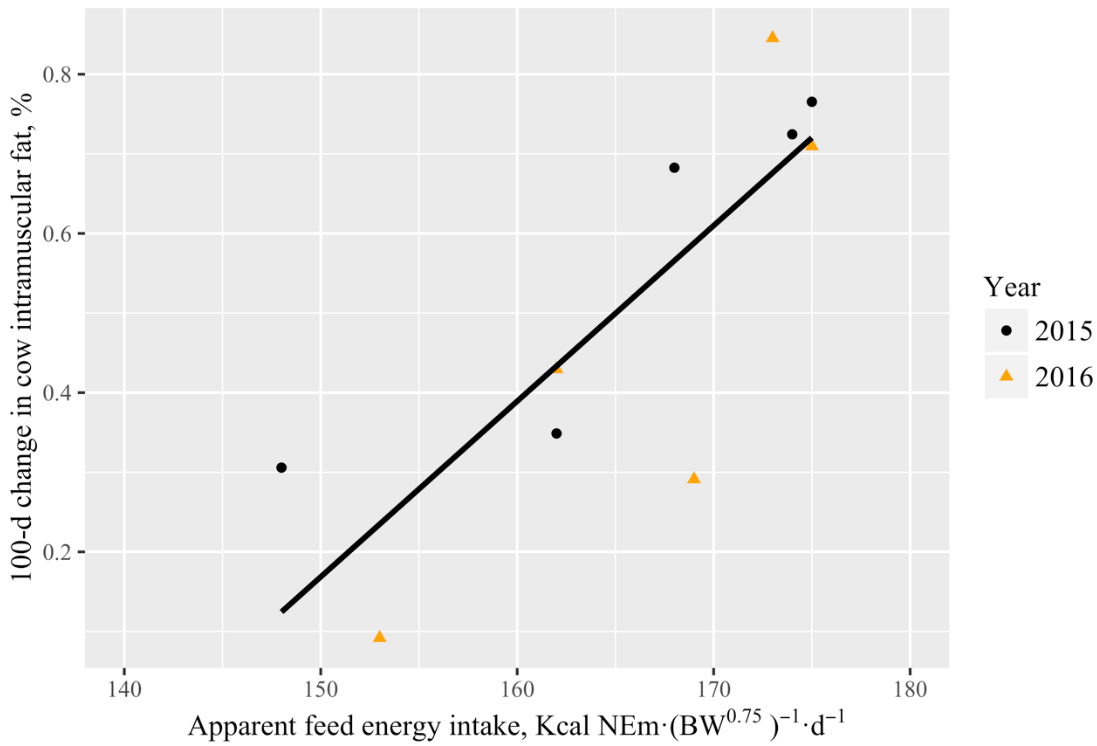

**Appendix 7.** Lactose percentage was not significantly influenced by calculated energy intake ($P$ = 0.11).



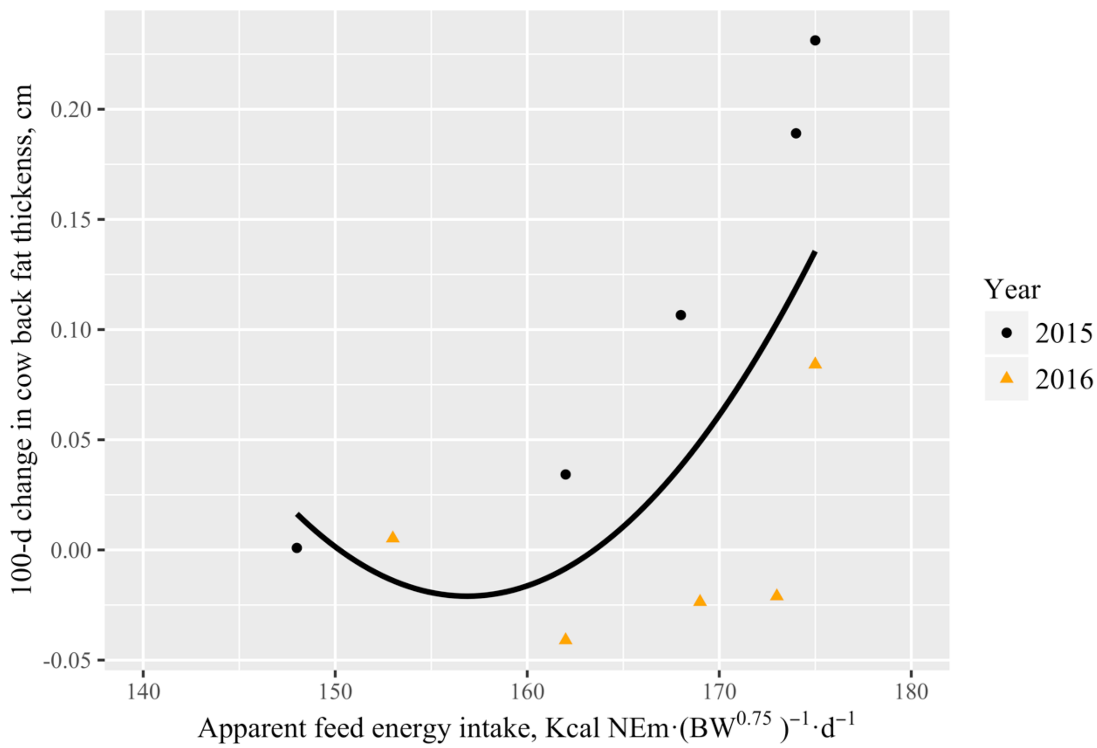

**Appendix 8.** Calculated cow feed energy intake did not significantly influence calf dry matter digestibility ($P$ = 0.75).



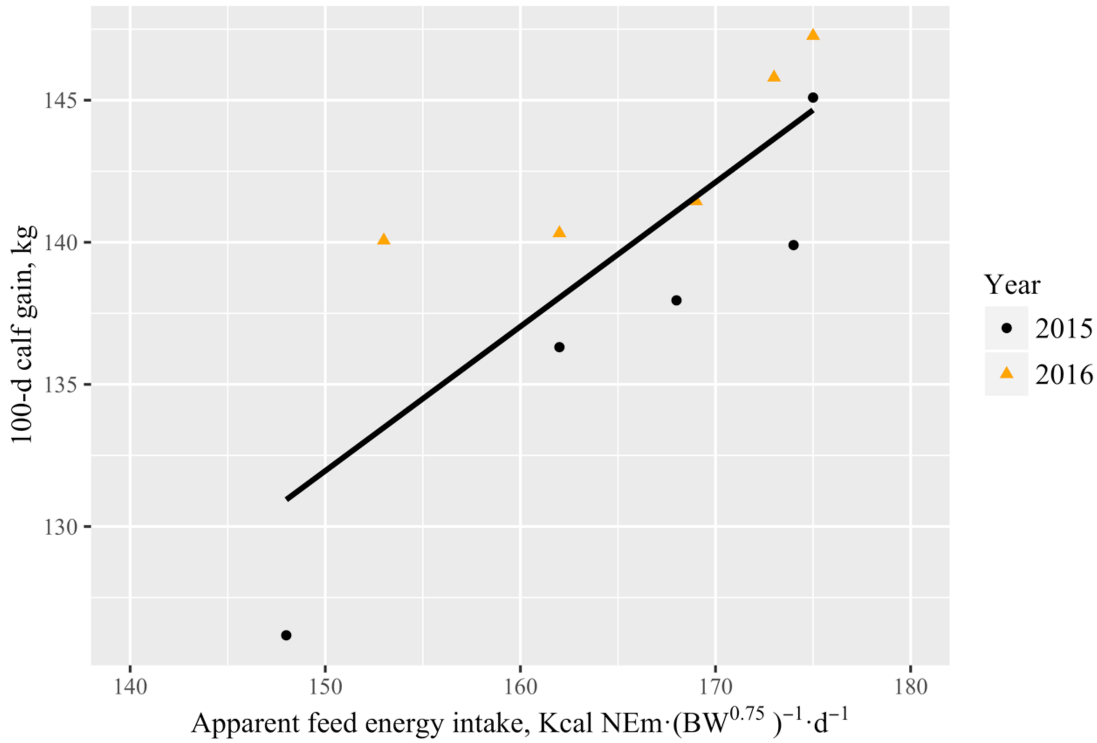

**Appendix 9.** Total BCS change for the experimental period increased with increasing apparent feed energy intake.



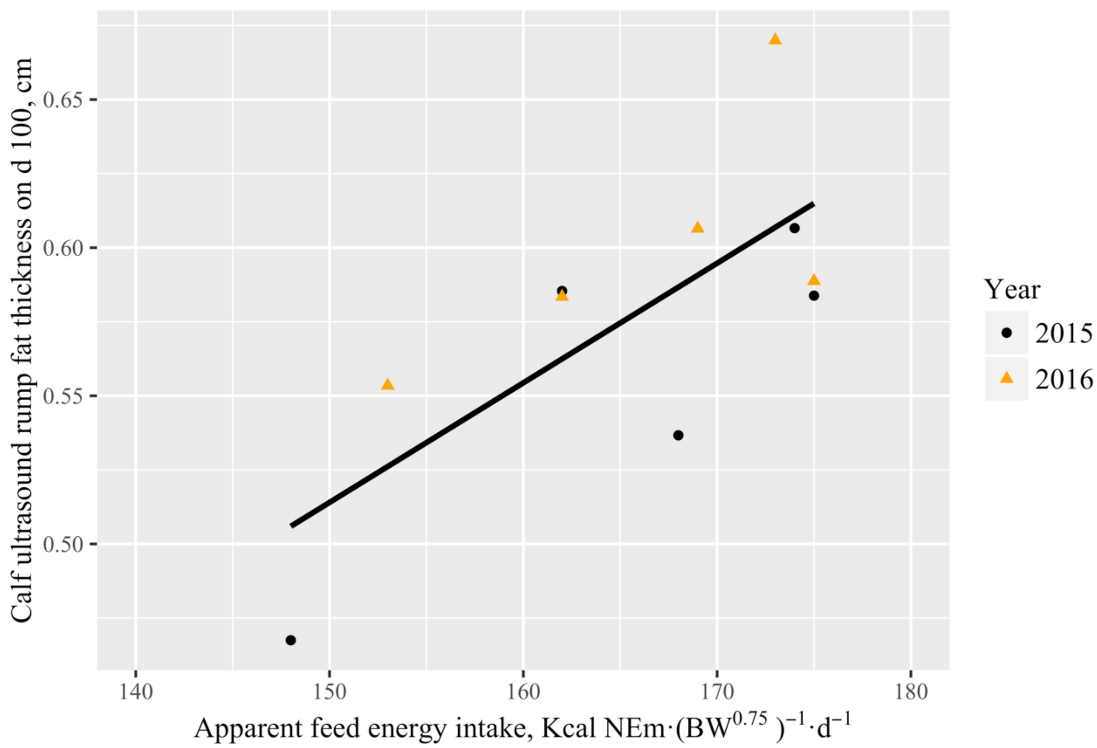

**Appendix 10.** Changes in cow intramuscular fat increased with increasing apparent feed energy intake.



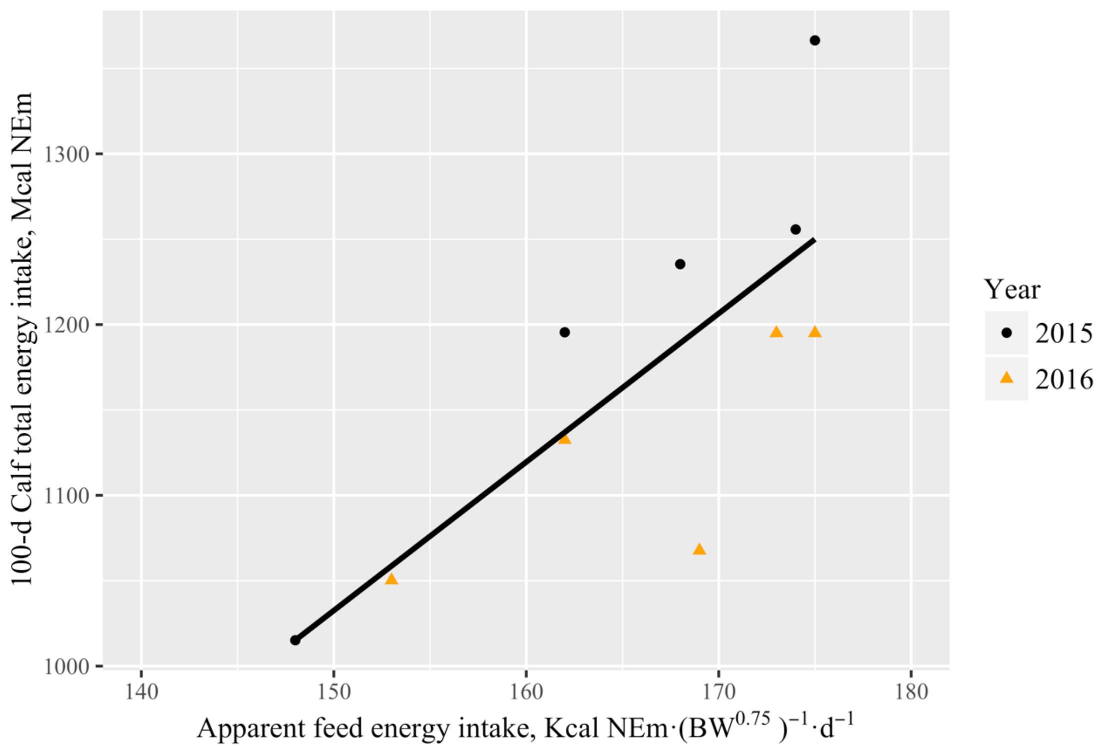

**Appendix 11.** Changes in cow back fat in response to increasing apparent energy intake.




**Appendix 12.** Calf BW gain increased linearly with increasing cow energy intake.




**Appendix 13.** Calf rump fat thickness at d 100 in response to increasing cow apparent feed energy intake.




**Appendix 14.** Total calf energy intake (creep feed and milk) increased with increasing cow energy intake.

# VITA

Courtney Marie Spencer

Candidate for the Degree of

Master of Science

Thesis: THE RELATIONSHIP OF MATERNAL DIETARY ENERGY INTAKE TO MILK PRODUCTION, BODY COMPOSITION, AND EFFICIENCY OF CALF GROWTH

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