EFFECTS OF TIMING OF WEANING ON PERFORMANCE AND ENERGY UTILIZATION OF PRIMIPAROUS BEEF COWS

By

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Abstract: Early weaning is used to minimize cow nutrient requirements in situations where feed inputs are scarce or expensive. For many years, maintenance energy requirements have been assumed to be 20% greater in lactating compared to non-lactating beef cows. Consequently, early weaning primiparous cow/calf pairs should improve overall efficiency, particularly in situations where mid- to late-lactation forage or feed nutritive value is low. The objective of this study was to determine the biological efficiency of early weaning and maintenance energy requirements of lactating versus non-lactating primiparous dams. Experiments were conducted in two consecutive years using 90 primiparous heifers and their calves (48 in yr 1, 42 in yr 2). Pairs were randomly assigned to one of 6 pens (8 pairs/pen yr 1, 7 pairs/pen yr 2) and pens were randomly assigned to each treatment; early weaning (EW, 130 d ± 15.4) and traditional weaning (TW, 226 d ± 13.1). Late-lactation cow and calf performance and feed consumption was measured for 92 d (yr 1) and 100 d (yr 2). Cows were limit-fed to meet maintenance requirements, while calves were offered ad libitum access to the same diet in a creep feeding area. Calves were not allowed access to the cows' feed. Cow feed intake, body condition score, body weight, milk yield and composition, and calf body weight gain and creep feed intake were recorded. After accounting for lactation and retained energy, there was a trend for higher maintenance energy requirements of lactating primiparous beef cows (P=0.07). From early weaning to traditional weaning, calf ADG (P<0.01) was significantly greater for TW calves. Feed and energy efficiency of the pair was improved for the TW system (P<0.01). Higher ADG was reported for EW calves during the stocker period (P=0.03), but there were no differences during the finishing period (P>0.40). During finishing, BW was higher (P=0.02) and G:F tended (P=0.06) to be higher for TW calves. The increased TW calf performance offset the additional maintenance costs of their lactating dams, allowing the TW system to be more efficient at converting total feed energy to kg of calf body weight gain.

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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. Chapter II has been prepared from the data collected includes an abstract, introduction, materials and methods, results and discussion, and literature cited section.

CHAPTER I

REVIEW OF LITERATURE

Traditional Beef-Cow Production

While beef production has not been vertically integrated like other livestock operations, it is still a vertically connected system stretching from the smallest of cow-calf operations all the way to the nation's largest stocker and feedlot operations (Tonsor and Schulz, 2015). Each stage has an essential role in providing a high quality protein to consumers, which has always been the main purpose of beef cattle production. With an increase in population there must be considerations to increase production while efficiently minimizing the amount of resources used. The population growth provides a challenge to all of agriculture in providing protein to consumers that are further removed from production. In order to continue producing beef and increase protein production, producers must continually investigate opportunities to modify practices to increase profitability.

A recent concern in the production of beef cattle has been the change in inventory of the cow/calf sector. The U.S. beef cow inventory hit a historic low in 2014 at 29 million animals, dropping from over 35 million in the early-1980's (Tonsor and Schulz, 2015). There has been a slight increase in recent years, but those numbers have now dropped to around 32 million (USDA-NASS, 2018). In order to grow production to meet the expanding population, there will need to be an increase in the number of cows in production, the overall efficiency in beef cattle production, or a combination of both. There has already been a dramatic increase in the efficiency of beef production. U.S. cattlemen are producing the same amount of beef as the mid-1970's with 30% fewer resources and 13 million fewer cows (Capper, 2011). A bottleneck resource for beef production would be the limited amount of land resources available causing a subsequent increase in price to both rent and purchase that land. The rise in land costs has shown continuing challenges towards producers as the breakeven associated with cow/calf production has continued to increase making it more difficult to remain profitable. A volatile market that is not vertically integrated causes cattle producers to become price takers making profitable production more difficult to achieve.

Traditionally, cow/calf production has been accomplished in a grazing system that allows the cow to graze range or other forage ad libitum to provide their nutritional requirements. In months where forage quality is decreased, protein supplementation is provided to ensure nutritional requirements are met. Recently, cow/calf producers have had additional competition for the grasslands traditionally used for grazing. Grasslands are being converted to crop production at an annual rate of 1 to 5.4% (Wright and Wimberly, 2013). As stated by Tonsor and Schulz (2015) the 2007 through 2012 *Census of Agriculture* reports the total pasture hectarage in the United States declined by 3.6% (USDA-NASS, 2014). The decreased amount of resources available to the cow/calf industry force alternative production systems to be evaluated in order to understand their potential production and economic effects on the beef industry. Intensified management systems have become a more widely accepted management tool. The adoption of confinement (or semi-confinement) practices that utilize limit-feeding and/or limit-grazing offer the opportunity to take advantage of resources more efficiently. If there were the possibility to increase production while lowering the amount of land resources needed, while still remaining economically feasible, it would be a great advantage to beef production.

<u>Confinement Management</u>

An intensified cow/calf system provides the opportunity for increased production while utilizing less land resources. Recent research has focused on the degree of confinement that can result in successful cow/calf management. Confining cows to a dry lot over the winter season when forage quantity and quality are limited has been a common practice. However, placing cows in dry lot over the summer grazing season has not been a traditional practice, unless the forages available have been limited or damaged (Farney et al., 2014). The practice of placing cows in dry lot was recently stimulated by decreased land availability, drought conditions, modest feed prices, excess feedyard capacity and high cattle prices (Bayliff et al., 2016). Dry lot management throughout the entire production cycle has not been extensively studied. Anderson et al. (2013) found that most aspects of cow/calf production were similar between traditional pasture grazing and dry lotting of cows. However, calves that remained in dry lot had lower BW gains along with increased total feed costs of the operation, creating an overall higher breakeven cost (Anderson et al., 2013). There are multiple advantages, but also challenges that may be provided by an intensified production system. The advantages, according to Anderson and Boyles (2007), are: reduced calf stress at weaning, increased beef production per unit of land, allowance for pasture or rangeland restoration, ease of synchronization and artificial insemination, greater control of herd health and management, increased marketability of crop residues, forages, and other feedstuffs, along with the potential for lower costs of production. The challenges include: higher labor and equipment costs due to feeding, more environmental concerns and challenges due to mud and dust, increased accumulation of manure, higher amount of harvested forages and feed required for rations, and the possibility of rapid spread of disease due to close approximation of the cow herd (Anderson and Boyles, 2007). Schake and Riggs (1969) found that cows placed in confinement demonstrated more restless behavior, particularly cows that were fed at lower levels of intake. This could represent another potential challenge as the restlessness was most likely brought on by hunger. In a dry lot setting, cows that were fed less walked up to 50% further than the cows fed at higher levels (Schake and Riggs, 1969). Even so, cows fed limited feed only traveled 10% of the total distance normally recorded by a range cow (Schake and Riggs, 1969).

Drought is often a major reason why cows are placed in dry lot or confinement scenario. When cows are provided with only low-quality forage, they cannot consume enough to meet their nutritional requirements to maintain milk production (Burns et al., 1983). This decrease in milk production causes a decrease in calf performance and depletion in the body reserves of the beef cow. Because early weaning of calves has been shown to result in similar or increased performance as compared with calves that remain with their dams (Lusby et al., 1981; Myers et al., 1999; Fluharty et al., 2000; Preedy et al., 2016), it becomes a management decision that should be evaluated thoroughly if the facilities will allow for the additional space needed to early wean. Kruse et al. (2007) found that in a drought situation, early management before the true onset and effects of the drought take place is the key to remaining profitable and allowing for forage resources to remain undamaged for years following. Kruse et al. (2007) model found by early weaning and feeding calves in a dry lot setting, there was an increase in overall gross margin of the ranch.

One of the major issues with feeding a cow throughout the production cycle is that the cow's energy requirements are dynamic throughout the stages of production. These changes are largely due to milk production level, age, body weight, body condition score, and environmental conditions (NASEM, 2016). Nutrient requirements of the growing calf must also be taken into consideration. Calves will normally graze and consume supplementation alongside their dam during the lactation phase. In the dry lot setting there is no longer ad-libitum forage available. Due to the nature of limit-feeding, cows aggressively compete for and consume feed very quickly. This forces the calves to compete with their dams for feed nutrients. In this setting, calves are limited in their growth due to it not being feasible for a suckling calf to compete with a mature cow for a limited feed supply. To avoid this issue, creep feeding areas can be provided to offer additional feed specifically to meet the calf's needs. Creep feeding has been a tool used to increase productivity of the cow/calf sector, whether it is in confinement or on range. Lusby et al. (1976) found a positive correlation between creep feed intake and calf body weight in a dry lot setting showing that offering additional feed will increase calf performance. Faulkner et al. (1994) found that supplementation of concentrate at either a limited creep or unlimited creep provided increased gains and weaning weights by calves still nursing their dams. Myers et al. (1999a) found similar results with calves supplemented on pasture having greater gains compared to calves that were not.

Early weaning is a technique that is commonly adopted during confinement feeding of cows. Instead of trying to meet the nutritional requirements for both the cows and the calves together, it is possible to directly provide the energy needed for the cow and the calf in separate feeding areas. It also changes the stage of production in the cow from lactating to dry, lowering her maintenance energy requirements (Ferrell and Jenkins, 1984). Myers et al. (1999b) discovered that calves are extremely efficient at converting high-concentrate feeds to body weight gain. By providing early weaned calves a diet directly formulated for their needs for growth and development, early weaned calves should show increased gains and higher feed efficiencies than if they were supplemented while still suckling.

There are other requirements beyond diet that should be considered for a dry lot system such as, water, pen space, and shelter from the elements. Pen space is highly variable and is influenced by the environment that production will occur. Farney et al. (2014) recommended that small, dry cows had adequate space when allowed access to at least 11.6 m^2 per cow and up to 65.1 m^2 per pair for large cows in wet environments. The common space for a cow/calf pair in confinement though is 37.2 m^2 along with 2.3 m^2 of shade (Farney et al., 2014). Bunk space is typically recommended to be about .64 to .76 linear meters per cow, with additional bunk space allotted for the calves if they will be eating beside their dam (Farney et al., 2014). Water becomes the limiting factor for many pen designs, as it is the most critical nutrient for all animals. A lactating cow can consume up to 50 to 80 liters of water per day (Anderson and Boyles, 2007). Calves will consume water alongside their dams as they continue to grow. In order to allow adequate water intake for calves, tanks should be banked or an alternative water source should be provided so that calves are able to access water as well (Anderson and Boyles, 2007). Other environmental factors to consider while in confinement are the effects of temperature and wind. In order to avoid adverse performance effects, cattle should be provided windbreak and bedding in the cold winter months and shade to combat heat stress in the summer (Mader, 2003).

Limit-Feeding Beef Cows

Diet Composition

Limit-feeding is the technique in providing a diet at a low level of intake that will meet the nutritional requirements of the cow. Often limit-feeding is considered when there is distress on the range forcing the cows to be moved into confinement. This could be from drought, hail, fire, or the lack of land available to house the number of cows in the herd. Limit-feeding can also be put into place utilizing a grazing situation as well. By implementing a rotational grazing system, or a time based grazing system, the amount of forage available to cows can be controlled to provide the desired amount of intake. While limit grazing is a viable option, the techniques discussed will consist of confinement systems utilizing a high to moderate concentrate diet.

Meeting the nutritional requirements of the cow utilizing an energy dense feed source that can be obtained economically while not negatively affecting performance is the main focus of limit-feeding beef cows. Accurately feeding the correct intake level to meet the amount of energy required for maintenance of the beef cow can provide multiple challenges. The cow's maintenance requirements vary greatly depending on the stage of production, age, breed and environmental factors (NRC, 2000).

Energy requirements could be met through different feeding strategies with multiple energy sources. The purpose has been to provide a nutrient dense diet that can be provided at lower quantities. Jenkins et al. (2015) found that ethanol by-products can provide an increased amount of energy in the diet and can be combined with forage sources in a limit-feeding situation. In three different experiments, there were either no differences in BW and BCS or an increase in BW and BCS when by-products were used in the diet, compared with ad libitum hay or forage (Jenkins et al., 2015). Shike et al. (2009) also investigated the effects of adding corn-co-products in a limit-fed diet on cow performance. By adding either corn gluten feed or dry-distillers grains to the diet, with inclusion rates as high as 75 percent, the performance of cows was adequate compared with traditional ad libitum hay diets. The inclusion of dry-distillers grains with solubles or corn gluten feed, depending on price and availability of co-products, is an option that can be utilized in providing an energy-dense, limit-fed diet (Shike et al., 2009). Faulkner et al. (2013) was able to compare the performance of cows program fed differing ethanol by-products and found cow performance was not affected and that by-products were an effective component to a limit-fed diet. Tjardes et al. (1998) tested to see if processed corn and supplemental fat could be used in a diet as additional energy in order to limit the cow's intake. Their results reported similar findings with cow and calf performance for either group not being affected when the cows were fed at a level of dry matter that still met the cow's maintenance requirement. They also found that an increase of four percent supplemental fat could increase milk production at peak lactation by 65%. The reported literature shows cows fed a limited amount of feed, but still provided with adequate energy to meet maintenance, will be able to hold their condition throughout the feeding period.

Cow Performance

The cow is the production center of a cow/calf operation. Energy requirements of the cow must be first taken into consideration, or the production system as a whole will struggle to create a profit. Hess et al. (2005) reported four reoccurring themes from previous reviews on cow nutritional status and reproductive success: 1) prepartum nutrition is more important than postpartum nutrition in determining the length of postpartum anestrus, 2) inadequate dietary energy during late pregnancy lowers reproduction even when dietary energy is sufficient during lactation, 3) a body condition score greater than 5 will ensure body reserves are adequate for postpartum reproduction, and 4) further declines in reproduction occur when lactating beef cows are in negative energy balance. Energy requirements of the cow shift throughout the stages of production (NASEM, 2016), and the performance of the cow is dependent on meeting those requirements. Body condition score is the most common way to determine the nutritional status of the cow and whether or not they are meeting their requirements or not. These requirements can also be affected by age, weight, genetics, and previous nutrition (NASEM, 2016). When nutritional requirements are lower than those provided in the diet, body reserves must provide the additional energy needed to maintain metabolic function (Moe et al., 1971). This is of highest concern in primiparous females as they have yet to reach physical maturity. The additional requirement of growth provides nutritional strain that is often seen in the loss of body condition.

Supplementation through additional feedstuffs can provide the energy needed to offset the additional costs of lactation, reproduction and growth, but they quickly become costly. Another common strategy to combat these nutritional imbalances is early weaning of the calf to remove the nutritional demand of lactation (Rasby, 2007) and the additional increase due to mammary tissue activity (NASEM, 2016). Depending on the timing of weaning, benefits could include increased reproductive performance, improved body condition score, and a decrease in forage pressure (Lusby et al, 1981; Myers et al., 1999b; Rasby, 2007).

Nutrition of Primiparous Heifers

Primiparous heifers have additional requirements than a multiparous cow. Primiparous heifers have not reached full mature weight yet and are still partitioning energy towards growth (Banta et al., 2005). Ferrell et al. (1976) compared the energy utilization of pregnant and nonpregnant heifers to analyze how a pregnant female used energy and to help establish the increased requirements of the pregnant heifer. Freetly et al. (2006) reported that the conversion of metabolizable energy to lactation energy and tissue was 72 and 71% respectively. These findings suggest that even though milk yields are much lower, the energy efficiencies of young beef cows are comparable to those of dairy cattle (Freetly et al., 2006). Due to increased energy needs for growth, primiparous females not managed separately from the mature cowherd can begin to lose body condition. Heifers that are managed within the herd with multiparous cows will tend to have lower BCS and lower reproductive performance (Banta et al., 2005). The most important factor in postpartum interval and reproductive success after first calving for primiparous females is cow condition at calving (Selk et al., 1988; Lalman et al., 1997).

Supplementation post calving to thin cows can improve reproductive success, however the condition score at calving is a much better predictor (Lalman et al., 1997).

While nutrition prepartum is the most critical for short postpartum interval and an efficient breeding season, steps can be made to assist in maintaining condition of primiparous females postpartum. Previous literature has shown increased BW gain and increased BCS along with increased reproductive performance (Lusby et al., 1981; Arthington and Kalmbacher, 2003). The primiparous female requires the most attention when preparing for calving and first rebreeding, but when managed correctly, they can provide a valuable asset to a cow/calf enterprise.

Maintenance Energy Requirements

Around 70% of the energy required for beef production can be associated with the cow-calf sector of production (Ferrell and Jenkins, 1984). Maintenance energy requirements account for 70-75% of the total energy required by the cow (Ferrell and Jenkins, 1984). Accordingly, approximately 50% of the total energy required to produce one kg of beef can be directly attributed to the maintenance costs of the cow, making maintenance energy requirements one of the most important aspects of beef production. The maintenance energy requirement is defined as the amount of feed energy intake that will results in no net loss or gain of energy from the tissues of the animal body (NRC, 2000). The processes that make up maintenance requirements include body temperature regulation, metabolic processes and physical activity. Using data primarily from growing steers and heifers of British decent, net energy for maintenance requirements have been estimated to be $NE_m = .077\ Mcal/EBW^{0.75}$ (NASEM, 2016). Factors effecting maintenance include: breed, body weight, sex, age, season, temperature, physiological state and previous nutrition (NASEM, 2016). The following sections will discuss these factors and their change in maintenance requirements in beef cattle.

Body Weight

Relating fasting heat production or maintenance requirements to a fractional power of BW is more accurate than $BW^{1.0}$ (Kleiber, 1961). While there has been considerable debated as to the correct power adjustment, $BW^{0.75}$, often referred to as metabolic BW, is the standard power used to scale energy requirements to BW. The general standard for beef cattle is to use SBW, which is 18h without feed but with water or BW x 0.96, when determining maintenance requirements (NASEM, 2016).

Breed

Differences in maintenance by breed have been noted since as early as 1911 when Armsby and Fries (1911) reported a difference in energy efficiency between an Aberdeen-Angus beef steer and a Jersey cross dairy steer. Since, many researchers have examined the effect of breed on maintenance requirements. Reported differences have been attributed to genetic variability between and among breeds along with experimental procedures and conditions. It has been generally accepted in growing cattle that *Bos Indicus* breeds (Africander, Barzona, Brahman, Sahiwal) have 10% lower maintenance energy requirements than *Bos Taurus* breeds (Angus, Hereford, Shorthorn, Charolais, Limousin) (NASEM, 2016). Also, a 20% increase in maintenance energy requirements has been reported for dairy or dual purpose *Bos Taurus* breeds relative to traditional *Bos Taurus* breeds (NASEM, 2016). While reported data is limited, the difference in maintenance requirements between breeds remained the same between growing or mature cattle. This can be interpreted to show a strong correlation between increased productivity traits (i.e. growth rate or milk production) and maintenance energy requirements (Montaño-Bermudez et al., 1990). Cattle with high production traits may also exhibit disadvantages when faced with a challenging or nutrient restricted environment, due to increased energy demand for elevated production levels along with increased maintenance requirements.

Physiological State

Physiological state has previously shown to influence the maintenance requirements of a cow throughout the production cycle. While no direct evidence has shown an increase through comparative slaughter techniques (Ferrell et al., 1976), there has been evidence suggesting that maintenance requirements of the cow increase with the progression of gestation (Ferrell and Reynolds, 1987). As the cow gestates, it has been seen that particular organs, such as the liver and gastrointestinal tract, can manipulate their energy usage to either conserve or increase dependent on the energy demand of pregnancy (Meyer et al., 2010). When estimating energy requirements it can be assumed that pregnancy increases heat production independent of specific tissue use (NASEM, 2016).

Maintenance requirements can also be affected by lactation. **Table 1.1** shows previous data reported on the effects of lactation on maintenance energy requirements. Studies using dairy type cattle have shown anywhere from a 22 to a greater than 30% increase in maintenance requirements of lactating dams compared to non-lactating utilizing calorimetry findings (Flatt et al., 1969; Moe et al, 1970; Patle and Mudgal, 1975, 1977). Using similar techniques, Reynolds and Tyrrell (2000) found a 24% increase in the lactating cows. Many authors have shown similar values in beef cows using weight stasis with increases in maintenance requirements of lactating cows being reported anywhere from 10 to 37% (Neville and McCullough, 1969; Neville, 1974; Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990). According to NASEM (2016), maintenance requirements of lactating beef cows should be estimated as 20% higher than those of non-lactating cows.

Digestibility

Digestibility has been shown to be influenced by level of feed intake. Limit-feeding beef cows a high to moderate concentrate TMR ration could potentially provide an increased level of digestibility due to the lower level of feed intake. An inverse relationship between digestibility, and increased net energy intake is a topic that has been noted for many years and the techniques of restricted, programmed, or limit-feeding all hope to take advantage of the increased digestibility associated with the lower level of energy required and the subsequent decrease in dry matter intake. In steers that were offered differing levels of net energy intake, Galyean et al. (1979) found that the total tract dry matter digestion was decreased by about eight percent as the amount of net energy intake was increased from 1.00 times maintenance requirement to 2.00 times the requirement. This increased efficiency has been shown to apply to limit-fed diets of cows as well. Trubenbach et al. (2014) found that cows fed in confinement had increased amount of organic matter digestibility. The cows that were fed an energy dense diet experienced a higher level of digestibility, which would be expected due to higher levels of DE intake (NASEM, 2016). It was also found that when intake was limited to 80 percent of the recommended requirements for ME, the amount of organic matter digestibility was increased by 4.5 percent (Trubenbach et al., 2014). This substantially reduced the amount of energy required for maintenance when cows were fed the high-energy diet from 0.077 Mcal/$EBW^{0.75}$ to 0.068 Mcal/$EBW^{.075}$ (Trubenbach et al., 2014). Early et al. (2016) found no difference in DM digestibility when cows were fed at four differing intake and energy levels. Cows were fed similar levels of forage and increasing levels of concentrate to meet the four energy levels while DM digestibility averaged 62% across all levels. While the reported data has some slight inconsistencies, it has generally been accepted that when intake is restricted digestibility of the feed stuff increases due to increased rumen retention time.

Weaning Age

Calf Performance

Early weaning has been a strategy applied to many cow/calf operations with different management practices, but it should only be applied if there is the opportunity to provide an additional profit or conserve a resource such as forage or cow body condition (Rasby, 2007). Early weaning's most common use is when feed is limited or expensive, or when the reproductive functions of the dam are at risk because of high nutrient requirements from lactation along with low quality food sources. However it can be applied in a normal year if there is the opportunity for the costs of production to be reduced, or higher performance by the dam or calf. A major concern voiced by early weaning is the maintenance of the health of the calf after maternal separation. Ideally calves should be preconditioned before maternal separation and treated with a vaccination protocol from a local veterinarian that fits the needs specific to the region (Rasby, 2007). Preconditioning of calves will allow for minimized stress, better immune response, and increased levels of performance when compared to non-preconditioned calves. Lusby et al. (1981) showed no differences in morbidity or mortality between steers weaned as early as 6 to 8 weeks of life compared to steers weaned at a more traditional weight. Myer et al. (1999) reported early weaned steers had a 91% reduction in respiratory morbidity. Previous literature has shown, with proper management, health of an early weaned calf can be maintained at the same level, or possibly more efficiently than if weaned at a later date.

Diet of the weaned calf can vary, but getting calves to have consistent intakes after weaning is the most important aspect. The quicker a calf starts to consume feed, the less likely they are to experience morbidity or mortality (Rasby, 2007). Calves should be offered an energy dense, highly palatable starter diet in order to entice the calf to consume around 1.0 – 1.5% of its body weight. The most important nutrient for any animal is water. Providing easy access to fresh clean water should be of major concern to bawling calves. Calves will normally pace and walk boundary fences when first weaned, so placing water along the border of the pen will create a natural opportunity for calves to find water (Rasby, 2007).

Weaning age of the calf has been a topic reported and investigated through many studies, and the optimal age depends on the goals and production techniques put in place by a specific operation. There are also many different opportunities to manage the calves after weaning with the main focus being growth and development. The nutritional requirements can be met through grazing systems (Moreil et al., 2014) or by placing the calf in confinement or semi-confinement and providing them with a high concentrate diet (Barker-Neef et al., 2001; Shoup et al., 2015). Facilities available often determine the management system used when early weaning calves. When ample space and pens are available to place calves in a semi-confinement system or total confinement system, the opportunity to feed a high to moderate concentrate diet becomes a more logical option. However, mixing of the diet and feed delivery should be taken into consideration as additional management challenges. The advantages to a confinement or dry lot weaning system include: ability to control the intake, easier to monitor health of the calves, tight facilities allow the ability to keep calves for escaping pens, and increased forage available for cows. Disadvantages include increased environmental concerns (dust, wet pens) and rapid spread of contagious disease (Anderson and Boyles, 2007). Other options would include allowing weaned calves to graze available forage while offering supplementation to increase performance. The weaning weight of a calf crop is the major profit center of most cow/calf producers making the performance of calves weaned at different ages is an area that has been studied extensively.

Many authors have reported success weaning beef calves at differing ages. The literature provides much discussion as to the correct age of weaning with varying results. Lusby et al. (1981) weaned calves at 42-56 days of age with little repercussions on growth and performance of calves as they performed similarly to control calves. Kimple et al. (1977) had similar results with early weaned pairs being more efficient at converting pounds of TDN to pounds of calf produced. A commonly studied age of weaning has been 90 day of age (Green and Buric, 1953; Myers et al., 1999a; Fluharty et al., 2000) and results have been mixed between added performance and no difference in treatments. Ages continue to increase from 120 days to 150 days, up to normal weaning age at 205 days, and even some late weaning trials with calves older than 300 days (Peterson, 1987; Harvey and Burns, 1988; Faulkner, 1994; Story et al., 2000; Hudson, 2010). Age at weaning can play a large factor in calf production and performance. Overall profitability of the cow/calf operation depends on fitting the management practice with a weaning age that can provide adequate performance of both the dam and the calf post-weaning.

Nutrition of the calf post-weaning can be provided through multiple sources with varying levels of performance and management. After weaning, a common management system is to return early weaned calves back to pasture and provide supplementation (Lusby et al., 1981; Harvey and Burns, 1988; Arthingon et al., 2005; Caldwell et al., 2011). Probably the most common practice is to place EW calves into a dry lot where they can be offered an energy dense diet (Lusby et al., 1981; Peterson et al, 1987; Grimes and Turner, 1991; Myers et al., 1999a). This has commonly resulted in early weaned calves having heavier or similar BW to normal weaned calves at the time of normal weaning. When this type of management is put into place, the cow is normally returned to graze pasture, effectively reducing the demand placed on the forage by removing the extra need due to lactation and intake of the calf. Warner et al. (2015) placed both the cow and calf into a dry lot setting to measure efficiency and calf performance. A common diet was fed to both cows and calves, with the early weaned cows and calves being separated and the normal wean pairs remaining together. Intake of the normal wean pairs was fed together so separate intakes of the cows and calves was not determined. Due to differing performance and feed efficiency of early and normal weaned calves between locations, Warner et al. (2015) suggests that early weaning could potentially provide no reduction in feed energy requirements. However, this feeding strategy allows for less variation in diet composition between cows and calves and a relief on labor considerations when feeding in a confinement setting. Feeding strategy of weaned calves can influence growth performance. Considerations should be made for facilities and equipment when developing a diet and feeding strategy.

Effects on Finishing Period Performance

Early weaning not only has consequences on the cow/calf sector of beef production, but also in feedlot performance of those calves. The management and diet composition of the early weaned calf has an essential role in the future performance of an early weaned calf. Fluharty et al. (2000) fed early weaned steers diets differing in energy and concentrate content compared with normal weaned calves. No differences in feedlot performance or carcass characteristics were reported however calves fed high concentrate, low protein diets had severe depression in growth at the conclusion of the trial with over 20% failing to reach 477 kg (Fluharty et al., 2000). It should be noted that feeding a high concentrate low protein diet to calves at a young age can cause adverse effects on finishing weights. Myers et al. (1999b) reported similar findings with early weaned steers requiring fewer days on feed yet having similar carcass characteristics. Schoonmaker et al. (2004) offered either *ad libitum* or limited access to a concentrate diet to early weaned calves with the *ad libitum* access causing decreased days of age, slaughter weight and marbling score, while the limited access showed increased efficiency and no difference in carcass characteristics.

However the literature is not in agreeance on the effects of early weaning on feedlot performance. Schoonmaker et al. (2001) found decreased performance of early weaned steers in the finishing period, most likely due to compensatory gain of normal weaned steers, but saw no difference in carcass characteristics. Meteer et al. (2013) saw a reduction in the performance of early weaned calves having increased dry matter intake, decreased efficiency and no difference in days on feed. Early weaning did provide advantages in carcass quality though with higher marbling scores (Meteer et al., 2013). While there are conflicting reports on the effects of early weaning on feedlot performance, there has commonly been no differences between early weaned and normal weaned calves. Early weaning should offer similar finishing performance and carcass characteristics when compared with normal weaning.

Economic Effects

Along with calf performance and feed efficiency, there are economic considerations to take into account when early weaning beef calves. Management strategy of the calf plays an influential role in the economics of the calf. Peterson et al. (1987) reported a 20.4% decrease in TDN intake for early-weaned pairs resulting in a 46.7% decrease in feed costs compared to traditional-weaned pairs. Increased calf gains combined with decreased feed costs resulted in an additional $95.26 increase net income (Peterson et al., 1987) showing a significant value provided by early weaning when selling calves at the time of traditional weaning. Cow costs can be reduced by early weaning, (Peterson et al., 1987; Story et al., 2000). When calves are sold immediately after early weaning, the decrease in cow costs is not sufficient to offset the lost income from lower calf weights (Story et al., 2000). Meteer et al. (2013) reported a decrease of profit from early weaned calves compared to creep fed calves when calves were sold at weaning or if ownership was retained through finishing. Barker-Neef et al. (2001) reported similar findings when studying the economic effects of early weaning in the finishing phase. Again, early weaned calves had improved feed efficiency, and lower cost of gain, but due to lower carcass weights the return to the cow-calf enterprise was lower when compared with traditional weaned calves (Barker-Neef et al., 2001).

Conclusion

Intensification of beef production is becoming a more common practice due to increased urbanization and rising prices for ownership and rental rates of land. Placing a cow/calf enterprise into confinement is a viable option with extra considerations for the health and development of the cow and calf. Limit-feeding of the cow can be accomplished through multiple feed stuffs and provides the ability to control the intake and quality of diet provided.

Performance of the cow must be the first priority when examining the needs of the cow/calf sector. The nutritional requirements must be met in a timely manner and body condition must be adequate prior to calving through breeding to ensure reproductive success. Extra attention must be given to primiparous females due to their increased requirements for growth post-calving. Maintenance requirements of cows make up 50% of the total energy needed for beef production. Breed, body weight, and physiological state can all effect maintenance requirements with lactation have a reported 20% increase in requirements.

Early weaning has been a common production practice used to deal with times of nutritional stress, such as drought situations, or to reduce the nutritional burden on the cow. Depending on the age of early weaning, it can also offer reproductive benefits when performed prior to 90 days of age. Early weaned calves can be managed in multiple settings resulting in different performance characteristics. While early weaning has shown to provide additional income prior to normal weaning of calves, the overall net return of early weaned calves is consistently lower when compared to normal weaned calves. When making the decision to early wean, facilities and equipment should be evaluated to determine the most efficient management practice for the calves.

Table 1.1. Maintenance energy value estimations for lactating and non-lactating cows presented in the literature

Source	Diet Energy Determination	Maintenance Energy Determination	Physiological State	Results
Reynolds and Tyrell, 2000				
Hereford x Angus	Digestion trial	Calorimetry	Lactating	159 kcal ME
			Non-lactating	123 kcal ME
Montaño-Bermudez et al., 1990				
Hereford x Angus, Red Poll x Angus, Milking Shorthon x Angus	Tabular values	Weight stasis	H x A, Lactating	128-133 kcal ME
			H x A, Non-lactating	100-117 kcal ME
			RP x A, Lactating	146-152 kcal ME
			RP x A, Non-lactating	114-128 kcal ME
			MS x A, Lactating	140-147 kcal ME
			MS x A, Non-lactating	110-127 kcal ME
Ferrell and Jenkins, 1985				
Angus x Hereford	Tabular values	Weight stasis with comparative slaughter	Lactating	151 kcal ME
			Non-Lactating	130 kcal ME
Neville, W. E., 1974				
Hereford	Sheep digestion trial	Weight stasis	Lactating	174 kcal ME
			Non-lactating	123 kcal ME
Moe et al., 1970				
Holstein	Digestion trial	Calorimetry	Lactating	122 kcal ME
			Non-lactating	100 kcal ME
Neville and McCullough, 1969				
Hereford	Tabular values	Weight stasis	Lactating	178 kcal ME
			Non-lactating	137 kcal ME

CHAPTER II

EFFECTS OF TIMING OF WEANING ON PERFORMANCE AND ENERGY UTILIZATION IN PRIMIPAROUS BEEF COWS

Abstract

Early weaning is used to minimize cow nutrient requirements in situations where feed inputs are scarce or expensive. For many years, maintenance energy requirements have been assumed to be 20% greater in lactating compared to non-lactating beef cows (NASEM, 2016). While not well established, maintenance energy requirements are thought to be greatest in primiparous cows and to decline with age. Consequently, early weaning primiparous cow/calf pairs should improve overall efficiency, particularly in situations where mid- to late-lactation forage or feed nutritive value is low. The objective of this study was to determine the biological efficiency of early weaning and maintenance energy requirements of lactating versus non-lactating primiparous dams. Experiments were conducted in two consecutive years using 90 primiparous heifers and their calves (48 in yr 1, 42 in yr 2). Pairs were randomly assigned to one of 6 pens (8 pairs/pen yr 1, 7 pairs/pen yr 2) and pens were randomly assigned to each treatment; early weaning (EW, 130 d ± 15.4) and traditional weaning (TW, 226 d ± 13.1). Late-lactation cow and calf performance and feed consumption was measured for 92 d (yr 1) and 100 d (yr 2). Cows were limit-fed to meet maintenance requirements, while calves were offered ad libitum access to the same diet in a creep feeding area. Calves were not allowed access to the cows' feed. Cow feed intake, body condition score, body weight, milk yield and composition, and calf body weight gain and creep feed intake were recorded. After accounting for lactation and retained energy, there was a trend for higher maintenance energy requirements of lactating primiparous beef cows (*P*=0.07). From early weaning to traditional weaning, calf ADG (*P*<0.01) was significantly greater for TW calves. Feed and energy efficiency of the pair was improved for the TW system (*P*<0.01). Higher ADG was reported for EW calves during the stocker period (*P*=0.03), but there were no differences during the finishing period (P>0.40). During finishing, BW was higher (*P*=0.02) and G:F tended (*P*=0.06) to be higher for TW calves. The increased TW calf performance offset the additional maintenance costs of their lactating dams, allowing the TW system to be more efficient at converting total feed energy to kg of calf body weight gain.

Introduction

Reproductive success in a defined breeding season is the culmination of the interval from parturition to first ovulatory estrus, conception rate of cyclic cows, and early embryo survival through the first trimester (Banta et al., 2005). Longer postpartum interval in primiparous cows has been identified as the primary cause of reproductive failure when compared to multiparous cows (Wiltbank, 1964; Bellows and Short, 1978; Triplett et al., 1995). Negative energy balance after calving further extends the postpartum interval in primiparous cows (Houghton et al., 1990; Lalman et al., 1997). However, increasing postpartum energy intake may not be economically advantageous because additional energy supplied is partitioned to both milk and maternal tissue retained energy (Jenkins and Ferrell, 1992; Reynolds and Tyrrell, 2000). Consequently, early weaning has been used to dramatically reduce energy requirements to avoid negative energy balance and to achieve maternal tissue gain when nutrient availability is limiting. Eliminating the nutrients required for lactation results in a 51 to 44% decrease in energy demands of the dam (Neville, 1974, Peterson et al., 1987).

Several experiments have reported that lactation increases maintenance energy requirements (Moe et al., 1970; Patle and Mudgal, 1975, 1977; Ferrell and Jenkins, 1985). Therefore, early weaning should result in an additional reduction in cow maintenance cost (NASEM, 2016) and this energy savings could be redirected to calf growth as additional feed, thereby potentially enhancing production system efficiency.

The objective of this study was to determine the biological effects of timing of weaning on energy utilization and production efficiency in primiparous beef cows and their progeny. The hypothesis of this study was there would be increased maintenance requirements of lactating females and that early weaning would be the more efficient system.

<u>Materials and Methods</u>

Animals

All procedures and protocols were approved by the Oklahoma State Animal Care and Use Committee (#AG-15-23) for the two-yr study. This experiment was conducted at the Range Cow Research Center near Stillwater, OK. Ninety fall calving Angus and Angus x Hereford primiparous cows (410 $\pm$ 38 kg initial BW) and their Angus and

Hereford sired calves (111 ± 16 kg initial BW) were used (48 in yr 1, 42 in yr 2). Pairs were randomly assigned to 6 pens (8 pairs/pen yr 1, 7 pairs/pen yr 2) and pens were randomly assigned to either early weaning (**EW**, 130 d ± 15.4) or traditional weaning (**TW**, 226 d ± 13.1). The 226-d weaning age for TW was selected due to traditionally later weaning age commonly used in Southern Great Plains fall calving systems compared to approximate 205-d weaning age used in spring calving systems (Hudson et al., 2010). Early weaned pairs were not allowed fence line access in order to eliminate the possibility of suckling.

Facilities

Cattle were housed in dry lot pens at the Range Cow Research Center. Traditional weaned cow/calf pairs, EW cows, and EW calves were kept in nine outdoor, dirt floor pens. Each pen was equipped with fenceline bunks and ad libitum access to water. Pens for TW cow/calf pairs and EW cows provided for approximately 103 m^2 of pen space per pair and 1.03 linear meters of bunk space per cow. A separate creep area, which used the same fenceline bunks as their dams, provided 0.34 linear meters of bunk space per calf. Early weaned calf pens provided 35 m^2 of pen space and 0.34 linear meters of bunk space per calf. Pens were equipped with a minimum of 1.50 linear meters of windbreak on the north perimeter. Replications were rotated clockwise every 28 d to a different pen.

An acclimation period of 10 d was used in both years. For the first 5 d, pairs were allowed to graze dormant native pasture, while being supplemented with the experimental ration. The following 5 d, pairs were brought into the experimental pens daily and fed in the bunks used throughout the trial, then returned to graze. Early weaning was performed and data collection began on January 13, 2016 in yr 1 and January 4, 2017 in yr 2 and continued for 93 and 100 d respectively.

Feed and Feeding

A total mixed ration (TMR) was used both yr (**Table 2.1)**. In yr 1, a coccidiostat (Deccox®, Zoetis Services, LLC, Florham Park, NJ) was added to the TMR at 100 mg · $hd^{-1} \cdot d^{-1}$ for prevention of coccidiosis in calves. In yr 2, an equal amount of Deccox® was top-dressed over the ration in a cracked corn-based supplement provided at the rate of 0.454 kg · $hd^{-1} \cdot d^{-1}$. Equations from NASEM (2016) were used to estimate the initial amount of feed required to achieve 0.3 kg daily BW gain in lactating and non-lactating primiparous cows (206 kcal ME· $(kg\ BW^{0.75})^{-1} \cdot d^{-1}$ for TW; 129 kcal ME· $(kg\ BW^{0.75})^{-1} \cdot d^{-1}$ for EW). Feed offered to cows was adjusted weekly as needed to maintain BW gain of approximately 0.3 kg/d. Slight BW gain was desired to accommodate for additional growth of primiparous dams as they reach maturity.

Diet energy value at 1x maintenance was determined using the summative equation (NRC, 2001) and NDF digestibility (Weiss, 1992) on a DM basis as follows:

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

where ADICP = acid detergent fiber insoluble crude protein, NDF_{CP} = crude protein-free NDF, and IVNDF = in vitro digestible NDF. Due to different levels of intake necessary to maintain similar BW gain among treatments, estimated TDN for TW cows was adjusted according to NRC, 2001 as follows:

$$Discount = \left(TDN_{1X} - \left(\left((0.18 \times TDN_{1X}) - 10.3\right)\right) \times Intake\right) / TDN_{1X}$$

where TDN_{1X} = TDN at maintenance intake and Intake = incremental intake above maintenance (e.g. for a cow consuming 3X maintenance, intake above maintenance = 2).

Feed was offered daily at approximately 0700 h. In order to differentiate between cow and calf feed consumption the TW treatment, calves were penned each d prior to feeding. Cows would consume their feed in approximately 1 h. After cows consumed their feed, calves were returned to their pen where they had *ad libitum* access to a creep area containing the same diet as the cows. Calf feed was increased weekly in yr 1 and daily in yr 2 to achieve *ad libitum* feed intake. Feed refusals from the creep areas were collected and weighted each d. Daily samples were composited weekly within each pen and dried (72 h, 50° C). Cows readily consumed their entire ration within a 1 h period, requiring no collection of orts.

Apparent Diet Digestibility

Diet digestibility was determined in a separate *in vivo* experiment using 4 lactating and 4 non-lactating 2- and 3-yr-old Angus and Hereford x Angus cows. Beginning 45 d prior to the collection period, cows had *ad libitum* access to grass hay (6.4% CP, 59% TDN), 1 kg/d of a protein supplement (32% CP, DM basis) and were fed 2 kg/d of the TMR (chemical composition shown in **Table 2.1**). On d -40 the TMR was increased by 1 kg and hay was reduced by approximately 2 kg. Hay and TMR feeding rate were adjusted similarly every 5 d until grass hay was completely removed from the diet and the desired TMR feeding rate was achieved. Beginning d -5 and throughout the collection period, cows were housed in 2.4-m x 3.7-m individual pens with rubber mat flooring and fed at the same g • kg of $BW^{0.75\ -1}$ rate as the cattle from the previous trial and offered *ad libitum* access to water. Lactating cows were housed next to their calves with fenceline exposure and calves were turned in with their dam to nurse at 0700, 1300, and 2000 h each d. The TMR was sampled at 0700 h daily. Total fecal collection was performed on d 5 to 9 at 0700 and 1900 h. Morning and evening collections were thoroughly mixed prior to sampling, and subsamples equaling 5% of the total sample were taken from both collection times. The subsamples were dried in a forced air oven for 72h (60˚ C), ground through a 1 mm screen (Wiley Mill, Thomas Scientific, Swedesboro, NJ) and equal daily aliquots were pooled within cow. Pooled samples were analyzed for GE, fat, ADF, NDF, and ash content. Gross energy was determined for feed and feces via bomb calorimetry (Dairy One Forage Laboratory, Ithaca, NY). Fat content was determined utilizing the ether extract method (AOAC, 2012.) The ADF and NDF content were determined using Van Soest et al. (1963, 1991). Samples were ashed in a muffle furnace at 500° C for 8 h to determine OM and ash concentrations. Digestibility components (GE, OM, NDF, ADF and EE) were determined as:

$$Component\ digestibilty = \big((Component\ concentration\ in\ feed - Component\ concentration\ in\ fecal) \div Component\ concentration\ in\ feed\big) \times 100$$

Animal Health

Prior to experimental initiation in both yr 1 and 2, calves were administered a respiratory vaccine (Titanium 5, Elanco Animal Health, Greenfield, IN), a clostridial vaccine (Vision 7, Merck Animal Health, Madison, NJ), and oral anthelmintic (Safeguard, Merck Animal Health, Madison, NJ). Cows were also administered the oral anthelmintic. Amprolium solution (Corid, Merial Limited, Duluth, GA) was added to drinking water to provide 10 mg amprolium/kg BW for 5 days (d 9-13 yr 1, d 11-15 yr 2) to prevent coccidiosis.

Breeding

Prior to the experiment, cows were synchronized for timed artificial insemination (**TAI**) using a Co-Synch protocol (Stein et al., 2015). A controlled internal drug release (**CIDR**; Zoetis, Inc., Parisppany, NJ) device was inserted into the vagina and (Factrel, (gonadorelin hydrocholiride, Zoetis Inc., Parisppany, NJ) was administered intramuscularly. Seven d later, the CIDR was removed and (Lutalyse, dinoprost tromethamine, Zoetic Inc., Parisppany, NJ) was administered intramuscularly. Sixty h later, TAI was performed and a Factrel injection was administered to induce ovulation on cows that were non-responsive to the previous protocol. Following AI, cows were exposed to breeding bulls for 21 d. Bulls were removed as pairs were transferred to the experimental pens. Cows were then observed morning and night for standing heat for the following 40 d. When estrus was observed, the cow was artificially inseminated approximately 12 h after the conclusion of estrous.

Milk Yield and Energy Content

Milk yield was initially measured on d 35 and d 20 in yr 1 and yr 2 respectively, and at 28-d intervals thereafter using a procedure modified from Marston et al. (1992). A milking machine (Portable Vacuum Systems, Springville, UT) was utilized for complete evacuation. Cows and calves were separated twice to allow for standardization of milk production across all dams. On the day before milking, calves were removed from their dams at 1400 h. Calves were not allowed access to creep feed during this period. At 2000 h calves were returned to their dams and were allowed to suckle until satiated. At the conclusion of the nurse out period (2045 h) calves were again removed from their dams. Milking began the next morning at 0500 h allowing for an 8 h separation on average. Cows were comingled in one pen and milked in random order. Cows were sent to one of two working chutes, allowing for two cows to be milked simultaneously. After entering the chute, cows were intramuscularly injected with 1 mL of oxytocin (Oxoject, Henry Schein Animal Health, Dublin, OH) to assist with milk let down. Teats were then washed with warm, soapy water, dipped with an antibacterial solution, wiped dry, and hand stripped before attaching the milking claw. The milking claw remained attached until flow ceased. After removal of the milking claw, teats were hand stripped, to ensure complete evacuation, and then dipped with the antibacterial solution. Cows were then reunited with their calves and returned to their home pen. Any milk obtained from hand stripping was combined with the milk machine sample and weighed on a calibrated platform scale (Defender 5000, Ohaus Corp., Parsippany, New Jersey) to determine total yield. In order to analyze milk composition, 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). Milk energy content was estimated using the following equation (Eq. 13-46, NASEM, 2016):

$$E = (0.092 \times MkFat) + (0.049 \times MkSNF) - 0.0569$$

where E = energy content of milk (Mcal/kg), MkFat = milk fat content (%), and MkSNF = milk solids not fat content (%). In order to adjust for differences in separation time, initiation and conclusion of milking were recorded. Milk yield was multiplied by the regression coefficient of yield on conclusion time in order to adjust all yields to an 8 h separation time. The 8 h yield was then multiplied by 3 to determine 24 h milk yield.

Energy Balance and Maintenance Requirements

Feed intake required to maintain similar BW and BCS change served as the basis for energy balance and calculation of maintenance energy requirements (MER). Feed ME concentration each yr was determined using average chemical composition, the summative equation for TDN (NRC, 2001) and in vitro NDF digestibility (Weiss et al., 19992). Diet TDN was adjusted to an *in vivo* basis using the percentage difference in summative equation TDN and *in vivo* GE digestibility. Finally, diet energy values were converted to ME and NEm according to NASEM (2016) and Galyean et al., 2016.

Maintenance energy requirements were determined as:

$$MER = (MEI - MkE - TE) \cdot MBW^{-1} \cdot d^{-1}$$

Where MER = maintenance energy requirements, MEI = metabolizable energy intake, MkE = milk energy, and TE = tissue energy. Milk energy was calculated using the equation from NASEM (2016) as previously described. Actual BW was used to calculate

$BW^{0.75}$ This was due to limit-feeding and the NASEM (2016) determination of SBW as 18 h without food but with water, which matched the scenario the dry lot cows were exposed to. Maternal tissue retained energy was determined as:

$$RE = TBE_F - TBE_I$$

where RE = retained energy, TBE_F = total body energy on d 93 year 1, d 100 year 2, and TBE_I = total body energy on d 0. Total body energy was calculated using equations 13-1, 13-2, 13-7, 13-8, 13-9 and 13-10 from NASEM (2016).

Stocker Period

After the conclusion of the confinement period, all calves were weaned at the North Range Cow Research Center. Calves from all treatments were comingled and allowed to graze on warm season perennial pasture from late April to early August for a period of approximately 120 d. Weights were collected on d 189 and 220 and d 198 and 216 in yr 1 and yr 2, respectively. Immediately after weaning, calves were provided 0.454 kg/d of a 38% (DM) CP supplement consisting primarily of cottonseed meal and wheat middlings containing 150 mg/kg monensin.

Finishing Period

In both yr 1 and 2 steer calves were shipped to a commercial feedlot for finishing in late summer (n=27 in yr 1, n=21 in yr 2). Steers were separated into their original replicates from the initial 100 d dry lot trial and assigned to pens accordingly (3 pens $\cdot$ trt^{-1} $\cdot$ yr^{-1}). A similar high-concentrate diet was fed throughout the finishing period. On arrival steers were allowed 16 h rest prior to processing, administered a modified-live

(Vista Once, Merck Animal Health, Madison, NJ) and clostridial vaccine (Vision 7, Merck Animal Health, Madison, NJ), as well as implanted with a combination trenbolone acetate and estradiol implant (Revalor-S, Merck Animal Health, Madison, NJ). Steers were then reimplanted with a combination trenbolone acetate and estradiol implant (Revalor-IS, Merck Animal Health, Madison, NJ) approximately 90 d later. Cattle spent 161 d and 176 d on feed and were harvested at 381 and 392 d in yr 1 and 2 respectively and carcass data were collected.

Statistical Analysis

Cow performance, milk yield and composition, digestibility, stocker and feedlot performance and carcass data were analyzed using the GLIMMIX procedures of SAS (SAS Inst. Inc., Cary, NC). Pen was considered the experimental unit. The model included treatment as a fixed effect and year as a random effect. Cow maintenance requirements, calf performance, and feed efficiency data was analyzed utilizing the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Considering there was only one treatment for the analysis of milk yield and composition, period of time was considered the fixed effect. Initial calf weight differed in year 1 ($P < 0.01$). Consequently, the model for calf performance included initial BW as a covariate. By design, cows were to be fed at levels to achieve similar BW gain. Estimates for ME required were based on calculations made based on physiological state and breed crosses (NASEM, 2016). However, there were differences in RE between treatments. Jenkins et al. (1991) had similar issues with estimation of ME required and adjusted weight changed utilizing regression to remove differences between treatments. Because of this, a similar procedure was used by including RE as a covariate in the model for maintenance energy requirements and feed efficiency. For all analyses where *P*-value ≤ 0.10, treatment means were separated using least square means and reported using α ≤ 0.05.

Results and Discussion

Cow Performance

Similar BW and BCS change were achieved when EW cows were provided 66% of the feed (kg DM/d) provided to TW cows (**Table 2.2**). As intended, there were no differences due to treatment in cow BW ($P < 0.75$) or BCS ($P < 0.25$) throughout the experiment. Because these were immature primiparous two-yr-old cows, feeding rate was adjusted weekly or bi-weekly to achieve modest maternal tissue gain. This objective was achieved for both treatment groups as cow BW and BCS increased during the experimental period. There was no difference in pregnancy rate ($P < 0.18$) between the two treatments. Previous literature has reported an increase in pregnancy rate of EW cows (Lusby et al., 1981). When performed prior to the breeding season, EW can result in improved pregnancy rate, especially for thin primiparous dams (Rasby, 2007). However, in the current experiment, calves assigned to the EW treatment were weaned after the conclusion of the breeding period.

Diet Intake and Digestibility

Traditionally, early weaning of calves has consisted of moving calves to a dry lot to consume a high to moderate energy diet while their dam is left to graze. The energy demand of lactation is removed and results in reduced nutrient intake and allows for more efficient partitioning of energy intake for maintenance, growth, or gestation. In times of nutrient restriction it is possible to feed a common diet in confinement to both cows and calves in order to limit the variation in diet composition and control intake of both the cow and weaned calf. Limit-feeding a high to moderate concentrate TMR diet to cows has proved to offer flexibility to producers in times of forage restriction or when land area available for production is reduced (Tjardes et al., 1998; Shike et al., 2009; Faulkner et al., 2013; Jenkins, 2013; Rasby, 2013; Farney et al., 2014; Jenkins et al., 2015).

Results of the *in vivo* apparent digestibility experiment are shown in **Table 2.3**. Treatment groups were fed at approximately the same g/kg $BW^{0.75}$ required to maintain similar BW change among treatment groups in the performance experiment. There was no difference in OM, GE, NDF, ADF, or fat digestibility between lactating and non-lactating cows ($P > 0.5$). In an experiment with a diet formulated to provide similar energy concentration, Trubenbach et al. (2014) reported a 7.5 percentage unit decline in GE digestibility in steers when feed intake increased. However, in a companion study using a similar diet and gestating beef cows, (Trubenbach et al., 2014), GE digestibility declined by 2.4 percentage units when feed intake was increased. Trubenbach et al. (2014) found no difference in GE digestibility when gestating cows were fed using four different feeding rates. In this experiment (Trubenbach et al., 2014), inclusion of wheat straw declined and diet concentrate components increased as feed intake level increased. Consequently, any potential influence of increasing feed intake on GE digestibility may have been offset by increasing digestible dietary components. In other work, Moe et al. (1965) found a linear decline in TDN with increasing level of feed 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. We are unaware of previously published data comparing digestibility in lactating and non-lactating beef cows. More work is required to elucidate diet, animal, and feeding management factors that influence energy availability in limit-fed cows.

Means for *in vivo* DE were not different (**Table 2.3**; $P > 0.79$) and averaged 3.3 Mcal/kg DM. This value is remarkably similar to DE concentration determined using the summative equation (NRC, 2001) and *in vitro* NDF digestibility method (3.41 Mcal/kg DM; **Table 2.1**).

Milk Production

Mean milk yield, milk fat and milk protein concentration measured in this experiment are similar to previous reports using primiparous cows fed to maintain or achieve moderate positive energy balance (Mondragon et al., 1983; Lalman et al., 2000). Mean milk yield was greater in February and March compared to January (**Table 2.4**; $P < 0.01$). Freetly et al. (2008) described an acute decline in heat production that occurs within 7 d of feed restriction. These authors also reported that after the acute phase of adaptation, heat production declined at a gradual rate for extended periods (Freetly et al., 2008). This pattern of adaptation could explain increased net energy partitioned to milk production after the first 30 d of feed restriction in the current experiment.

There was no difference among collection periods for concentration of milk fat, protein, lactose, or solids non-fat ($P > 0.19$) and a tendency ($P = 0.06$) for reduced MUN concentration during the second collection period.

Maintenance Energy Requirements

Non-lactating primiparous cows required 66% of the MEI required to maintain similar body weight gain in lactating primiparous cows (**Table 2.5**). Maintenance energy requirements were calculated using equations from two different systems (Garrett, 1980; and Galyean et al., 2016). After subtracting retained energy for milk production and maternal tissue gain, there was a tendency ($P < 0.1$) for about 5% greater maintenance energy requirement in lactating cows, regardless of the system used to convert DE to ME and NEm (**Table 2.3**). While this difference is lower than previously reported, this finding is in agreement with literature suggesting that maintenance requirements are elevated in lactating beef cows (NASEM, 2016). Using *in vivo* digestibility and respiration calorimetry, Reynolds and Tyrrell (2000) estimated 29% greater maintenance energy requirements in lactating primiparous beef cows compared to non-lactating cows. In their work daily feed DM consumption for non-lactating cows was about 67% that of lactating cows resulting in 4.5 percentage units higher DM digestibility in non-lactating cows. Using similar techniques, Moe et al. (1970) reported a 22% increase in maintenance energy requirement of lactating Holstein and Jersey cows.

Compared to non-lactating Hereford cows, Neville and McCullough (1969) and Neville (1974) reported an increase in maintenance energy requirements for lactating cows of 30 and 38%, respectively. In the case of Neville (1974), sheep were used to determine *in vivo* diet digestibility at one level of feed intake and MEI was calculated using a constant of 3.62 Mcal ME per kg of TDN. In the case of Neville and McCullough (1969), MEI was calculated at one level of feed intake using equations relating chemical composition of forages to TDN and tabular TDN values for concentrate feeds used. Similarly, Montaño-Bermudez et al. (1990) reported a range of 10 to 27% increase in maintenance energy requirements for lactating cows using a constant diet ME value. Ferrell and Jenkins (1985) reported a 16% increase in maintenance energy requirements for pregnant, lactating Angus x Hereford dams compared with non-pregnant, non-lactating Angus x Hereford dams by comparing several previous studies. MEI was calculated using tabular values similar to that of Neville and McCullough (1969). Freetly et al., (2006) documented increased heat production with increased retained energy and increased feed intake. Consequently, some of the differences in maintenance requirement previously reported for lactating versus non-lactating cows could be a result of differences in diet digestibility as well as increased heat production due to higher levels of feed intake.

Our estimate of 70 Kcal/ $SBW^{0.75}$ for non-lactating Angus and Hereford x Angus primiparous cows compares to 77 recommended for Angus and Hereford cattle (NASEM, 2016). The default or recommendation for MER in lactating Angus cows is 92.4 Kcal/ $SBW^{0.75}$ and the recommended MER for lactating Hereford cows is 77 Kcal/kg $SBW^{0.75}$ (NASEM, 2016). These values compare to an estimate of 74 Kcal/kg $SBW^{0.75}$ for lactating primiparous cows in the current experiment which is substantially lower than the recommended average for crossbred Hereford X Angus (84.7 Kcal/kg $SBW^{0.75}$) or Angus (92.4 Kcal/kg $SBW^{0.75}$) cattle (NASEM, 2016).

Calf Performance

Both TW and EW calves were allowed *ad libitum* access to the same diet as their dams. Voluntary feed intake was 17.5% greater for EW calves ($P < 0.01$, **Table 2.6**) compared to TW calves still nursing their dams. However, the sum of feed and milk energy intake for TW calves was 36.5% greater compared to feed energy intake alone in EW calves ($P < 0.01$). As a result, traditional weaned calves had greater ADG ($P < 0.01$) and total BW gain ($P < 0.03$). A review of the literature shows mixed results for calf performance when early weaning management is compared to more traditional weaning age. Arthington and Kalmbacher (2003) found contrasting results with EW calves offered supplemental grain on ryegrass (*Lolium multiflorum*) pasture depending on stocking rate. With lower stocking rate EW calves gained 0.17 kg/d more, although more intense stocking rate caused EW calves to gain 0.24 kg/d less compared to TW calves. When comparing two different weaning ages (EW, 103 d; TW, 203 d) Fluharty et al. (2000) reported EW steers gained 0.46 kg/d more than TW during the time period leading up to traditional weaning. Lusby et al. (1981) found no difference in the weaning weights of EW or TW calves when EW calves remained in a dry lot. In contrast, weaning weight was lower when EW calves were allowed to graze on pasture and offered creep *ad libitum*. Meteer et al. (2013) reported EW calves fed a starch or fiber based diet had higher ADG than TW calves creep fed either a high starch or fiber diet, with both groups having higher gains than calves not offered creep. In similar studies (Myers et al. 1999a; Story et al., 2000), EW calves had increased ADG over steers weaned at a later date. Taken together, published work suggests that EW calves offered a nutrient-dense concentrate diet generally gain faster compared to calves nursing dams and grazing moderate and possibly declining quality forage. Our results may differ in part because TW calves were offered the same nutrient-dense diet *ad libitum*.

Feed efficiency was measured using kg and Mcal of feed intake on both a calf and pair basis. Inflated values for TW calves G:F are due to milk energy intake's influence on growth not being taken into account. The ratio of BW gain per kg of TMR for EW calves was 0.207, which is comparable to data reported by Myers et al. (1999b). This supports the previous findings of EW calves being extremely efficient at converting a nutrient-dense diet into BW gain. Feed efficiency of the pair was increased for the TW system ($P < 0.01$). Peterson et al. (1987) found EW pairs 43.9% more efficient at converting pair intake into calf BW gain when cows were offered *ad libitum* access to long stem hay and EW calves offered a nutrient-dense diet. However, TW calves were creep fed and cows offered a nutrient-dense diet in the current study, which could be a possible cause for the differences in efficiency. Warner et al. (2015) fed cows and calves the same diet in dry lot and found no differences in feed efficiency of the pair. Feed efficiency was also analyzed using energy intake. There was no difference in energy utilization when calves' TMR and milk energy intake were both taken into account ($P > 0.11$). On a pair basis, the TW system was more efficient at converting Mcals of TMR intake into calf BW gain ($P < 0.01$). We are unaware of previous research utilizing energy intake to determine feed efficiency between traditional and early weaning systems. The differing results between calf and pair energy intakes could possibly be due to partitioning of energy due to lactation.

Overall traditional weaning resulted in increased ADG and total calf BW gain. Higher energy intakes lead to increased ADG, and total kg of calf BW gain. Efficiency was interpreted as both feed and energy intakes. Calves were extremely efficient at converting TMR to calf BW gain. On a pair basis, the TW system was more efficient at converting kg and Mcals of TMR into calf BW gain. However, there was no difference in efficiency when only the calf's TMR and milk energy intake were taken into account.

With varying techniques and methods from previous research suggesting advantages to both systems, the method of cow and calf management at weaning chosen would determine the system that provides the most return.

Stocking Period Performance

After calves assigned to the TW system were weaned, calves from both treatments were returned to native pasture consisting of Indian grass (*Sorghastrum nutans)*, little bluestem (*Schizachyrium scoparium)*, and switch grass (*Panicum virgatum)* for a 122-d growing period. Traditional weaned calves entered the grazing period 22 kg heavier ($P < 0.01$, **Table 2.7**). During the growing period EW calves had greater ADG ($P < 0.01$). Overall grazing ADG was 16% greater for EW calves ($P < 0.01$). Compensatory gain from nutrient restriction has been a known phenomena researched extensively with the term compensatory gain first used extensively by Bohman (1955). Slower initial rate of gain of EW calves, followed by more rapid early grazing period gain suggests that growth was restricted during the EW phase due to lack of milk consumption. Lewis et al. (1990) found calves from low milk producing cows exhibited compensatory gain post-weaning. While calves from Lewis et al. (1990) all consumed milk, their results show similar compensatory gain when calves are restricted in milk consumption. However, increased ADG by EW calves was not enough to compensate for the difference in initial BW resulting in lighter BW at the end of the growing period ($P = 0.04$).

Feedlot Performance and Carcass Characteristics

Steer calf performance was recorded from the conclusion of the growing period through harvest. Traditional weaned steers were heavier at initiation ($P < 0.01$, **Table 2.8**), reimplantation ($P < 0.01$), and at harvest ($P < 0.02$). There was no difference in ADG at any point between treatments ($P < 0.55$). Interestingly, there was decreased DMI ($P < 0.05$) and a trend for increased feed efficiency ($P < 0.07$) of the TW steers from initiation to reimplantation. The same was true from initiation to harvest for DMI ($P < 0.09$) and G:F ($P < 0.06$). Previous literature has mixed results on the effects of weaning age and weight on feedlot performance. There are other reports showing similar results of increased efficiency of TW steers (Shike et al., 2007; Meteer et al. 2013). However both Shike (2007) and Meteer et al. (2013) found increased DMI and ADG. The current studies decrease in DMI of TW calves has not been explained. Many reports show no differences in BW gain, G:F or DMI of EW and TW calves (Arthington et al., 2005; Caldwell et al., 2011). Fluharty et al. (2000) found an increase in ADG and DMI of TW steers early in the finishing phase. These workers concluded the difference was most likely due to compensatory gain of TW calves caused by modest pre-weaning nutrient restriction compared to EW calves. Myers et al. (1999a) found opposite results of increased G:F, ADG, and lower DMI of EW calves. Nevertheless, further research is needed to determine if finishing performance could be negatively influenced by lack of late-lactation period milk consumption. On the other hand, it is possible that availability of a nutrient-dense diet during late lactation by TW calves could positively influence finishing-phase performance.

Timing of weaning had no impact on HCW, back fat thickness, ribeye area, yield grade, or marbling score ($P > 0.10$, **Table 2.9**). Results on carcass characteristics are varied in previous research. The most commonly found effect of weaning age on carcass attributes is increased marbling score and quality grade of the EW calves (Myers et al., 1999a,b; Story et al., 2000; Shike et al., 2007; Meteer et al., 2013). This most likely results from EW calves being placed into a feedlot on a high-concentrate diet immediately after weaning. Workers allowing EW calves to graze or have a growing period commonly show no differences in carcass characteristics due to weaning age (Fluharty et al., 2000; Arthington et al., 2005; Caldwell et al., 2011).

Implications

Early weaning of calves at 120 d in a confinement system did not provide the additional efficiency that was expected. Increased calf growth with moderate additional maintenance costs due to lactation allowed the TW system to be more efficient at converting total feed energy into calf BW gain. While some effects of compensatory gain were seen during the stocking period, EW calves remained smaller throughout the growing and finishing periods. Weaning age did not have an effect on the carcass characteristics of finished steers. Early weaning can be a viable option to benefit the cowherd when faced with a drought situation. However, when utilizing a dry lot cow-calf system the additional energy provided through lactation, along with creep feeding, can allow for improved calf performance. Traditional weaning calves in confinement can provide additional output from prior to weaning through finishing with proper management practices

REFERENCES

Anderson, V.L., and S. L. Boyles. 2007. Dry lot beef cow/calf production. NDSU. North Dakota Agricultural Experiment Station. AS-974.

Anderson, V.L., B. R. Ilse, and C. L. Engel. 2013. Dry lot vs. pasture beef cow-calf production: Three-year progress report. NDSU Beef Report. 13-16.

AOAC. 2012. Official Methods of Analysis of AOAC international. 19th edition. AOAC International, Gaithersburg, Maryland, USA

Armsby, H. P., and J. A. Fries. 1911. The influence of type and of age upon the utilization of feed by cattle. Bulletin No. 128. Washington, DC: U.S. Department of Agriculture, Bureau of Animal Industry.

Arthington, J. D., and R. S. Kalmbacher. 2003. Effect of early weaning on performance of three-year old, first-calf beef heifers and calves reared in the subtropics. J. Anim. Sci. 81:1136-1141.

Arthington, J. D., J. W. Spears, and D. C. Miller. 2005. The effect of early weaning on feedlot performance and measures of stress in beef calves. J. Anim. Sci. 83:933-939

Banta, J. P., D. L. Lalman, and R. P. Wetteman. 2005. Symposium paper: post-calving nutrition and management programs for two-year-old beef cows. Prof. Anim. Sci. 21:151-158.

Barker-Neef, J. M., D. D. Buskirk, J. R. Black, M. E. Doumit, and S. R. Rust. 2001. Biological and economic performance of early-weaned Angus steers. J. Anim Sci. 79:2762-2769.

Bayliff, C. L., M. D. Redden, J. R. Cole, A. L. McGee, R. Reuter, G. W. Horn, and D. L. Lalman. 2016. Energy requirements of lactating beef cows in a dry lot system. J. Anim. Sci. 94(Suppl. 1):15 (Abstr.) doi.org/10.2527/ssasas2015-030

Bellows, R. A., and R. E. Short. 1978. Effects of precalving feed level on birth weight, calving difficulty, and subsequent fertility. J. Anim. Sci. 46:1522-1528.

Burns, J. C., R. W. Harvey, F. G. Giesbrecht, W. A. Cope, and A. C. Linnerud. 1983. Central Appalachian hill land pasture evaluation using cows and calves. III. Treatment comparisons of per animal and hectare responses. Agron. J. 75:878.

Caldwell, J. D., K. P. Coffey, W. K. Coblentz, J. A. Jennings, D. S. Hubbell III, D. L. Kreider, M. L. Looper, D. L. Galloway, E. B. Kegley, and C. F. Rosenkrans Jr. 2011. Livestock Sci. 135:44-52

Capper, J. L. 2011. The environmental impact of beef production in the United States: 1977 compared with 2007. J. Anim. Sci. 89:4249-4261.

Early, N. M., J. E. Sawyer, L. A. Trubenbach, C. J. Boardman, J. R. Baber, N. L. Bell, and T. A. Wickersham. 2015. Effect of dietary intake on nutrient utilization, performance, and maintenance requirements in late gestation cows and their calves. J. Anim. Sci. 94(Suppl. 1):19

Farney, J., C. Reinhardt, G. Tonsor, J. Petersilie, and S. Johnson. 2014 Managing cows in confinement. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF-3115.

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

Faulkner, M. J., P. M. Walker, R. L. Atkinson, and L. A. Forster. 2013. Performance characteristics of beef cows program fed by-products from corn ethanol production. Prof. Anim. Sci. 29:613-620.

Ferrell, C. L., and T. G. Jenkins. 1984. Energy Utilization by mature, nonpregnant, nonlactating, cows of different types. J. Anim. Sci. 58:234-243.

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

Ferrell, C. L., and L. P. Reynolds. 1987. Oxidative metabolism of gravid uterine tissues of the cow. Energy Metabolism of Farm Animals: Proc. of the 10th Symposium. Pp. 298-301.

Ferrell, C. L., W. N. Garrett, N. Hinman, and G. Grichting. 1976. Energy utilization by pregnant and non-pregnant heifers. J. Anim. Sci. 42:937-950.

Flatt, W. P., P. W. Moe, A. W. Munson, and T. Cooper. 1969. Energy utilization by high-producting dairy cows. II. Summary og energy balance experiments with lactating Holstein cows. Energy Metabolism of Farm Animals: Proc. of the 4th Symposium. Pp. 235-239.

Fluharty, F. L., S. C. Loerch, T. B. Turner, S. J. Moeller, and G. D. Lowe. 2000. Effects of weaning age and diet on growth and carcass characteristics in steers. J. Anim. Sci. 78:1759-1767.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2006. Changes in heat production by mature cows after changes in feeding level. J. Anim. Sci. 84:1429-1438.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brand. 2006. Partitioning of energy during lactation of primiparous beef cows. J. Anim. Sci. 84:2157-2162.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2008. Partitioning of energy in pregnant beef cows during nutritionally induced body weight fluctuation. J. Anim. Sci. 86:370-377.

Galyean, M. L., D. G. Wagner, and F. N. Owens. 1979. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 49:199-203.

Galyean, M. L., N. A. Cole, L. O. Tedeschi, and M. E. Branine. 2016. Board-Invited Review: Efficiency of converting digestible energy to metabolizable energy and reevaluation of the California Net Energy System maintenance requirements and equations for predicting dietary net energy values for beef cattle. J. Anim Sci. 94:1329-1341.

Garrett, W. N. 1980. Energy utilization by growing cattle as determined by 72 comparative slaughter experiments. Proc. 8th Symposium on Energy Metabolism. Pp. 3-8.

Green, W. W. and John Buric. 1953. Comparative performance of beef calves weaned at 90 and 180 days of age. J. Anim. Sci. 12:561-572.

Grimes, J. F. and T. B. Turner. 1991. Early weaning of fall-born beef calves. II. postweaning performance of early- and normal-weaned cavles. J. Prod. Agri. 4:468-471.

Harvey, R. W., and J. C. Burns. 1988. Creep grazing and early weaning effects on cow and calf productivity. J. Anim. Sci. 66:1109-1114.

Hess, B. W., S. L. Lake, E. J. Scholljegerdes, T. R. Weston, V. Nayigihugu, J. D. C. Molle, and G. E. Moss. 2005. Nutritional controls of beef cow reproduction. J. Anim. Sci. 83 (E. suppl.):E90-E106.

Houghton, P. L., R. P. Lemenager, K. S. Hendrix, G. E. Moss, and T. S. Stewart. 1990. Effects of body composition, pre- and postpartum energy intake and stage of production of energy utilization by beef cows. J. Anim. Sci. 68:1447-1456.

Hudson, M. D., J. P. Banta, D. S. Buchanan, and D. L. Lalman. 2010. Effect of weaning date (normal vs. late) on performance of young and mature beef cows and their progeny in a fall calving system in the southern great plains. J. Anim. Sci. 88:1577-1587.

Jenkins, K. H., Using crop residues and by-products to limit feed cows in confinement (2013). Proc. Range Beef Cow Sym. Paper 320

Jenkins, K. H., S. A. Furman, J. A. Hansen, and T. J. Klopfenstein. 2015. Limit feeding high-energy, by-product-based diets to late-gestation beef cows in confinement. Prof. Anim. Sci. 31:109-113.

Jenkins, T. G., and C. L. Ferrell. 1992. Lactation characteristics of nine breeds of cattle fed various quantities of dietary energy. J. Anim. Sci. 70:1652-1660.

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

Kimple, K., M. McKee, G. Fink. and K. Conway. 1977. Early weaning and creep feeding calves in dry lot. In: Cattlemen’s Day Conference. Manhattan, KS. pg. 8-12.

Klieber, M. 1961. The fire of life: an introduction to animal energetics. New York: John Wiley and Sons.

Kruse, R. E., M. W. Tess, and R. K. Heitschmidt. 2007. Livestock management during drought in the northern great plains. II. Evaluation of alternative strategies for cow-calf enterprises. Prof. Anim. Sci. 23:234-245.

Lalman, D. L., J. E. Williams, B. W. Hess, M. G. Thomas, D. H. Keisler. 2000. Effect of dietary energy on milk production and metabolic hormones in thin, primiparous beef heifers. J. Anim. Sci. 78:530-538.

Lalman, D. L., D. H. Keisler, J. E. Williams, E. J. Scholljegerdes, and D. M. Mallet. 1997. Influence of postpartum weight and body condition change on duration of anestrus by undernourished suckled beef heifers. J. Anim. Sci. 75:2003-2008.

Lewis, J. M., T. J. Klopfenstein, R. A. Stock, M. K. Nielson. 1990. Evaluation of intensive vs extensive systems of beef production and the effects of level of beef cow milk production on postweaning performance. J. Anim. Sci. 68:2517-2524

Lusby, K. S., R. P. Wettermann, and E. J. Turman. 1981. Effects of early weaning calves from first-calf heifers on calf and heifer performance. J. Anim. Sci. 53:1193-1197.

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

Meteer, W. T., K. M. Retallick, D. B. Faulkner, J. W. Adcock, and D. W. Shike. 2013. Effects of weaning age and source of energy on beef calf performance, carcass characteristics, and economics. Prof. Anim. Sci. 29:469-481.

Meyer, A. M., J. J. Reed, K. A. Vonnahme, S. A. Soto-Navarro, L. P. Reynolds, S. P. Ford, B. W. Hess, and J. S. Caton. 2010. Effects of stage of gestation and nutrient restriction during early to mid-gestation on maternal and fetal visceral organ mass and indices of jejunal growth and vascularity in beef cows. J. Anim. Sci. 88:2410-2424.

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

Moe, P. W., H. F. Tyrrell, and W. P. Flatt. 1970. Partial efficiency of energy use for maintenance, lactation, body gain and gestation in the dairy cow. Energy Metabolism of Farm Animals: Proc. of the 5th Symposium. Pp. 65-68.

Moe, P. W., H. F. Tyrrell, and W. P. Flatt. 1971. Energetics of Body Tissue Mobilization. J. Dairy Sci. 54:548-553.

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

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

Moreil, P., S. E. Johnson, J. M. B. Vendrmini, M. A. McCann, D. E. Gerrard, V. R. G. Mercandante, M. J. Hersom, and J. D. Arthington. Effects of calf weaning age and subsequent management systems on growth performance and carcass characteristics of beef steers. J. Anim. Sci. 92:3598-3609.

Myers, S. E., D. B. Faulkner, F. A. Ireland, L. L. Berger, and D. F Parrett. 1999a. Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. J. Anim. Sci. 77:330-310.

Myers, S. E., D. B. Faulkner, F. A. Ireland, and D. F. Parrett. 1999b. Comparison of three weaning ages on cow-calf performance and steer carcass traits. J. Anim. Sci. 77:323-329

Myers, S. E., D. B. Faulkner, T. G. Nash, L. L. Berger, D. F. Parrett, and F. K. McKeith. 1999c. Performance and carcass traits of early-weaned steers receiving either a pasture growing period or a finishing diet at weaning. J. Anim. Sci. 77:311-322.

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press.

Neville, W. E. 1974. 1974. Comparison of energy requirements of non-lactating and lactating hereford cows and estimates of energetic efficiency of milk production. J. Anim. Sci. 38:681-686.

Neville, W .E. and M. E. McCullough. 1969. Calculated energy requirements of lactating and non-lactating Hereford cows. J. Anim. Sci. 29:823-829

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

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

Patle, B. R. and V. D. Mudgal. 1975. Maintenance requirements for energy in crossbred cattle. Brit. J. Nutr. 33:127-139.

Patle, B. R. and V. D. Mudgal. 1977. Utilization of dietary energy requirements for maintenance, milk production and lipogenesis by lactating crossbred cows during their midstage lactation. Brit. J. Nutr. 37:23-33.

Peterson, G. A., T. B. Turner, K. M. Irvin, M. E. Davis, H. W. Newland, and W. R. Harvey. 1987. Cow and calf performance and economic considerations of early weaning of fall-born beef calves. J. Anim. Sci. 64:15-22.

Preedy, G. W., J. R. Jaeger, J. W. Waggoner, and K. C. Olson. 2016. Effects of early or conventional weaning on beef cow and calf performance in pasture and dry lot environments. J. Anim. Sci. 94(Suppl. 5):610

Rasby, R. 2007. Early Weaning Beef Calves. Vet. Clin. Food. Anim. 23:29-40.

Rasby, R. 2013. Confinement feeding beef cows. Proc. 42^{nd} Cornbelt Cow-Calf Conference.

Reynolds, C. K., and H. F. Tyrrell. 2000. Energy metabolism in lactating beef heifers. J. Anim. Sci. 78:2896-2705.

Schake, L. M., and J. K. Riggs. 1969. Activities of lactating beef cows in confinement. J. Anim. Sci. 28:568-572.

Schoonmaker, J. P., F. L. Fluharty, S. C. Loerch, T. B. Turner, S. J. Moeller, D. M. Wulf. Effect of weaning status and implant regimen on growth, performance, and carcass characteristics of steers. J. Anim. Sci. 79:1074-1084.

Schoonmaker, J. P., M. J. Cecava, F. L. Fluharty, H. N. Zerby, and S. C. Loerch. 2004. Effect of source and amount of energy and rate of growth in the growing phase on performance and carcass characteristics of early- and normal-weaned steers. J. Anim. Sci. 82:273-282.

Selk, G. E., R. P. Wetteman, K. S. Lusby, J. W. Oltjen, S. L. Mobley, R. J. Rasby, and J. C. Garmendia. 1988. Relationships among weight change, body condition and reproductive performance of range beef cows. J. Anim. Sci. 66:3153-3159.

Shike, D. W., D. B. Faulkner, M. J. Cecava, D. G. Parrett, and F. A. Ireland. 2007. Effects of weaning age, creep feeding, and type of creep on steer performance, carcass traits, and economics. Prof. Anim. Sci. 23:325-332.

Shike, D. W., D. B. Faulkner, D. F. Parrett, and W. J. Sexten. 2009. Influences of corn co-products in limit-fed rations on cow performance, lactation, nutrient output, and subsequent reproduction. Prof. Anim. Sci. 25:132-138.

Shoup, L. M. A. C. Kloth, T. B. Wilson, D. Gozalez-Pena, F. A. Ireland, S. Rodriguez-Zas, T. L. Felix, and D. W. Shike. 2015. Prepartum supplement level and age at weaning: I. Effects on pre-and postpartum beef cow performance and calf performance through weaning. J. Anim Sci. 93:4926-4935.

Story, C. E., R. J. Rasby, R. T. Clark, and C. T. Milton. 2000. Age of calf at weaning of spring-calving beef cows and the effect on cow and calf performance and production economics. J. Anim. Sci. 78:1403-1413.

Tjardes, K. E., D. B. Faulkner, D. D. Buskirk, D. F. Parrett, L. L. Berger, N. R. Merchen, and F. A. Ireland. 1998. The influence of processed corn and supplemental fat on digestion of limit-fed diets and performance of beef cows. J. Anim. Sci. 76:8-17.

Tonsor, G. T., and L. L. Schulz. 2015. Beef species symposium: Economic considerations related to U.S. beef herd expansion. J. Anim. Sci. 93:4227-4234

Triplett, B. L., D. A. Neuendorff, and R. D. Randel. 1995. Influence of undegraded intake protein supplementation on milk production, weight gain, and reproductive performance in postpartum Brahman cows. J. Anim. Sci. 73:3223-3229.

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

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

USDA National Agricultural Statistics Service (USDA-NASS) 2014. Cattle (January 2014). http://usda.mannlib.cornell.edu/usda/nass/Catt//2010s/2014/Catt-01-31-2014.pdf. (Accessed 24 April 2018).

USDA National Agricultural Statistics Service (USDA-NASS) 2018. Cattl (January 2018). http://usda.mannlib.cornell.edu/usda/current/Catt/Catt-01-31-2018.pdf. (Accessed 24 April 2018).

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feed. II. A rapid method for the determination of fiber and lignin. Journal of A.O.A.C. 46:830.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

Warner, J. M., K. H. Jenkins, R. J. Rasby, M. K. Luebbe, G. E. Erickson, and T. J. Klopfenstein. 2015. The effect of calf age at weaning on cow and calf performance and feed utilization by cow-calf pairs. Prof. Anim. Sci. 31:455-461.

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

Wiltbank, J. N., W. W. Rowden, J. E. Ingalls, and D. R. Zimmerman. 1964. Influence of post-partum energy level on reproductive performance of Hereford cows restricted in energy intake prior to calving. J. Anim Sci. 23:1049-1053.

Wright, C.K., and M. C. Wimberly. 2013. Recent land use change in the Western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. 110:4134-4139

Table 2.1. Ingredient and chemical composition of total mixed ration (DM-Basis)

	2016	2017	Digestibility
Ingredient, % DM			
Bermuda grass hay, chopped	33.3	33.3	33.3
Dry-distillers grains w/ solubles	32.3	32.3	32.3
Rolled corn	24.1	24.1	24.1
Soybean meal, 47.5% CP	2.6	2.6	2.6
Limestone	2.1	2.1	2.1
Salt	0.5	0.5	0.5
Liquid supplement[1]	5.1	5.1	5.1
Composition, % DM			
	2016	2017	Digestibility
DM, %	90.3	90.2	56.9
CP, %	17.7	17.8	19.6
aNDF, %	36.9	39.8	32.4
ADF, %	20.6	21.8	16.0
Ash, %	7.0	8.4	8.6
TDN, %[2]	71.8	66.6	77.4
GE, Mcal/kg	4.55	4.53	4.48
DE, Mcal/kg	3.27	2.93	3.41
ME, Mcal/kg	2.68	2.40	2.79
NE_m, Mcal/kg[2]	1.76	1.52	1.86
NE_g, Mcal/kg	1.14	0.93	1.22

[1]Liquid supplement contained 15% CP, 0.8% Ca, 0.84% P, 0.57% Mg, 416.2 ppm Cu, 239.6 ppm Fe, 70,500 IU Vitamin A, 2.0% Salt, per kg DM (Quality Liquid Feeds Inc., Dodgeville, WI).

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

Table 2.2. Effects of timing of weaning on primiparous cow feed intake[1], body weight, body condition score, and pregnancy rate

Item	Trt[2] TW	EW	SEM	*P*-Value
N	6	6	-	-
Feed intake[1], g/kg $BW^{.75}$	80.5	52.9	-	-
Cow BW, kg				
January	417	414	65	0.75
March	429	428	14	0.95
April	445	445	12	0.98
Cow BCS[3]				
January	4.7	4.7	0.09	0.82
March	5.0	5.0	0.09	0.84
April	5.1	5.2	0.13	0.25
Pregnancy rate, %	68.9	82.2	6.9	0.18

[1]Feed required to maintain similar BW change
[2]TW = traditional weaning, EW = early weaning
[3]Body Condition Score on a 1(emaciated) to 9 (obese) scale.

Table 2.3. Effects of weaning age on TMR digestibility of lactating (TW) and non-lactating (EW) primiparous beef cows

	Trt[1]			
n = 8	TW	EW	SEM	*P*-Value
DM Intake, kg	7.59	4.99	0.21	<0.01
OM digestibility, %	72.7	73.1	2.03	0.85
GE digestibility, %	74.1	73.3	2.81	0.79
NDF digestibility, %	60.0	61.5	4.21	0.60
ADF digestibility, %	57.7	61.9	5.11	0.51
Fat digestibility, %	89.4	89.4	1.17	0.99

[1] TW = traditional weaning, EW = early weaning

Table 2.4. Milk yield and composition in primiparous beef cows during mid and late-lactation

n = 6	January	February	March	SEM	*P*-Value
Milk yield, kg/d[3]	5.70[a]	7.02[b]	6.85[b]	0.26	<0.01
Milk energy, Mcal/kg[1]	0.68	0.69	0.71	0.01	0.11
Milk fat, %	3.15	3.22	3.33	0.10	0.49
Milk protein, %	2.93	3.05	3.01	0.05	0.19
Milk lactose, %	5.01	4.96	4.97	0.02	0.34
Milk SNF, %[2]	9.13	9.24	9.37	0.09	0.21
MUN, %[2,4]	17.5[c]	15.4[d]	16.3[c,d]	0.56	0.06

[1]Milk energy production (Mcal NE_m), calculated using NASEM 2016 Eq. 13-46: (0.092*%Fat) + (0.049*%SNF) – 0.0569
[2]SNF = solids non-fat, MUN = milk urea nitrogen
[3]Means with differing superscript differ by $P < 0.01$
[4]Means with differing superscript differ by $P < 0.10$

Table 2.5. Effects of timing of weaning on maintenance energy requirements of lactating (TW) and non-lactating (EW) dams

	Trt[1]			
n = 12	TW	EW	SEM	P-Value
ME intake, Mcal	20.4	13.4	15	<0.01
Milk energy, Mcal ME	6.8	0	---	---
Retained energy, Mcal ME	3.1	3.6	81	0.22
Garret, 1980[2]				
Maintenance energy req., ME[3]	113.2	107.3	2.05	0.08
Maintenance energy req., NE_m[4]	75.1	71.4	1.39	0.10
Galyean et al., 2016[5]				
Maintenance energy req., ME[3]	118.2	112.4	2.00	0.07
Maintenance energy req., NE_m[4]	72.9	69.0	1.24	0.06

[1] TW = traditional weaning, EW = early weaning

[2]ME and NE_m determined as $ME = DE \times 0.82$ and $NE_m = 1.37ME - 0.138ME^2 + 0.0105ME^3 - 1.12$

[3] Kcal ME/kg $BW^{0.75}$

[4] Kcal NE_m/kg $BW^{0.75}$

[5]ME and NE_m determined as $ME = 0.9611 \times DE - 0.2999$ and $NE_m = 1.1104ME - 0.0946ME^2 + 0.0065ME^3 - 0.7783$

Table 2.6. Effects of weaning age on energy intake, performance and feed efficiency

	Trt[1]			
n = 12	TW	EW	SEM	*P*-Value
Calf Age, d				
d 0 [2]	131	129	-	-
d 96 [3]	227	225	-	-
Cow energy intake, cumulative Mcal ME	2032	1338		
Calf energy intake, cumulative Mcal ME				
TMR	1031	1231	31	<0.01
Milk	649	---	---	---
Total	1680	1231	36	<0.01
Pair cumulative Mcal TMR ME	3063	2521		
Calf BW, kg				
January	114.5	107.4	1.8	0.02
April	238.2	202.6	5.2	<0.01
Calf ADG, kg	1.32	1.01	0.02	<0.01
Calf BW gain, kg	123	95	4.2	<0.01
G:F				
Calf TMR G:F[4]	326	207	6.6	<0.01
Pair G:F[5]	109	99	2.4	<0.01
G:Energy Intake				
Calf total G:EI[6]	73.2	77.2	2.5	0.11
Pair G:EI[7]	40.2	37.0	0.85	<0.01

[1] TW = traditional weaning, EW = early weaning
[2] Age of early weaning across both years.
[3] Age of traditional weaning across both years.
[4] Calf BW gain in grams · kg of calf TMR intake^{-1}
[5] Calf BW gain in grams · kg of TMR intake of the pair^{-1}
[6] Calf BW gain in grams · Mcal of calf TMR intake and milk intake^{-1}
[7] Calf BW gain in grams · Mcal of pair TMR intake^{-1}

Table 2.7. Effects of weaning age on calf BW gain during growing period

	Trt[1]			
n = 12	TW	EW	SEM	*P*-Value
Calf BW, kg				
April	237	216	5.3	<0.01
August	301	290	3.7	0.06
Calf ADG, kg				
d 96 – d 218	0.52	0.60	0.04	0.03
Total Calf BW gain, kg	64	74	3.5	<0.01

[1] TW = traditional weaning, EW = early weaning

Table 2.8. Effects of weaning age on steer finishing period performance

	Trt[1]			
n = 12	TW	EW	SEM	*P*-Value
Calf BW, kg				
August	313	293	11.0	<0.01
November	498	476	16.3	<0.01
January	596	579	8.9	0.02
DMI, kg/d				
d 218 – d 303	7.56	9.38	0.90	0.05
d 303 – d 389	9.07	10.05	0.59	0.21
d 218 – d 389	8.30	9.70	0.74	0.09
Calf ADG, kg				
d 218 – d 303	2.18	2.16	0.04	0.70
d 303 – d 389	1.18	1.24	0.20	0.40
d 218 – d 389	1.68	1.70	0.09	0.55
Calf G:F[2]				
d 218 – d 303	0.301	0.236	0.03	0.07
d 303 – d 389	0.131	0.124	0.02	0.30
d 218 – d 389	0.205	0.176	0.03	0.06
Total Calf BW gain, kg	283	286	3.9	0.54

[1] TW = traditional weaning, EW = early weaning

[2] Kg calf BW gain · kg of feed intake^{-1}

Table 2.9. Effects of weaning age on steer carcass characteristics

	Trt[1]			
n = 12	TW	EW	SEM	*P*-Value
HCW, kg	370	364	18.3	0.19
Dressing percentage	61.74	61.77	0.82	0.97
Back fat, cm	1.40	1.52	0.30	0.44
REA, cm^2	84.4	83.2	3.87	0.81
Yield Grade[2]	3.16	3.29	0.40	0.74
Quality Grade[3]	494	485	28.7	0.58
≥Low Choice, %	90.9	95.7	---	0.53
≥Ave Choice, %	40.9	52.2	---	0.45

[1] TW = traditional weaning, EW = early weaning

[2] Calculated yield grade

[3] 400 – 499 = small, 500 – 599 = modest

APPENDICES

Appendix A. Summary of treatments means of four different methods utilized to calculate apparent digestibility

Method	Year	Treatment	Digestibility, %
ADIA	2016	TW	86.3
		EW	93.8
	2017	TW	78.2
		EW	86.9
	Avg.	TW	82.3
		EW	90.4
iADF	2016	TW	52.5
		EW	66.1
	2017	TW	59.7
		EW	65.0
	Avg.	TW	56.1
		EW	65.6
Performance calculated	2016	TW	68.0
		EW	71.0
	2017	TW	68.5
		EW	74.2
	Avg.	TW	68.3
		EW	72.6
In vivo trial	2018	TW	73.5
		EW	73.1

Appendix B. Raw digestibility data utilized in determining apparent digestibility through two different marker methods

Method	Year	Trt	Rep	ADF, %	Marker, %	Digestibility, %
ADIA	2016	Feed		21.40	1.01	
		TW	1	33.91	10.09	90.13
			2	35.24	11.59	91.71
			3	30.23	5.85	76.99
		EW	1	36.90	16.09	93.53
			2	43.05	26.19	96.56
			3	37.93	12.13	91.37
	2017	Feed		21.05	1.537	
		TW	1	27.37	6.30	77.02
			2	34.84	11.76	84.63
			3	28.42	5.20	73.04
		EW	1	31.79	12.07	87.08
			2	34.68	10.38	86.56
			3	30.80	10.99	86.91
iADF	2016	Feed		40.11	13.42	
		TW	1	41.82	30.22	55.40
			2	41.42	30.30	55.64
			3	39.74	25.08	46.46
		EW	1	44.24	37.70	64.39
			2	48.84	48.40	72.25
			3	41.54	35.04	61.62
	2017	Feed		39.88	10.85	
		TW	1	40.46	26.71	59.22
			2	42.17	30.40	64.28
			3	41.58	26.52	55.51
		EW	1	42.69	32.43	66.55
			2	41.21	28.02	61.28
			3	43.06	33.24	67.30

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