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Optimal Calving Time for Beef Cows in Southwest Missouri

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OPTIMAL CALVING TIME FOR BEEF COWS IN SOUTHWEST MISSOURI

A Master's Thesis

Presented to

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In Partial Fulfillment

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Master of Science, Agriculture

By

Briana Rose VerPloeg

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ABSTRACT

The purpose of this study is to determine if a optimal time of year exists for beef producers to have cows give birth in southwest Missouri for maximal net returns from calf sales and increased cow reproductive performance. To make this determination, data were collected which included year-round forage nutritive value, calf pre-weaning growth, cow energy efficiency and reproductive performance, and income and cost values. Cow and calf field data were gathered for the 2014-2018 production years at Missouri State University's Leo Journagan Ranch. Monthly forage samples were collected from study cow pastures from 2016 through 2018. Calf, cull cow, and hay prices for 2014 through 2018 were recorded from USDA Market News Archives. The Cattle Value Discovery System model was used to predict cow energy efficiency and requirements based on cow and calf performance and feed and forage inputs. Cow/calf pairs were grouped for comparison by calving month. Bull calves had greater BW, WW, and sale value than heifer calves, and cows with bull calves had greater energy requirements and milk production and better cow energy efficiency. Calves born January through May had heavier BW than calves born August and September. Calves which had the greatest weaning age (January, August, and September) also had the greatest WW, and the youngest calves at weaning (April, May) had the lightest WW. However, 205-d adjusted WW were not different between months. Cows that calved in September and October had greater BCS at calving than cows that calved in January through April; however, Weaning BCS were not significantly different between calving months. Pregnancy rate and CI were not consistent for particular times during the year, but significant differences were observed between some months. No significant differences were observed for energy for maintenance or total energy, but energy for pregnancy was lesser for cows that calved in August and September than calved January through May and October. Cows that calved in January through March had greater MEL than cows that calved in May, June, and August through November. In both EEI categories, September calving cows had significantly more desirable EEI than some months, and May calving cows significantly less desirable EEI than some months. Cows that calved in January through May had greater peak milk yields than cows that calved August through October. Calves born in September had the greatest sale value and, along with January, the greatest net returns.

KEYWORDS: beef cattle, calving season, ruminant nutrition, metabolizable energy efficiency, seasonal economics

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I dedicate this thesis to my grandparents, Junior and Joyce VerPloeg and Richard and Karen Rankin, who made their livelihoods raising crops, cattle, and hogs; and to all farmers who continue to feed the world.

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INTRODUCTION

Justification for the Study

In a world with an ever increasing population, the provision of an adequate food supply is a constant concern. According to the United States Census Bureau (2020), the world population in 2020 is over 7.6 billion, and the population of the United States is close to 330 million. The agriculture industry feeds the mass of humanity; however, the number of farms and land involved in agriculture is continually decreasing. Since 1999, the number of farms in the United States has decreased by 6.6% and the land in farms by 5% according to summaries by the National Agricultural Statistics Service (NASS; 2011, 2019). Technology and biological advances have improved production yields, enabling more products to be produced by fewer individuals and on less land. Due to expanding urbanization, it is increasingly important to make best use of natural resources by employing methods which will have minimal impact on the environment and be profitable while still meeting food supply needs.

Beef production is an agricultural industry which can be performed with minimal impact on natural land. Cattle are able to convert cellulose of native plants into meat for human consumption. Additionally, land which is not conducive to crop farming can often be utilized as cattle pasture with little to no development. While many beef cattle are finished in a feedlot setting, most calf-birthing operations house livestock on pasture and utilize the regenerating natural resource of native flora as the primary feed source for cows. The terrain in Southwest Missouri is generally hilly with rocky, shallow soil which does not support crop farming but grows forages on which cattle can thrive. As a result, Missouri had the third largest beef cow inventory in the United States as of 2019, exceeded only by Oklahoma and Texas (NASS, 2020).

Cow reproductive performance, nutrient requirements, and calf growth can all be affected by forage availability and quality and weather which change throughout the year (Beede and Collier, 1986; Birkelo et al., 1991; Provenza, 1995; Moore and Jung, 2001). Cow nutrient requirements are greatest during late gestation and early lactation (NASEM, 2016). Cow and calf performance often suffer if nutritional needs are not met, which may incur additional costs for feed or replacement cows, or calves may be lighter at weaning and, thus, bring less revenue when sold. Aligning periods of increased forage growth with periods of increased cow requirements reduces supplemental feed costs (Sprott, 2001). However, climatic temperatures may have negative effects on intake and/or energy requirements and, therefore, performance (Degen and Young, 1981; Fuquay, 1981; Beede and Collier, 1986; Monteiro et al., 2016; Nabenishi and Yamazaki, 2017). Additionally, prices for weaned calves fluctuate throughout the year due to supply and demand and may cause variance in net returns.

Studies have been conducted comparing calving seasons to determine if differences in performance arise based on timing of parturition. It is of note that results of studies vary based on location. Studies performed in northern locations showed better success when calves were born in late spring to early summer (Deutscher et al., 1991; Pruitt et al., 2003; Reisenauer Leesburg, 2007). Alternatively, studies performed in southern locations showed greater benefit when calves were born in the fall (Bagley et al., 1987; Payne et al., 2009). Results for studies in either northern or southern locations are likely influenced by the timing of temperature extremes and forage growth. However, the central United States is generally more temperate which enables growth of both cool- and warm-season forages which allows for a long period of forage productivity. Consequently, study conclusions for locations in the central United States tend to

be less polarized and vary as to the most beneficial timing for calving season (Smith et al., 2012; Caldwell et al., 2013; Campbell et al., 2013).

Problem Statement

In order for beef producers to continue in this industry, revenue must not only exceed costs but provide net returns sufficient to support them and their families. Timing of calving season may have an effect on cow and calf performance as well as net returns. However, more research in the central United States is necessary to conclude how timing of calving season affects performance and net returns.

Objective and Null Hypothesis

The objective of this study is to determine the productivity and net returns of beef cow-calf operations based on the time of year cows give birth. The null hypothesis is that the time of year when calving season occurs has no effect on cow/calf performance or net returns.

LITERATURE REVIEW

Forage Classifications

Native forages grown for livestock production vary by region and climate. The vast majority of common forages are categorized as either grasses or legumes and having either a cool-season or warm-season growth pattern. Forage types vary in growing season and nutritional value; therefore, a balanced grazing pasture will contain a variety of forage types to maximize grazing year-round. Cool-season and warm-season species are categorized as either C_3 or C_4 species. Species of C_3 and C_4 differ in nutritional value, the conditions under which they thrive, and how they are digested in the gastrointestinal tract of grazers.

Cool-Season vs. Warm-Season Species. Forage species are classified as either cool-season or warm-season plants. This classification refers to the growth pattern exhibited by species with cool-season plants capable of growing in cooler temperatures than warm-season plants. This difference in temperature preference for growth is caused by variation in the photosynthetic pathway of cool-season plants (also known as C_3) and warm-season plants (also known as C_4).

Examples of cool-season grasses include Fescue (*Festuca arundinacea*), Timothy grass (*Phleum pretense*), and Orchardgrass (*Dactylis glomerata*). Maximum growth rates for cool-season grasses occur between twenty and twenty-five degrees Celsius (Figure 1); however, growth can be observed at temperatures as low as 0ºC (Regehr and Bazzaz, 1976; Heath et al., 1985). As a result, locations with cooler climates have a greater concentration of native C_3 forages than native C_4 forages (Cabido et al., 1997). Cool-season grasses have a lesser tolerance for water stress than warm-season grasses and require a consistent water presence for continued

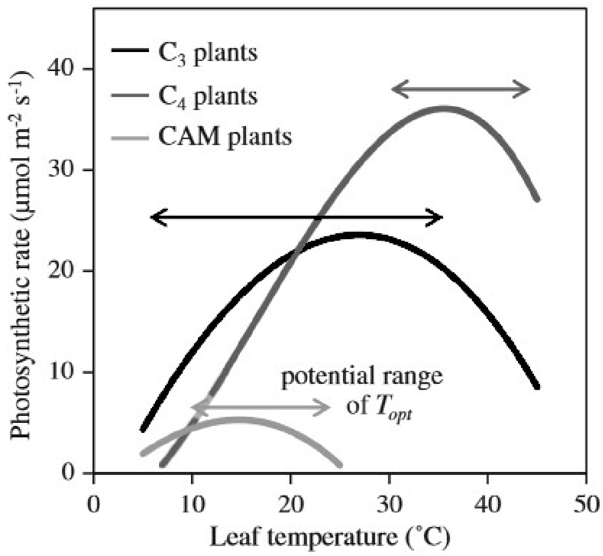

Figure 1. Photosynthetic rate of C3 and C4 species in reaction to temperature (citation *Temperature Response of Photosynthesis in C3, C4, etc.*, Yamori et al., 2014)

growth (Nayyar and Gupta, 2006). Cool-season grasses have greater crude protein content and are, therefore, generally considered to be of greater nutritive value. Cool-season grasses are able to store excess carbohydrates in the form of the fructose polymer fructan which is metabolized by enzymes that remain functional at cooler temperatures than enzymes for starch metabolization, possibly contributing to C_3 adaptation to cooler temperatures (Chatterton et al., 1989).

Warm-season grasses, which are usually C_4 species, begin optimal growth at temperatures reaching approximately 25ºC and have little tolerance for low temperatures such as are favored by cool-season grasses (Teeri and Stow, 1976; Bunce, 2000; Figure 1). Unlike cool-season grasses, warm-season grasses experience increased photosynthesis and growth during temperatures reaching to 40ºC before growth reduction is observed (Heath et al., 1985; Monson and Jaeger, 1991). Species in the C_4 categorization are adaptable to increased temperatures and solar radiation. In addition to differences in optimal temperatures for growth, root systems of C_4 species grow deeper into the soil than C_3 species', giving C_4 plants a greater drought tolerance (Heath et al., 1985). Warm-season grasses' affinity for increased temperatures combined with the ability to grow in restricted water conditions makes them stable forages for hot climates with little rainfall. Bermuda (*Cynodon dactylon*), Switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*) are common examples of warm-season forages. However, C_4 species tend

to have greater stem to leaf ratios and be of a lesser nutritive value. Although protein content is lesser, warm-season forages have greater levels of RUP which is digested slowly and more efficiently (Mullahey et al., 1992). Carbohydrates in warm-season forages are stored as starches amylose and amylopectin which are less-digestible energy sources than fructosan stored by cool-season forages (Mundee, 1999).

Classifying plants as C_3 and C_4 is derived from the carboxylic acid initially synthesized from CO_2 during photosynthesis. Species with a photosynthetic pathway producing 3-phosphoglyceric acid (Figure 1) are categorized as C_3. The enzyme, Rubisco, utilized for photosynthesis is capable of re-synthesizing CO_2 which can then be released back into the environment via photorespiration. Photorespiration increases with temperature, causing efficiency of CO_2 utilization to decrease in C_3 species at greater temperatures. In contrast, C_4 species add a step to the process by first utilizing the enzyme Phosphoenolpyruvate (PEP) carboxylase to fix CO_2 as HCO_3 which is then transformed by Rubisco into oxaloacetate (Figure 2) , a 4-carbon acid, hence the name C_4. Oxaloacetate diffusion is restricted to interior leaf cells causing the C_4 process to be more efficient by limiting photorespiratory CO_2 release (Ehleringer and Cerling, 2002).

Grasses vs. Legumes. Most forage legumes have a C_3 photosynthetic pathway but some are more adaptive and similar to C_4 type. Alfalfa (*Medicago sativa*), for example, can begin photosynthesizing at 0°C, has optimum growth between 5°C-30°C, and does not reduce photosynthetic rate until 35°C (Heath et al., 1985). Many legumes will germinate and grow over a wide variety of temperatures although

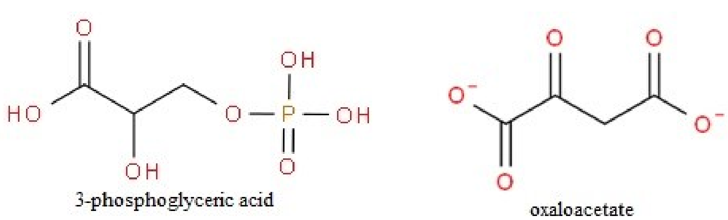

Figure 2. Molecular structures of 3-phosphoglyceric acid and oxaloacetate

optimal growth temperatures differ between legume species with some preferring cool temperatures, such as white clover (*Trifolium repens*), and other species functioning as warm-season, like lespedeza (Whiteman, 1968; Smith, 1970; Dart and Day, 1971). Legumes are more concentrated in protein compared to grasses. Crude protein concentrations for forage legumes range from 20% to 31% while grass pasture ranges from 8% to 22% crude protein (Diary One, 2019). The majority of crude protein is found in leaves. In a three-year study, Mowat et al. (1965) found that alfalfa leaves contain 2 ½ to 3 times the protein found in stems compared to various grasses which contained twice as much protein in leaves as in stems. Unlike grasses which store excess carbohydrates from photosynthesis above ground, legumes store extra carbohydrates in plant roots. Since legumes have a greater stem percentage than grasses, having excess carbohydrates stored below ground is advantageous for re-growth after leaf cover has been removed which limits the plant's ability to photosynthesize.

Forage Quantity Factors

Quantity of forage changes depending upon the growing season of the forage species present in a given pasture. Forage quantity is also affected by grazing intensity and water availability. In order to optimize grazing, pastures should contain forage species from both the cool-season and warm-season groups to ensure adequate forage for a greater portion of the year (Figure 3) .

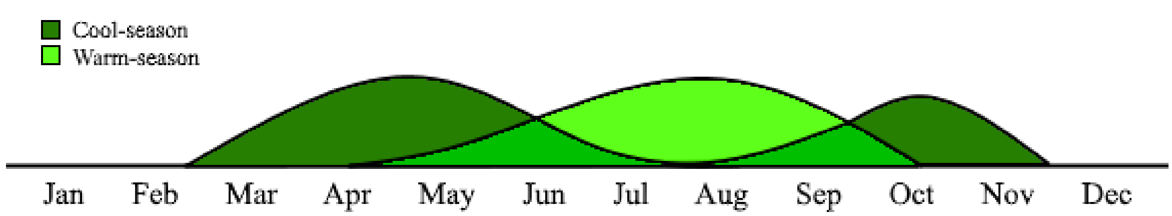

Figure 3. Seasonality of warm and cool season forage productivity

Temperature. The growing season for cool-season forages in temperate climates usually begins in early spring when minimum temperatures are around 5ºC. Growth for these species will continue until temperatures exceed 25ºC at which point growth of cool-season species will decrease. Cool-season forages will renew growth in late summer or fall when temperatures no longer exceed 25ºC and continue until temperatures approach 0ºC. Warm-season forages begin growth in early summer but only minimally before temperatures reach 15ºC (Heath et al., 1985). Unlike cool-season species, warm-season forages thrive under hot temperatures and will continue to grow despite and even as a result of the heat of summer. Warm-season species' ability to flourish during greater temperatures fills the gap in productivity of cool-season species during the hottest summer months.

Water Availability. In the mid-western United States, spring and fall are usually the times of year that receive the most rainfall which is beneficial to the growth of cool-season species that are more dependent on soil moisture than warm-season species. Alternatively, in these latitudes warm-season species grow best during summer when temperatures are warmer and are less affected by typically lower soil moisture. Pastures containing both cool and warm season species can provide nutrients to grazing animals throughout the year.

Forage Quality

Observed animal performance and animals' willingness to consume a forage are used to determine the quality of a forage (Heath et al., 1985). Factors affecting quality can be chemical or physical and include plant species, leaf to stem ratio, maturity, land management, and weather.

Leaf-to-Stem Ratio. Leaf to stem ratio refers to the quantity of leaves compared to that of stem. Plants carry more digestible nutrients in leaves than stems, if compared within the same plant species (Mowat et al., 1965; Arzani et al., 2004). As a result, leafier plants are considered better quality than forages with a greater stem to leaf ratio when plant type and overall nutrient content are equal. For example, a legume that has had its top cover of leaves grazed off will have lesser nutritional value than the same legume that has not been grazed. However, a grazed legume may still have greater nutritional value than ungrazed grass since legumes are generally better quality than grasses overall. Plant maturity must also be considered since it affects the leaf-to-stem ratio (Arzani et al., 2004). A legume at a later maturity stage may be a lesser quality than, for example, a warm-season grass that is in an early stage of maturity and greater leaf growth.

Plant Maturity. Forage quality of a plant changes as the plant progresses toward maturity. As a plant moves through the maturation process, leaf to stem ratio will shift toward more stem and, therefore, overall decreased digestibility and protein content (Mowat et al., 1965; Mullahey et al., 1992). Additionally, as plants mature, lignin concentration in the cell wall increases causing thickening of cell walls and decreased access to the encased soluble nutrients (Belyea et al., 1993; Figure 4). Increases in lignin concentration are directly correlated to a decrease in both cell wall and overall dry matter digestibility and (Jung and Vogel, 1986). Consequently, as plant maturity progresses and lignin content increases,

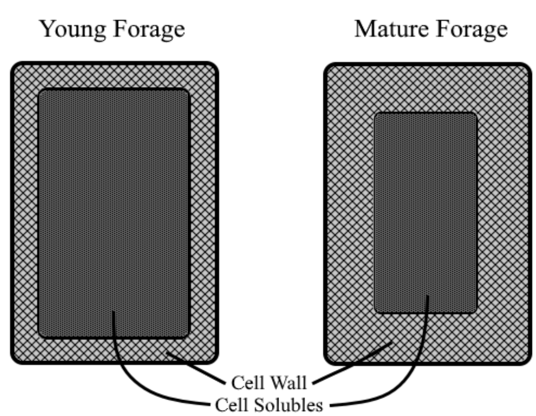

Figure 4. Relationship between maturity stage and cell wall concentration (From Belyea et al., 1993)

nutritive value of forages decrease (Van Soest, 1994).

The three major stages of plant maturation are vegetative, reproductive, and seed development. Vegetative, the earliest stage, is the period when forages have their greatest nutritive value. During this time, the plant primarily grows leaf to increase photosynthetic ability. The second growth stage is the reproductive stage which includes floral development, and the final maturity stage is seed development. Forage quality decreases in the later maturity stages as more stem is produced and lignin concentration is increased in cell walls to increase rigidity of the stem for supporting reproductive structures (Grabber et al., 1992). Conrad et al. (1962) studied the effects of maturity on dry matter digestibility, nutrient intake, and milk production in dairy cows by feeding alfalfa-grass forages of progressing maturity dates. They found that dry matter digestibility decreased by approximately two percentage units per week, and a marked decrease in milk production was also observed (Table 1). Decreased digestibility and production are synonymous with a decrease in crude protein and increase in less soluble neutral detergent

Table 1. Effects of alfalfa maturity on dry matter (DM) digestibility and milk yield

Cutting Date	DM Digestibility, %	Digestible DM, kg/ha	2nd & 3rd Cutting DM, kg/ha	Theoretical Milk Yield, kg/ha
May 17	66.5	360	958	1521
May 24	65.0	366	936	1417
May 31	62.5	408	846	1360
June 7	60.5	456	874	1378
June 14	58.5	457	846	1326
June 21	56.6	438	861	1282
June 28	55.0	438	461	1138

(Adapted from Conrad et al., 1962)

and acid detergent fibers as well as lignin in both legumes and grasses as can be seen in Table 2 (Rohweder et al., 1978).

Grazing Management. Forage quality can be manipulated by management practices including grazing system and stocking density. Rotational grazing is a practice used to manage forage quality and production by rotating grazing herds between multiple pastures as opposed to continuously grazing a herd on a single large plot of land. Stocking density is a collective measure of the number of animals on a specified amount of land for a particular length of time and is often greater in rotational grazing systems than continuous grazing systems. The theory behind rotational grazing is that by increasing stocking density (and therefore, grazing intensity) for temporary and reduced periods of time, land utilization can be more efficient. In addition, frequent movement can increase pasture uniformity by preventing livestock from spot grazing. This controlled forage harvest by livestock encourages universal forage regrowth and prevents overgrazing of only particular plant species. When the desired forage height or time span has been reached, cattle are moved to the next plot and the initial plot allowed to regrow high quality immature forage for grazing when the herd is returned. The goal in comparing rotational grazing

Table 2. Crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) content in alfalfa and grasses at various maturity stages

	Alfalfa			Grass		
Maturity	CP	ADF	NDF	CP	ADF	NDF
Bud/Boot	>19	<31	<40	>18	<33	<55
Mid-bloom/Head	17-19	13-35	40-46	13-18	34-38	55-60
Full bloom/Milk	13-16	36-41	46-51	8-12	39-41	61-65
Post bloom	<13	>41	>51	<8	>41	>65

(Adapted from Rohweder et al., 1978)

to continuous grazing is to determine which practice, if either, is superior for improving land sustainability, forage quality, or livestock performance.

Effects on Soil and Forage. Grazing method and stocking density can affect land sustainability by influencing soil durability and diversity of plant species. Regardless of whether a plot is rotationally or continuously grazed, low stocking levels have less negative effect on soil and plant growth than heavy stocking density (Brisk et al., 2008). Heavy stocking rates for an extended period of time can result in soil packing from heavy trampling, causing reduction in water permeation and increased run-off (Warren et al., 1986; Milton et al., 1994). Prolonged heavy stocking can also cause overgrazing of forage, reducing the organic matter layer which helps retain soil moisture and damaging plants' ability to regrow which may allow less desirable plant species to outgrow desired forages (Schwan et al., 1949; Milton et al., 1994).

Moderate stocking or temporary high intensity grazing by a rotational grazing system can benefit forage quality by encouraging consistent plant regrowth which increases forage quality and preventing excessive organic layer ground cover which may hinder precipitation from reaching the soil (Schwan et al., 1949; Georgiadis and McNaughton, 1990). Forage collected from rotationally grazed pastures with higher stocking rates were found to be of greater quality with better digestibility and greater concentrations of crude protein and minerals (Walton et al., 1981; Heitschmidt et al., 1987). Heitzchmidt et al. (1987) also observed amounts of live forage to be the same for both the rotational and continuous grazing treatments despite continuously grazed pastures having greater total forage accumulation; however, these differences were suggested to be caused by differing stocking rates (3.7 ha/cow for rotational grazing versus 5.9 ha/cow for continuous grazing).

Effects on Performance and Returns. Although not a direct contributor to animal performance, grazing management can affect animal performance by affecting forage quality and availability. In a six-year study, Heitschmidt et al. (1990) observed that cows in moderately stocked pastures achieved better conception rates, percent calves weaned, and greater average weaning weight and returns per cow than heavily stocked pastures regardless of whether pastures were continuously or rotationally grazed. Walton et al. (1981) observed total weight gain and kilograms gained per hectare to be greater from rotational grazing treatments than from continuous grazing treatments.

However, many studies are unable to definitively declare which method of grazing, rotational or continuous, is the superior method (Laycock and Conrad, 1981; Pitts and Bryant, 1987; Hart et al., 1988). In review of rotational grazing, Briske et al. (2008) compiled results from an extensive number of studies evaluating grazing systems to summarize effects on plant productivity and livestock production per head and per land area. Overall, grazing method appears to have no significant difference on plant production regardless of stocking density. If stocking densities are equal for both rotational and continuous grazing treatments, production per head or land area are not significantly different. However, if stocking density of continuously grazing groups is less than that of rotating groups, continuously grazing groups often had greater livestock production per head while rotating grazing groups had greater livestock production per area. Studies by Walton et al. (1981) and Heitschmidt et al. (1990) agree with Briske et al.'s (2008) conclusion that rotational grazing appears to make most efficient use of land when considering weight produced and returns per land area.

Nutritional Elements of Feed

When determining forage quality, nutritional elements that should be reviewed include crude protein (CP), energy (carbohydrates), and crude fat. Total digestible nutrients (TDN) refers to the summation of the beneficial attributes of a feedstuff which are necessary to the animal diet including digestible fiber, protein, lipids, and carbohydrates. Total digestible nutrients is a measure of the energy value of a feed and is often calculated from acid detergent fiber content (Cullison and Lowrey, 1987; Lemenager et al., 2011). Digestible dry matter (DMD) is a measure of dry matter components that can be digested by livestock. Values for TDN and DMD are nearly synonymous except TDN only measures nutrients with energy potential. For example, absorbable mineral counts toward DMD value for the characteristic of simply being digestible; however, minerals do not have an energy value and so would not be considered in TDN values (Cullison and Lowrey, 1987).

Crude Protein. Protein content is one of the most important factors influencing forage quality. Proteins are made of amino acids. Amino acids are categorized as either "essential" or "non-essential". Microorganisms present in the rumen are able to synthesize many amino acids. Essential amino acids are necessary to the diet but cannot be synthesized in the amounts required unless acquired through feed. Non-essential amino acids can be synthesized in adequate amounts by microorganisms for host use from other amino acids. (Cullison and Lowrey, 1987)

In ruminants, protein can be digested in the rumen, known as rumen digestible protein (RDP), or in the small intestine, known as rumen undegradable protein (RUP or bypass protein; Pastor, 2016). Rumen digestible protein is broken down in the rumen by microbes into amino acids and ammonia which the microbes then utilize to form microbial proteins. Microbial protein and intake protein not degraded in the rumen passes out of the rumen in to the small intestine

where it is broken into amino acids to be absorbed through the mucosa into the blood stream. Bypass protein is more efficient than RDP since amino acids are absorbed directly by the animal. Fermentation of RDP requires energy expenditure for microbial breakdown of amino acids and synthesis into microbial proteins. As rumen microbes are passed into the more caudal regions of the gastrointestinal tract, they are digested and the amino acids absorbed. Animals at a greater level of performance, such as cows in early lactation, can struggle to maintain body condition on a diet concentrated in RDP that doesn't contain adequate energy. A study by Garrett (1970) reported that beef heifers fed a 21% CP diet required an average of 20% more feed to maintain energy equilibrium than heifers fed a 12% CP diet. This phenomenon is caused by the increased use of energy to metabolize amino acids in the rumen (Reid, 1974). However, diets deficient in CP caused decreased feed intake as microbial fermentation slows due to lack of available nitrogen from RDP (Provenza, 1995). Köster et al. (1996) found that cows fed low-quality forage (1.9% CP) increased intake when supplemented with increasing amounts of an RDP infusion to a limit. Consequently, forage quality is determined not only by CP concentration, but a balance between RDP and RUP for efficient metabolism based on performance requirements.

Carbohydrates. Livestock require energy to utilize proteins for growth and to maintain homeostasis. Energy can be acquired from excess protein in the diet; however, intentionally using protein as an energy source would become expensive and inefficient. Carbohydrates are an efficient source of energy and can be obtained from a variety of sources. Carbohydrates are fermented by microbes in the rumen to produce volatile fatty acids (VFA). Volatile fatty acids are absorbed across the rumen wall directly into the hepatic portal system and provide about 70% of ruminant energy (Moran, 2005).

The main precursors to VFA in ruminant diets are non-structural carbohydrates (NSC) which include sugars, fructans, starches, and structural carbohydrates in the form of fiber. With the exception of some insoluble starches, NSC are exceptionally soluble and 90%-100% are digested in the rumen (Van Soest et al., 1991). Grains contain substantial concentrations of NSC. Since forages contain greater concentrations of fiber; therefore, grazing cattle obtain a large portion of their energy from structural carbohydrates. Fibers are less effective than NSC due to decreased solubility. Greater levels of fiber, particularly those with low digestibility, decrease intake due to undigested feed taking longer to pass out of the rumen, causing the animal to feel physically full and reduce intake (Caton and Dhuyvetter, 1997, Moore and Jung, 2001). Fiber content is measured using neutral detergent fiber (NDF) and acid detergent fiber (AFD). Neutral detergent fiber content of forages is negatively correlated with dry matter intake. Neutral detergent fiber is a measure of total plant fiber content including cellulose, hemicellulose, and lignin and is the best chemical predictor of dry matter intake (Van Soest, 1965; Waldo, 1986). Acid detergent fiber is similar to NDF except that it doesn't include hemicellulose but does include ash and can be used to estimate TDN of forages (Van Soest, 1965; Belyea, 1993).

The least digestible source of fiber is lignin. Lignin is a major component of plant cell walls, that provides structural support and rigidity to plants. As plants mature, lignin concentration increases in the plant cell walls decreasing forage digestibility by crosslinking cellulose and hemicellulose fibers and decreasing hydrolysis by rumen microbes (Jung, 2012). On a dry matter basis, lignin concentrations between legumes and grasses are similar; however, lignin digestibility differs between legumes and grasses. Although legumes contain more lignin than grasses, they have greater total DM digestibility due to lesser overall NDF content even though the digestibility of NDF in legumes is less than in grasses. Conversely, grasses have

greater total fiber concentrations than legumes and are less digestible overall, but have greater NDF digestibility (Buxton and Russell, 1988). Figure 5 illustrates the relationship between fiber digestibility and lignin proportion of fiber in grasses and legumes. This seeming contradiction to lignin's negative effect on digestibility indicates an influence of cell wall structural differences between legumes and grasses (Jung and Vogel, 1986).

Fats. In addition to excess protein and carbohydrates, ruminants also obtain energy from fats. Fat content in feed is commonly referred to as crude fat. Crude fat, also known as ether extract, equals the portion of feed that is soluble in ether. Fats provide 2.25 times more energy per kilogram than carbohydrates and can be an excellent diet addition for livestock at demanding performance levels. However, this relationship is quadratic in that it comes with a threshold at which increased fat diets can cause depressed digestibility of fat and fiber as well as have negative effects on fat absorption (Moore et al., 1986; Palmquist, 1991). Saturated fats are less detrimental than unsaturated fats since their greater melting point lessens adherence to fibrous contents in the rumen which would block microbial digestion and has less toxic effect on rumen bacteria (Harvatine and Allen, 2005). Many studies have explored the effects of fat supplementation on dairy cows which perform at a consistently high level of production and consume diets high in concentrates. Fat not exceeding 5% is beneficial to dry matter intake and milk production and quality (Palmquist and

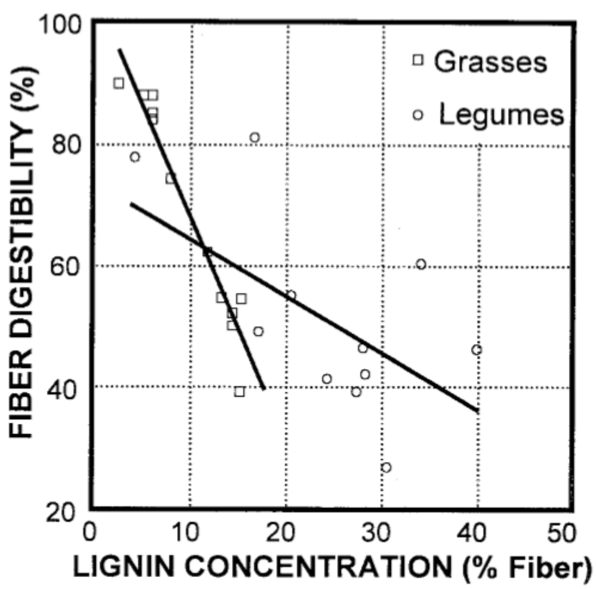

Figure 5: "Relationship between lignin concentration of fiber and fiber digestibility in legumes and grasses" (Moore and Jung, 2001)

Jenkins, 1980; Palmquist, 1991). Moore et al. (1986) studied the effects of fat addition for steers fed an increased-forage diet. In this study, fat supplementation was added in 2%, 4%, and 8% of dry matter. Increases in intake and digestibility were observed except in the 8% fat treatment which agrees with other studies showing that fat supplementation of 2-4% can increase forage intake, but greater concentrations of fat in diets depress intake and digestibility (Erwin et al., 1956; Moore et al., 1986; Brokaw et al., 2000; Leupp et al., 2006). Fat absorption also decreased dramatically when fat intake exceeded 600g/d (Moore et al., 1986). After comparing results from high-forage diets with supplemental fat, Hess et al. (2008) concluded cattle on high-forage diets should receive a maximum of 3-4% fat in the diet to maintain diet efficiency while providing additional dietary energy. Fats are a beneficial part of ruminant diets by helping provide energy to increase performance without loss of body condition.

Vitamins and Minerals. Vitamins and minerals are diet components that are required in small quantities; however, they are essential for basic to complex body functions including nerve transmission, bone development, metabolism, reproduction, etc. (Greene, 2016). Vitamins are composed of mostly organic elements including carbon, hydrogen, oxygen, and nitrogen. All other elements required in the diet are usually referred to as the inorganic or mineral elements. Minerals are divided into two categories: macrominerals which include calcium, phosphorus, magnesium, sodium, potassium, chlorine, and selenium, and the microminerals which encompass all other necessary inorganic elements required in parts per million or billion of the diet.

For cows on pasture, most vitamin and mineral requirements can be satisfied through diet or, in the case of some vitamins, synthesis (Cullison and Lowrey, 1987). In a grazing diet, these elements are generally acquired from plants which obtain them from the soil. Mineral uptake can be affected by factors such as soil moisture, temperature, and nutrient leaching. Soil pH and pH

variations can affect which minerals are absorbed by plants (Smart et al., 1981). Temporary changes causing dietary supply to fall below requirements can be buffered by cattle's ability to store some excess vitamins and minerals in body tissues (Greene, 2016). However, deficiency can have severe consequences if supplementation is not provided. Dietary requirements can vary between breeds, productions stages, and season of the year (NASEM, 2016).

Cow Nutrition

Formulation of a nutrition program for beef cows must be approached differently than that of growing cattle. Cows are unique in that they must not only maintain themselves, but also provide for a growing calf both during gestation and post-parturition by providing milk. Nutritional requirements change over the course of the breeding season as the cow prepares to be bred, carries a calf through gestation, and finally begins producing milk. Physiological state or level of production has the greatest influence on changes in the nutritional requirements of cows. The basic production levels of beef cows are maintenance, gestation, and lactation. Maintenance is the state of a cow not pregnant or lactating but simply maintaining current body condition and is the base from which a diet is built. Gestation is the time period when a cow is pregnant, and lactation refers to the time a cow produces milk for the nursing calf. Nutrients which fluctuate significantly in response to the production cycle include energy, protein, calcium, and phosphorus (Table 3).

In experimental studies, units often used to measure or compare changes in energy requirements are total digestible nutrients (TDN), which is measured as a percentage of weight, or metabolizable energy (ME) or net energy (NE), which are measured in kilocalories (kcal) or Megacalories (Mcal). Energy can be obtained from multiple nutrient sources including protein,

Table 3. Production cycle nutrient requirements for mature pregnant, lactating cows

	Early lactation	1st trimester	2nd trimester	3rd trimester
Net energy, Mcal/d	15.7	13.8	12.4	15.0
Protein, g/d	813	665	543	620
Calcium, g/d	35	27.8	20.8	30.3
Phosphorus, g/d	23.1	19.1	15.1	18.5

(Adapted from NASEM, 2016)

carbohydrates, and fat. Energy is the driving force for production and, therefore, receives much consideration when formulating diets.

Factors Affecting Maintenance Requirements. Maintenance requirements are estimated to consume over 70% of metabolizable energy intake in pregnant lactating cows (Ferrell and Jenkins, 1985; Klosterman and Parker, 1976; Neville and McCullough, 1969). The amount of maintenance energy needed in a non-pregnant, non-lactating cow's diet will cause neither increase nor decrease to current body condition while allowing the body to fulfill essential functions. Maintenance energy requirements vary between individuals based on size, weight, age, physiological state, environmental conditions, and genetics.

Physical Characteristics. Larger framed and heavier cows have greater maintenance requirements than smaller, lighter cows. Body weight is generally used to estimate maintenance requirements (Klosterman et al., 1968). Greater body weight is usually associated with larger frame size; however, greater weights may also be the result of over-conditioning.

Since a small framed cow likely has lesser nutritional requirements, excess energy intake will be laid down as fat and increase weight which would give the illusion of greater requirements if weight alone is considered. In this case, weight should not be used to calculate maintenance requirements unless it is desirable the cow remain in heavy condition. Also, large

breeds and/or breeds with greater milk potentials may have greater maintenance requirements than would be predicted from weight alone. When determining energy requirements, visual body condition, production level, and weight should all be considered. (Lemenager et al., 1980; Fox et al., 1988).

Once cows have reached mature weight, maintenance requirements decrease per unit size since the cow is no longer supporting its own growth. In a study with sheep, Graham et al. (1974) calculated basal metabolic rate decreased by 8% each year and stated this number could be applied to growing and mature cattle by multiplying his equation by 1.3. While requirements generally decrease with age, intake of some nutrients may need to increase since nutrient absorption often decreases in aged cows (Hansard et al., 1954).

<u>Environmental Factors.</u> Environmental factors including season, temperature, and wind speed affect metabolic rate and, therefore, maintenance requirements. Energy required to maintain weight fluctuates some with season, tending to be less in fall and winter then increasing in spring and through summer as can be seen in Figure 6 (Byers et al., 1987; Laurenz et al., 1991). However, appearance of seasonal variance in maintenance requirements is likely due to body composition and temperatures experienced during the seasons (Birkelo et al., 1991; Laurenz et al., 1991).

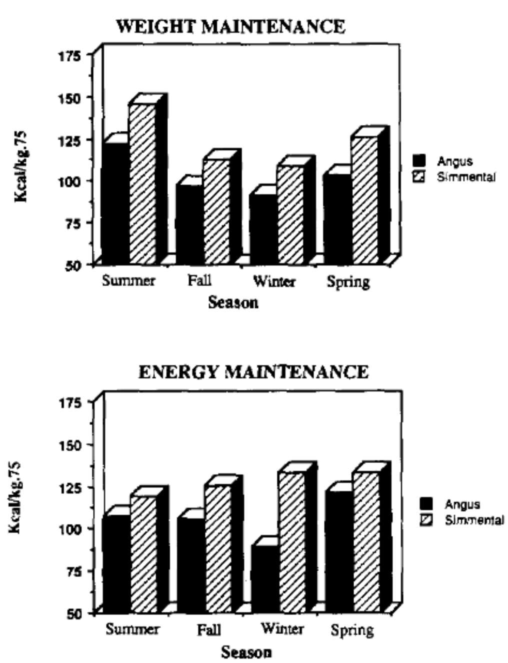

Figure 6. Seasonal daily maintenance requirement for energy by weight for Angus and Simmental cows. (Laurenz, et al., 1991)

Length of photoperiod is a contributing factor to observed seasonal effects (Walker et al., 1991). Multiple studies have reported longer photoperiods to

be associated with increased lean growth as well as increased milk production if experienced during lactation (Petitclerc et al., 1983; Dahl and Petitclerc, 2003; Dahl et al., 2012). Longer photoperiod is associated with increase in bone and muscle deposition whereas short photoperiod is associated with deposition of fat which possibly contributes to the trend in maintenance seen in Figure 6 (Faulconnier et al., 1999; Small et al., 2003). Cows or heifers exposed to a short photoperiod during their dry period leading up to parturition have increased mammary development and greater milk production than those exposed to longer photoperiods (Miller et al., 2000; Auchtung et al., 2005; Wall et al., 2005). However, while exposed to short photoperiods, dry cows were observed to have increased intake and decreased feed efficiency compared to those exposed to long photoperiods (Petitclerc et al., 1983; Miller et al., 2000; Auchtung et al., 2005).

Deviations above and below critical temperature can affect maintenance requirements through effects on intake, digestion, and metabolism. In cases of heat stress, intake generally begins to decrease when ambient temperatures reach 25-27°C (Beede and Collier, 1986). Fermentation and metabolism produce heat, and passage rates slow in an attempt to reduce heat production. Digestion increases due to increased retention time caused by slower passage rate (Lippke, 1975). Requirements of some nutrients & energy may change during heat stress while the body attempts to maintain thermoneutrality & homeostasis. Energy expenditure increases to accommodate cooling behaviors such as panting and sweating and the increased chemical reactions necessary to produce needed ATP (Fuquay, 1981). Maintenance energy requirements increase to meet this need (Beede and Collier, 1986). Nitrogen balances can become deficient as a combined consequence of decreased intake and increased energy requirements, and microbes may resort to using protein for energy (Kamal and Johnson, 1970). Water and electrolyte

requirements increase due to loss from sweating. Ruminants particularly lose potassium through sweating rather than sodium (Beede and Collier, 1986). While energy metabolism initially increases with heat stress, chronic heat stress will eventually decrease metabolic rate (McDowell et al., 1969).

Of livestock species, ruminants are perhaps the most adaptable to cold temperatures. Lower critical temperatures (LCT) will vary based on insulation, production level, and acclimation but generally range between -10ºC and almost -40ºC assuming dry conditions with no wind (Young, 1981). Presence (or absence) of other environmental factors such as wind, moisture, and sunlight can dramatically affect LCT (Webster, 1970). Heat produced by fermentation and metabolism is an advantage during cold exposure, and the rate of metabolic heat production must increase to maintain internal body temperature when ambient temperatures drop below the cow's LCT. The effects of cold stress on digestive function contrast those of heat stress by causing increased intake, gut motility, thyroid hormone, and faster passage rates (Westra and Christopherson, 1976; Kennedy et al., 1977). As a result of increased passage rate, gut motility, and thyroid hormone, digestibility decreases; however, this is due to increased flow out of the rumen (Kennedy and Milligan, 1978). Kennedy and Milligan (1978) observed post-ruminal digestion increased in cold-exposed sheep when compared to those maintained within their thermoneutral zone, leading to improved efficiency in cold conditions. Degen and Young (1981) calculated that for each 1ºC decrease in temperature, resting metabolic rate increases .69 $kcal/kg^{.75}$. Maintenance energy requirements in adapted cattle also increase about .91% for each degree below 20ºC (NRC, 1981). Wintering cow intake must increase to meet increased energy requirements resulting in decreased digestibility due to faster passage rate.

Genetic Effects on Feed Efficiency. Besides phenotypic and environmental effects, genetic variation exists in feed efficiency which can strongly affect maintenance requirements. Feed efficiency determines a cow's utilization of intake by measuring the proportion required for maintenance. Efficiency improves as feed intake decreases (kg/day) and performance products increase (ADG, milk, weaned calf weight) to create a negative linear relationship. Genetic factors often appear to be correlated with those already discussed since patterns can be observed in characteristics such as size and ideal environment for particular breeds and types. Multiple studies have been conducted which compare efficiency performance of the two bovine types *bos taurus* (Angus, Hereford, etc.) and *bos indicus* (Brahman, other Zebu cattle). In hot to temperate environments, *Bos indicus* cattle are overall more feed efficient having lesser maintenance requirements/kg body weight than *bos taurus* (Kennedy and Chirchir, 1971; Frisch, 1973; Frisch and Vercoe, 1977). *Bos indicus* cattle also perform better on low quality feeds likely due to faster passage rates (Phillips et al., 1960). Reid et al. (1991) observed that *bos taurus* cows tended to lose more weight on a restricted diet than *bos indicus*. However, purebred *bos indicus* have poor cold tolerance and tend to have decreased feed efficiency during cold temperatures compared to *bos taurus* despite having faster passage rates (Olbrich et al., 1972; Boyles and Riley, 1991; Josey et al., 1993).

Breeds selected for increased milk production or growth, such as Holsteins or Charolais, have increased maintenance requirements and are susceptible to metabolic inefficiency if diet is inadequate. In cases of inadequate diet, a greater proportion of nutrient intake will be required for maintenance, forcing the cow to decrease production and/or draw from body reserves. However, increased feed/energy intake levels enable the genetic potential of cows in greater levels of production to be fully expressed in milk production and calf growth, thereby decreasing

the proportion of intake that will be required for maintenance and increasing feed efficiency (Jenkins and Ferrell, 1994).

Some individuals of similar characteristics are genetically more efficient than others, having decreased maintenance requirements in proportion to potential performance. DiCostanzo et al. (1991) compared expected ADG calculated from body weight and dry matter intake (DMI) to observed ADG to test for energy efficiency variation within a herd of mature dry, non-gestating Angus cows. Cows whose ADG was within 1 SE of the expected value were considered average (A), and cows with ADG greater than 1 SE above or below the mean value were labeled efficient (E) or inefficient (I), respectively. They found that when fed a maintenance diet based off body weight and condition, I cows had less ADG than A and E cows indicating greater maintenance energy requirements per body weight. However, during an ad libitum period, I cows had greater intake and were only then able to outperform A and E cows. Efficient cows gained more weight with less intake than both groups and were more productive reproductively, raising more calves per cow on average and having heavier weaning weights than I and A cows.

Efficiency traits are moderately heritable, and multiple studies have been conducted testing the effectiveness of selection for efficiency. Two common efficiency measures are the feed conversion ratio (FCR) and residual feed index (RFI). Both methods are calculated using daily intake; however, RFI differs by comparing actual intake to an intake estimated from ADG and body weight. Residual feed index has been vastly more popular and effective in selection studies. Selection for lesser (efficient) RFI produces cows that consume less while gaining as much or more weight than less efficient, greater RFI scoring cattle (Arthur et al., 2001; Herd et al., 2011). Selection for FCR tends to lead to larger, heavier cows. Long-term selection for RFI

can eventually lead to increased cow weights, but not as rapidly. Low RFI cows have longer gestation periods, but other reproductive traits aren't significantly affected (Arthur et al., 2005; Basarab et al., 2007).

A newer efficiency measure that particularly pertains to cows is the energy efficiency index (EEI). The EEI method puts more emphasis on the cow's ability to convert feed to milk by using a ratio which compares an estimate of cow energy requirements to calf weaning weight (Tedeschi et al., 2006). Cows with low EEI make more milk and wean heavier calves while utilizing the same estimated energy requirements as greater EEI cows. Lesser EEI cows put more energy to milk production and less to fat deposition yet have lesser maintenance requirements. However, this trait is strongly correlated with the mature cow weight to calf weaning weight ratio which is lowly heritable (Macneil, 2005).

Nutrition during Lactation. Undoubtedly, lactation and gestation are more nutritionally demanding physiological states than maintenance since, in addition to maintaining normal functions, a cow is now also either producing milk, growing a calf in utero, or both. In order to manufacture additional outputs, it is logical that a cow must consume additional protein to act as building blocks, energy to transform nutrients and carry out body functions, and vitamins and minerals to aid in nutrient transport, formation, etc, and all nutrients must increase in balance. Protein is necessary for any form of production, but energy must be increased proportionally to allow for amino acid degradation and synthesis both by microbes and post-absorptively. Vitamin and certain mineral requirements increase as well since these will be essential for the utilization of other nutrients. Two especially crucial minerals that must be balanced not only with nutrient intake but each other in a 1:1-4:1 ratio are Ca and P. Calcium and Phosphorus are both crucial to bone development (in pregnant cows) and, specifically, Ca to milk production and P to cell

Table 4. Forage intake guidelines for beef cows

		Dry	Lactating
Forage quality	TDN, %	DMI capacity, % BW	DMI capacity, % BW
Low	<52	1.8	2.2
Average	52-59	2.2	2.5
High	>59	2.5	2.7

(Adapted from Lalman, 2004)

growth and energy utilization (Dowe et al., 1957; Wise et al., 1963). To meet increased nutritional requirements in grazing cows, either forage quality (%TDN) must be improved or intake (DMI) increased. Low quality forages require greater microbial digestion and, therefore, have slower passage rates which limits TDN intake whereas forages of greater quality can be digested more quickly and pass out of the rumen, allowing for increased intake (Table 4).

During lactation, intake can increase 35-50% compared to dry cows (ARC, 1980). Feed intake increases as milk production increases in proportion to BW. As has been previously stated, protein and energy requirements increase during milk production. Milk production requires sufficient energy to efficiently extract amino acids from blood (NASEM, 2016). Depending on level of milk production, energy required for lactating beef cows to maintain body condition is approximately 20% greater than dry cows (Ferrell and Jenkins, 1985; Montaño-Bermudez et al., 1990). Protein type is also an important consideration for lactating cows. While RUP more efficiently meets metabolizable protein requirements and is necessary for increased milk yields, Blasi et al. (1991) observed that excessive RUP has a negative effect on milk yield and, subsequently, calf ADG. Forage quality is generally greater when spring herds begin calving which is advantageous to allow for greater milk production without losing excessive condition and compromising rebreeding ability (Figure 7). However, peak milk occurs 5-10

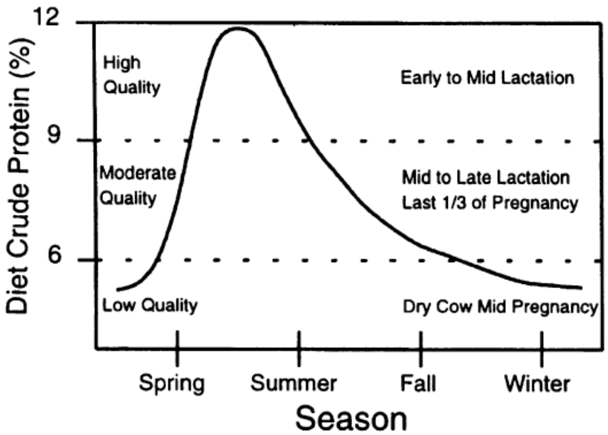

Figure 7. Milk production matching with seasonal forage growth for spring calving cows (Adams et al., 1996)

weeks after calving and, depending on how early in the season a cow calved, forage quality likely is declining by this period. Most forages are low in RUP and supplementation may be necessary during increased milk production to maximize milk yields and, therefore, calf growth.

Nutrition during Gestation. While pregnancy isn't nearly as demanding as lactation, requirements do increase substantially. By late gestation, energy and protein requirements can increase by as much as 59% beyond that of a dry, non-pregnant cow (NASEM, 2016). Inadequate nutrition during gestation negatively impacts reproductive performance including return to estrus and follicle growth, persistence, and ovulation (Short et al., 1990; Murphy et al., 1991; Mackey et al., 1999). However, it is important to not over-feed pregnant cows either as both under and over-feeding can lead to decreased calf birth weights and milk production and increased calving difficulty (Hight, 1966; Tudor, 1972; Swanson et al., 2008).

Nutrition during early lactation can greatly affect fetal development, impacting subsequent growth and reproductive processes postnatally. Underfeeding during early pregnancy can compromise fetal development both in growth and major organ development and function (Long et al., 2009; Meyer et al., 2010). Fetal folliculogenesis occurs during early gestation, and heifer calves born to cows fed low energy diets during early gestation may have decreased follicle numbers and ovulation rates when they reach puberty, leading to decreased pregnancy rates (Rae et al., 2002; Evans et al., 2012). Studies done with sheep report that restriction during

early gestation may also lead to decreased glucose tolerance and insulin sensitivity, causing lambs to develop greater subcutaneous fat and less muscle (Ford et al., 2007). The second trimester is the only period during which moderate diet restriction may not affect calf production if adequate nutrition is provided during the final trimester of gestation (Corah et al., 1975; Freetly et al., 2005).

Depending on resources, ensuring cows have adequate nutrition during the third trimester may be difficult if grazing is not adequate. This issue is confounded by decreased intake that occurs during this period of gestation. Ingvartsen et al. (1992) reported a 1.5% decrease in intake during the last 14 weeks of gestation due to physical limitations of the reticulorumen and GI tract as well as hormonal regulation. Cows on low quality pasture during late gestation, such as early spring calving cows, need rumen degradable protein in order to digest low quality forages (Patterson, 2001). Protein restriction may affect calves' ability to absorb immunoglobulins, leading to compromised calf health (Blecha et al., 1981). Gunn et al. (2015) observed that heifers supplemented with dried distiller's grains as an energy source with greater amounts of RUP during late gestation bore calves with heavier weaning weights. Heifer calves from this group also had a heavier body weight at puberty and had better conception rates.

Heifer Development. Development of replacement heifers requires additional considerations to those of a mature cow since heifers are still growing leading up to and after first breeding and calving. The goal of successful heifer development is to produce quality, low-cost replacement heifers that will consistently produce calves and, ideally, remain in the calving herd though their lifetime. Outside of genetic factors, success can be affected by controlling heifer weight gain and achieving target weights by certain maturity/production levels. The goal of reaching target weights is to encourage early puberty. Heifers that reach puberty early are

more mature at breeding, likely having gone through multiple estrous cycles, and are more likely to conceive within a 45-day breeding season. Byerley et al. (1987) reported that heifers bred during their third estrous had a 78% conception rate while heifers bred during first estrous had a 57% conception rate. When puberty is achieved sets the timing cycle for the heifer's reproductive life. Heifers with an early first calving conceive earlier and have greater lifetime productivity (Lesmeister et al., 1973)

Puberty and reproductive performance are influenced by energy balance and nutrition (Randel, 1990; Robinson, 1990). Target weight milestones for replacement heifers are 55-65% of mature weight by a heifer's first breeding (13-15 months of age), and 80% of mature weight by first calving (22-24 months of age; NASEM, 2016). Heifers developed to a lighter weight at breeding incur lesser feeding costs but also have worse conception rates than heavier heifers. However, over-conditioned heifers tend to require more services to conceive, more assistance during calving, and have greater calf mortality in addition to weaning lighter calves (Funston et al., 2012a). Swanson (1960) observed abnormal udder development in obese heifers which contributes to decreased milk production and, consequently, lighter weaning weights (Arnett et al., 1971).

Puberty occurs around the time that energy use is channeled from lean growth to energy reserves (Brody, 1945). After weaning, heifer replacements are typically put on a increased-roughage diets to promote lean tissue and skeletal growth without excess fattening. This increased forage diet is often supplemented with additional energy, protein, and vitamins and minerals as may be necessary (based on forage quality) to meet target weights by breeding and first calving (NASEM, 2016). Target gains of 0.45-0.90 kg/d leading up to first breeding are effective to bring heifers to target weight (NASEM, 2016). Various strategies have been tested

regarding the rate and timing of post-weaning weight gain leading up to breeding which compare alternating slow followed by rapid growth periods or vice versa and continuous growth. Altering rate and timing of weight gain has been found to not affect reproductive performance. However, slow growth followed by rapid gains shows less total energy required to reach target weights, resulting in decreased costs (Clanton et al., 1983; Lynch et al., 1997).

Body Condition Scoring. Body condition scoring (BCS) is a common practice used to evaluate body energy reserves of livestock using a numerical scale based on visual appraisal. The numerical scales most widely used are either 1-5 scale or 1-9 scale with the least number indicating extremely thin animals lacking energy reserves ranging to the greatest numbers indicating obese animals with excessive energy reserves causing a body composition with greater percent body fat. Since BCS is based on visual appraisal, some variation occurs due to individual interpretation. Factors considered when determining an animal's BCS include muscle atrophy (in thin animals), visibility or palpability of ribs or spinal processes, and fat deposition particularly over the back and ribs, at the tail head, and in the udder. This system is useful in field settings for rapid appraisal of livestock since it does not require knowledge of exact body weight and can be applied consistently across frame sizes and breeds.

<u>Development.</u> Three main BCS systems are recognized in cattle scoring. Two of these systems use a scale of 1-5 and the third using a scale of 1-9. The first 1-5 scale was developed by Wright and Russel (1984a,b), and was adopted by the Commonwealth Scientific and Industrial Research Organization and the French National Institute for Agricultural Research. The second 1-5 scale was developed from studies at Purdue University but differs from the previous system in that it uses plus, average, and minus distinctions for each BCS. The 1-9 system was developed by studies at Oklahoma State University and Colorado State University and was adopted by the

National Research Council (NRC) beginning in 1996 publications (NASEM, 2016). All these systems are used to define energy reserves and develop nutrient recommendations based on desired performance, and calculations can be made to shift between them.

The NRC committee developed equations from data sets provided by the U.S. Meat Animal Research Center (U.S. MARC) of mature cows of a variety of breed types and body sizes. These data were analyzed to determine the relationship of BCS to empty body percentages of fat, ash, protein, and water. Since BCS is an evaluation of body energy reserves, knowledge of the impact of reserve level on performance allows for more exact calculation of nutrient and energy requirements based on a system of visual appraisal.

The change in reserve level required for a change in BCS can be applied as changes in either weight or body energy content (Mcal/kg). Numbers from Fox et al. (1992) suggest that fat cows, or those with increased BCS, require a greater change in weight than thin cows to change BCS. However, it must be considered that fat cows will likely gain or lose mostly fat since they have a greater fat percentage of body composition, and thin cows have greater percentage of protein compared to fat. Fat is more energy dense than protein; so, if BCS is a mirroring of body energy reserves, a fat cow should be able to achieve a change in BCS with less actual weight change than a thin cow. The NASEM compared three studies (Houghton et al., 1990; Buskirk et al., 1992; Graffam, 1992) to the base data set from U.S. MARC to discover an adjustment factor that pertains to weight change/BCS. These data were converted to reflect shrunk body weight (SBW) of a mature cow with BCS of 5 on a 1-9 scale. The final adopted weight change/BCS is a 36.57kg change in SBW or a weight adjustment factor (WAF_{BCS}) can be calculated using the constant 7.105% of SBW/BCS as seen in Equation 1 where BCS is the current body condition score on a 1-9 scale. Current shrunk body weight (SBW') may then be divided by WAF_{BCS} in

Equation 2 to calculate SBW at BCS 5 (SBW_5). However, it is noted that these constants may actually vary some with cow size or in primiparous females (NASEM, 2016).

Equation 1: $WAF_{BCS} = 1 – 0.07105 \times (5 - BCS)$

Equation 2: $SBW_5 = SBW'/WAF_{BCS}$

Change in energy is a more precise method of differentiating between BCS. The NRC used Fox et al. (1999) and Tedeschi et al. (2006) to determine Mcal/kg change in reserves to gain or lose BCS. These values vary by body condition score, but energy reserve differences have a direct relationship with BCS changes and are calculated in units of Mcal of body energy reserves/kg SBW.

Effects on Reproductive Performance: By understanding body condition scoring and its effects on reproduction, beef producers can make nutritional management decisions to aid in maximizing production and the health of their livestock. Cows being too fat or thin risks metabolic debility, disease, and compromised reproductive performance and calf growth (Meyer et al., 2010; Funston et al., 2012b; Long et al., 2012). Generally, BCS 4 and below are considered thin, BCS 5-7 are considered moderate, and BCS 8-9 are considered fat.

Thin cows have longer post-partum intervals than moderate/fat cows (Richards et al., 1986; Houghton et al., 1990). However, thin cows achieve estrous sooner if they are gaining weight leading up to calving rather than losing weight after calving leading up to breeding (Dunn and Kaltenbach, 1980). There is discrepancy as to whether thin or fat cows require more services to become pregnant; but overall pregnancy rates are better in cows that gained, rather than lost, weight between calving and breeding, regardless of BCS at calving (Richards et al., 1986; Selk et al., 1988; Houghton et al., 1990). Rae et al. (1993) observed that moderate and fat cows that maintained weight had better pregnancy rates than thin maintaining cows. Cows of moderate

BCS that either maintain or gain weight post-partum appear to have the best pregnancy rates (Selk et al., 1988).

Effects on Calving and Calf Growth. Multiple studies show trends but not significant direct correlation between BCS and dystocia (Waltner et al., 1993; Ruegg and Milton, 1995). Berry et al. (2007) suggests this may be due to low numbers of over- or under-conditioned cows used in these studies. However, Gearhart et al. (1990) did observe negative effects resulting from losing condition leading to calving, and Chassagne et al. (1999) observed a tendency toward increased stillbirths in fat cows that gained weight leading to calving. Body condition score at calving has some but not a strong effect on birth weights (Bellows and Short, 1978; Gardner et al., 2007). Weaning weights were lighter from cows with inadequate nutrition after calving (Richards et al., 1986; Houghton et al., 1990). Richards et al. (1986) also found weaning weights were not affected by cows losing weight before calving if they gained post-partum.

Calf Growth

Calf Nutrition. Calves are not born with a fully functional rumen, but undergo progressive digestive development through the pre-weaning period. There are three phases of digestive development: pre-ruminant, transitional, and ruminant.

Digestive Development. During the pre-ruminant phase, which begins immediately after birth, the rumen is small and mostly undeveloped. During this time, a calf functions like a non-ruminant with most digestion occurring in the abomasum which functions as a simple stomach, and small intestine. Vitamins and amino acids which can be produced by a mature ruminant must be acquired via the diet similarly to non-ruminants in the absence of microbial fermentation (Van Soest, 1994).The transitional phase begins after two to three weeks as a calf begins to eat some

dry foods in addition to milk. Rumen volume and musculature develops in response to size and weight of dry foods; and development of papillae and rumen mucosa occurs in response to fermentation of VFAs (Sander et al,. 1959; Tamate et al., 1962). Papillae development also has a direct relationship to dry feed intake. Coarse feed promotes greater length and surface area, and papillae development can regress if a calf reverts back to greater milk intake over roughage (Tamate et al., 1962; Beharka et al., 1998). The transitional phase continues up to weaning when the calf ceases milk consumption and relies solely on forage and/or concentrate feed. At this point, the calf enters the final phase of a fully developed ruminant.

Newborn calves lack the microbial population of mature ruminants and, therefore, the fermentation necessary for normal ruminant digestion. Until the rumen and microbial population develop, ingested milk bypasses the forestomach and travels directly to the abomasum via the esophageal groove, a temporary structure which forms by reflexive impulse to the calf nursing. Like the simple stomach of monogastrics, the abomasum is strongly acidic (1-2 pH) and performs an important role in feed breakdown in the absence of a diverse microbial population. Calves are born with enzymes to hydrolyze primarily lactose, the main carbohydrate in milk, and rely on milk to meet nutrient requirements for the first two to three weeks of life (Davis and Drackley, 1998; Drackley, 2008). As dry matter intake increases, ruminal pH decreases allowing microbial diversity to expand, providing a greater variety of digestive enzymes (Davis and Drackley, 1998). Microbe species in very young calves are mostly aerobic, but the population shifts to increased anaerobic species, especially cellulolytic and methanogenic species, at four to six weeks of age (Anderson et al., 1987). Beharka et al. (1998) found physical form of feed affects microbial populations as well. Ten-week-old calves fed ground feed had greater levels of amylolytic bacteria, whereas calves fed unground feed contained greater numbers of cellulolytic

bacteria. As the diet transitions from milk to dry feeds, the microbial population develops to that of a mature ruminant.

Metabolizable energy required for maintenance (ME_m) increases with calf growth (Table 3). However, the percentage of dietary protein required for maintenance out of total protein required for growth decreases as microbial populations develop and are able to provide amino acids and microbial protein. Milk provides the most ideal amino acid profile for a growing calf compared to milk replacers or alternative protein sources in terms of digestibility, growth, and digestive development (Nitsan et al., 1972; Seegraber and Morrill, 1986; Khorasani et al., 1989). Biological value (BV) is used to determine how well the amino acid balance of consumed protein is meeting amino acid requirements by comparing the percentage of amino acids absorbed to amino acids retained. Under ideal conditions, the BV of milk is 80-90% (Roy, 1970). However, since energy is required for protein synthesis, BV is limited by the ratio of digestible energy to digestible crude protein. Donnelly and Hutton (1976) reported BV values decrease substantially as crude protein is increased if energy concentrations are not also increased.

Feed Sources. As the calf grows and nutritional requirements change, the nutrient sources must change as well. Colostrum is essential for early health of the calf. Fat, protein, and most vitamins and minerals are more concentrated in colostrum than whole milk which is necessary since the microbial population of a newborn calf is negligible, and the additional nutrients will help the calf stabilize in its new environment. Colostrum also provides immunoglobulins for establishment of passive immunity. It is recommended a calf receive at least 7kg of colostrum within the first twenty-four hours post-parturition (Roy, 1990). A cow will produce colostrum for the first few days post-parturition before producing regular milk.

At peak milk, beef cows produce 7-8kg of milk per day containing approximately 4% fat and 3.8% protein (NASEM, 2016). Increased milk production encourages increased milk intake which has a direct relationship to calf growth (Tedeschi and Fox, 2009). If milk production is inadequate, calves will seek out alternative food sources at an earlier age. Adequate milk intake affects calf gains not only during lactation, but also post-weaning (Clutter and Nielsen, 1987). At four months of age, milk alone no longer meets a calf's nutritional needs, which causes an increase in forage intake (Robison et al., 1978).

In the last few months leading up to weaning, calves may be offered supplemental creep feed to provide additional nutrients to ensure requirements are met and encourage growth. Creep feeding calves yields heavier weaning weights. However, Prichard et al. (1989) reported that calves offered creep feed for 5 months prior to weaning did not have heavier weaning weights than calves offered creep feed only 2 months prior to weaning, indicating no benefit to early supplementation.

Creep feeding practices are beneficial for calves destined for slaughter; however, multiple studies show negative effects on reproductive performance in replacement heifers. While creep-fed heifers have heavier weaning weights and body condition scores, pregnancy rates, calf birth weights, and milk production are decreased (Martin et al., 1981; Sexten et al., 2004). Martin et al. (1981) reported weaning weights of calves born to creep-fed heifers were less than calves of non-creep-fed heifers regardless of whether the calves themselves had been creep fed. Creep feeding heifers appears to affect biochemical variables related to metabolism (Reis et al., 2015). Creep-fed heifers have decreased post-weaning average daily gains and do not achieve earlier puberty (Martin et al., 1981; Hixon et al., 1982; Reis et al., 2015).

Environmental Effects on Calf Growth. Just as environment affects cow functions, environment has effects on calf growth and viability. Cold and heat stressors affect both calf birth weights and weaning weights in large part because of environmental effects on the dam. Other environmental factors such as wind speed and precipitation can compound or relieve these effects.

Effects on Birth Weight and Calf Mortality. Temperatures experienced during the last 2-3 months of gestation can have a significant effect on calf birth weight. Andreoli et al. (1988) observed birth weights were lighter in calves whose dams were exposed to sub-freezing temperatures than those whose dams were exposed to sub-temperate temperatures. However, this finding appears to contrast with other studies which found that birth weights increased as temperatures decreased (Colburn et al., 1996; Deutscher et al., 1999). An indirect relationship between birth weight and temperature agrees with findings on heat stress effects. Heat stressed dams with no access to shade or other cooling assistance bore calves with lighter birth weights (Collier et al., 1982; Wolfenson et al., 1988). The cause for this relationship is likely due the effect of temperature on uterine blood flow (Roman-Ponce et al., 1978). During prolonged cold exposure, blood flow is increasingly internalized to maintain core body temperature which, consequently, provides more nutrients to the pre-natal calf. Conversely, heat stress causes increased external blood flow as a physiological cooling mechanism which decreases uterine blood flow. Heat stress also depresses nutrient intake, thus decreasing nutrient availability for calf growth (West et al., 2003).

Environmental conditions affect calf mortality as well. Cold temperatures often result in increased calving difficulty and mortality as a consequence of increased birth weight (Azzam et al., 1993; Colburn et al., 1996; Deutscher et al., 1999). Azzam et . (1993) found that calf

mortality begins to accelerate when dams are exposed to temperatures of 0-10^{o}C. Newborn calves are more susceptible to cold stress and low temperature-humidity indexes (Mellado et al., 2014; Nabenishi and Yamazaki, 2017). Precipitation decreases the ability of the hair coat to insulate and regulate a newborn calf's body temperature. The amount of precipitation has a direct relationship with the incidence of calf mortality since it raises the ambient temperature at which cold stress can occur (Azzam et al., 1993).

Effects on Calf Growth. Environmental stressors can negatively affect calf growth. When cows are heat stressed during late gestation, cow dry matter intake and milk yield is significantly lesser than cows which are kept cooled (Amaral et al., 2009; Monteiro et al., 2016). These effects likely contribute to observations showing that calves born to heat-stressed cows have lighter weaning weights and compromised immune function (Tao et al., 2012; Monteiro et al., 2016). Heifer calves of cows that were heat-stressed during late-gestation also show negative phenotypic effects on their own future milk production (Monteiro et al., 2016). Calves, like mature cattle, also show decreased intake when heat-stressed (Broucek et al., 2008). Nabenishi and Yamazaki (2017) observed that calves are most susceptible to cold-stress immediately after birth, but after three months of age, calves are more susceptible to heat-stress. Except for newborns, calves are not more negatively affected by moderate cold if adequate nutrition is provided than calves in more temperate environments. (Nonnecke et al., 2009).

Timing of Calving Period

Optimal calving season is determined by the calving period which results in greatest net returns. Individual factors which influence profits are cow reproductive performance, calf growth performance, input costs, and calf and cull cow values. The time of year producers can plan to

have cows give birth can vary. While it is common practice for livestock to give birth during spring months, it has been found that birthing during fall months may be more beneficial for producers depending on geographic location. Since the United States has a spectrum of climates, optimal calving time during the year can vary between regions depending on forage growth patterns and weather typical of the region.

Aligning increases in forage growth with the period of increased cow requirements occurring during late gestation and early lactation reduces the need for supplemental feed expenditures (Sprott, 2001). Utilizing high-quality forage growth during periods of increased requirements is also beneficial to cow performance and calf growth. However, environmental conditions must also be considered since heat or cold stress and humidity can have negative effects on performance. Heat stress and high temperature humidity indexes during estrus through early gestation can cause reduced conception rates and abnormal embryonic development (Ingraham et al., 1974; Biggers et al., 1987; Putney et al., 1988; Putney et al., 1989). Since cold stress can be particularly dangerous for newborn calves, planning for cows to give birth during typically cold months can cause an increase in calf mortality (Azzam et al., 1993; Mellado et al., 2014; Nabenishi and Yamazaki, 2017). Regardless of region, cattle prices are higher in spring and summer. Because fall-born calves are weaned and sold during this period, fall calving systems are the most likely to benefit from these increased prices . However, feed costs are often greater for a fall calving season as both the calf and lactating cow will likely need supplemental feed through the winter as a result of forage dormancy (Henry et al., 2016).

Studies have shown optimal calving time to vary by region. Studies in northern regions, which experience colder winters and a later start to forage growth, had the best results with spring calving seasons. Spring calves had heavier weaning weights followed by summer calves

with fall calves weighing the lightest (Reisenauer Leesburg, 2007). When calves were born in late spring to early summer, cows also lost less weight leading up to breeding which likely led to their superior pregnancy rates, and net returns were greater (Deutscher et al., 1991; Pruitt et al., 2003). Alternatively, fall calving seasons are more beneficial for producers in southern regions where winter temperatures are mild but summers are hot and humid. Because of warmer temperatures year-round, forages growing in southern regions are largely warm-season species which grow during the summer and into the fall, providing high-quality forage during the period when fall-calving cows are in late gestation and early lactation. Calf mortality is also lower in fall calving herds and net returns are higher (Bagley et al., 1987; Payne et al., 2009)

Central regions of the United States differ from the northern and southern regions in that they have a combination of temperatures and cool- and warm-season forages. This induces a longer growing season, allowing producers broader chances of success with either spring or fall calving seasons. However, differences in results still exist between the two calving seasons. A major forage species present in much of the central states is tall fescue (F*estuca arundinacea*). Tall fescue is a beneficial forage due to its hardiness and nutritive value, but has a propensity for becoming infected with fungal endophyte (*Neotyphodium coenophialum*) which can cause Tall Fescue Toxicosis in livestock. Caldwell et al. (2013) observed that fall calving herds performed better than spring calving herds when cows were allowed to consume endophyte-infected fescue. Conclusions for whether average daily gains, weaning weights, and calving interval are better for spring or fall calving seasons are not consistent (Smith et al., 2012; Caldwell et al., 2013; Campbell et al., 2013). However, other performance factors and considerations point to a fall calving season being superior to a spring calving season in the central region. Fall-calving cows lose less body condition during breeding and have consistently better calving rates (Smith et al.,

2012; Caldwell et al., 2013; Campbell et al., 2013). Despite spring calving herds having lower feed costs, net returns are consistently greater when calves are birthed in the fall (Smith et al., 2012; Campbell et al., 2013; Henry et al., 2016). Besides prices being greater in the spring and summer when fall calves are weaned and sold, fall-calving cows have better herd longevity and the time interval required from birth to first calving is less for fall-born heifers (Campbell et al., 2013). Overall, risk of negative net returns is less when a fall calving season is practiced in central regions of the United States (Henry et al., 2016).

MATERIALS AND METHODS

A research protocol was submitted for approval by the Missouri State University Institutional Animal Care and Use Committee (Protocol #16-035.0). It was deemed by the committee that a protocol was not necessary since the data collected on cows and calves were generally accepted production data. The care and use of animals followed the Guide for the Care and Use of Agricultural Animals in Research and Teaching.

Research was conducted at Missouri State University's Leo Journagan Ranch (LJR) located south of Mountain Grove, MO. The five-year study, which was conducted from 2014-2019, utilized field data from Hereford cow-calf pairs (n=1886) owned by LJR and cared for by LJR employees and MSU students. Performance data were recorded by LJR employees as a part of normal production practices in a beef cattle seedstock operation. Cow-calf pairs were grouped based on calf birth month (Table 5).

Cow data gathered included American Hereford Association (AHA) registration number, dam tag ID, BCS at calving and weaning, mature cow weight, and pregnancy status. Body condition scores were gathered years three through five by visual appraisal using methods as described by Eversole et al. (2005). At weaning, mature cow weight was recorded using Tru Test scale models XR 3000 or EW5i (Nanton, Alberta, Canada), and pregnancy status checked via palpation. Calf data gathered included calf AHA registration number, date of birth, calf sex, birth weight, weaning weight, and weaning date. Calf birth weight was recorded within 24 h post-parturition using a weight tape or portable sling scale. Collected records were used to calculate calving interval and calf weaning age and 205-day adjusted weaning weight. Due to the nature of using field data, data collection was partially incomplete; in these cases, some data gaps were

able to be filled using the AHA online registry records. If missing data included mature cow weight or calf weaning weight, the cow/calf pair was excluded from the CVDS model analysis.

Cow/Calf Management

Calves were born throughout the year, but cows were managed as either calving in the spring or fall. Spring calving cows gave birth January through July generally, and fall calving cows gave birth August through December. Occasionally, some calves born in June and July were weaned with the fall group calves; these decisions were made by the ranch manager. Most

Table 5. Number of cows included in the study that calved at Journagan Ranch[1] in each month of the year from 2014-2018

Month	2014	2015	2016	2017	2018	Month Total
January	84	5	20	37	6	152
February	201	176	187	199	104	867
March	77	116	122	80	160	555
April	26	48	33	35	37	179
May	12	17	12	9	8	58
June	0	8	2	5	0	15
July	2	3	0	0	0	5
August	4	22	3	3	0	32
September	28	40	59	43	32	202
October	29	15	29	28	23	124
November	6	2	5	6	4	23
December	5	2	1	1	1	10
Year Total	474	454	473	446	375	2222

[1]Journagan Ranch located at 36.993897, -92.258733

cows were bred via natural service in pasture, but about 100 cows/year (mostly heifers) were bred via artificial insemination. A bull selected for breeding was released into a chosen cow pasture for about 75 days. Bulls breeding spring-calving cows were released into selected pastures around April 20 and removed the beginning of July. Bulls breeding fall-calving cows were released into selected pastures at the end of November and removed the beginning of February.

Cows and calves were managed on a pasture grazing system year-round and were split into multiple groups assigned to the ranch's pastures by the ranch manager beginning in April through May. Pastures ranged in size from 16-65 h. Some groups continuously grazed a single pasture and others were minimally rotated to alternate pastures throughout the year as grazing necessitated based on forage availability. The major forage species was Tall Fescue (*Festuca arundinacea*), and other cool-season species included Timothy grass (Phleum pratense), Orchard grass (Dactylis glomerata), Korean lespedeza (*Kummerowia stipulacea*), and Red (*Trifolium pratense*) and White (*Trifolium repens*) Clovers. Warm-season grasses available in pastures included Big Bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and Johnson Grass (*Sorghum halepense*). Hay of similar native species was produced from ranch fields and fed during winter months (generally December-April). Amount of hay provided was about 9-11.5 kg per cow a day. Pasture management included fertilization every third year with urea, and hay pastures were fertilized every year.

Cows were provided with supplement during the winter and respective breeding seasons. Spring cows were supplemented 0.91 kg/(cow · day) from late January to March and 0.70 kg/cow/week from April to June. Fall cows were supplemented 1.13 kg/cow semi-daily from August to December and 0.91 kg/(cow · day) from late January to April. Fall calves were

provided with creep feed from March to May via a self-feeder. Target creep feed intake was 2.27-3.63 kg/day. The same grain mix was used for cow supplement and calf creep feed (Table 6).

Forage Sampling

Forage samples (n=182) were collected monthly from all pastures in which study cows were residing during years three through five. Hay core samples were collected once a year using an Oakfield Hay Sampler (American Agriculture Laboratories, McCooks, NE, USA) with an 18" tube. Each year, hay samples were gathered from approximately 10% of total hay inventory. Bales were sampled from each row of stored hay bales to ensure all cuttings and fields were included in the yearly sample. Monthly pasture samples consisted of 4 to 6 combined sub-samples per pasture collected from locations chosen by observing the grazing pattern of cattle. Plants and plant parts were selected to closely imitate the observed grazing pattern of the study cattle. Samples from individual pastures were stored separately. Pasture name, date of collection, and wet weight were recorded for each sample. Hay and pasture forage samples were dried in paper bags in a temperature control forced air oven (Cascade Tek, Cornelius, Oregon, USA) at 55°C and dry weights recorded for dry matter calculation. Dried samples were ground to pass

Table 6. Nutritional content[1] means of hay and supplement feed provided to cows at Journagan Ranch[2] from 2014-2018

Feed	DM%	CP%	NDF%	ADF%	TDN%
Hay	86.96	9.46	90.79	40.7	51.08
Supplement	89.73	14.75	40.25	22.07	72.17

[1]DM% = % dry matter; CP% = crude protein % of DM; NDF = neutral detergent fiber % of DM; ADF = acid detergent fiber % of DM; TDN = total digestible nutrients % of DM
[2]Journagan Ranch located at 36.993897, -92.258733

through a 2mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) then further ground using a Cyclone Sample Mill (UDY Corporation, Fort Collins, Colorado, USA) and stored in plastic ziplock bags. Ground samples were analyzed for nutrient content using near infrared spectroscopy (NIRS SpectraStar, Unity Scientific, Milford, Massachusetts, USA). Prior to NIRS analysis, samples were dried at 95ºC until a constant weight was reached to reduce variability and inaccuracy of forage analysis with NIRS (personal communication, Forage Consortium). Two samples of each forage sample were analyzed. Total digestible nutrients (TDN) were calculated using Equation 3 (University of Arkansas, 2018). Metabolizable energy (ME) was calculated from TDN according to NASEM (2016) calculations using Equation 4. Samples with TDN CV > 1.4 were re-dried at 95ºC for 24 h and immediately re-analyzed.

Equation 3: $$TDN = 58.4 + 1.034(\%CP) - 0.42(\%ADF)$$

Equation 4: $$ME = (TDN/100) \times 4.4 \times 0.82$$

Nutritional content of hay samples is listed in Table 6. Average monthly nutrient content of forage samples collected in 2016-2018 is listed in Table 7.

Economic Analysis

Historic prices for supplemental feed, hay, weaned calves, and cull cows were used to determine costs and returns. Supplemental feed (Custom mix52) was purchased from South Central MFA Agri Services (Mountain Grove, MO), and prices were obtained from MFA invoice records from the five years of the study. Prices for hay, weaned calves, and cull cows were obtained from USDA market report archives (https://www.ams.usda.gov/market-news/search-market-news). Hay prices were from the Missouri Weekly Hay Summary (report code jc_gr310) for June and July when hay was harvested. Average prices for each year were

Table 7. Average nutrient content[1] of Journagan Ranch[2] cow-pasture forage by month for years 2016-2018

Month	DM%	CP%	NDF%	ADF%	TDN%
January	62.40	11.54	67.11	41.64	52.84
February	43.55	12.70	64.96	39.98	54.74
March	43.02	17.98	58.05	34.12	62.66
April	39.79	20.51	52.20	31.29	66.47
May	21.81	15.98	55.34	33.56	60.83
June	37.82	12.43	57.04	37.17	55.64
July	41.00	11.59	60.34	37.61	54.58
August	28.61	15.29	56.58	34.77	59.55
September	34.39	14.24	57.64	35.35	58.28
October	39.08	13.46	57.10	35.29	57.50
November	77.07	10.90	61.99	39.23	53.20
December	72.81	10.63	62.36	39.06	52.98

[1]DM% = % dry matter; CP% = crude protein % of DM; NDF = neutral detergent fiber % of DM; ADF = acid detergent fiber % of DM; TDN = total digestible nutrients % of DM
[2]Journagan Ranch located at 36.993897, -92.258733

calculated using values for round bales in the report category "Good quality Mixed Grass hay" This hay category had a CP content of 9-13% which most closely represented CP content of forage samples from June and July when baling occurred.

To account for seasonal cattle price fluctuation, methods for calculating weaned calf and cull cow prices were more complex than that used for hay price calculation. Weaned calf prices were from USDA-MO Dept of Ag Market News Feeder Cattle Reports for Joplin Regional

Stockyards (report code jc_ls758), Springfield Livestock Marketing Center (report code jc_ls771), and Ozarks Regional Stockyard (report code jc_ls763). The category used was Feeder Cattle Steers Medium and Large 1-2. Prices for all weight classes were recorded excluding those for calves weighing over 453.6 kg. Prices for individual calves were calculated from the report dated to immediately follow the weaning date of the individual calf. The price-weight relationship was described using polynomial regression, and this equation was used to compute the price of individual calves. Cull cow prices were from USDA-MO Dept of Ag Market News Slaughter/Replacement Cattle Reports for Joplin Regional Stockyards (report code jc_ls174) and Springfield Livestock Marketing Center (report code jc_ls140) using values for the Boner-Average Dressing category. Boner price was used for sows with a BCS 5-7, and Lean price was used for cows with a BCS less than 5.

Cow Efficiency Model

Cow efficiency was evaluated using the Energy Efficiency Index (EEI) which is calculated as the ratio of total metabolizable energy to calf weaning weight (Mcal/kg). This index was computed using a beef cow model developed by Tedeschi et al. (2004) for the Cattle Value Discovery System (CVDS). Performance inputs required for this model were Mature Cow Weight (MCW) at weaning, calf date of birth, birth weight, weaning weight, sex, weaning date, and date of MCW. These values were obtained from LJR performance data collected during the years of the study. Other inputs included Cow Mature Weight (CMW), Peak Milk, and Relative Milk Production (RMP); these were pre-set values applied to all cows as follows: CMW = 550 kg, Peak Milk = 10 kg/d, and RMP = 5 (on a 1-9 scale). Cow Mature Weight was an estimate for

mature calf shrunk body weight used to calculate calf daily weight gain. Peak milk set maximum milk production, and RMP set the standard milk production of the study cows at average.

Forage sample ME values were averaged for all pastures by each month collected during the study for input into the model. Years of the study that preceded the forage collection period used a monthly average across all years of the forage collection period as the input forage ME values. Hay vs. pasture forage consumption was estimated based on ranch management practices. Consumption estimates were as follows: December to March = 100% hay, April = 75% pasture and 25% hay, and May to November = 100% pasture. Cow-calf supplement samples were analyzed for nutrient content by DairyOne laboratories services (Ithaca, NY). Model inputs included cow supplement and calf creep-feed daily intake and ME values. Spring calving cows were fed for a target supplement intake of 0.91 kg/(cow · day) January to March and 0.68 kg/(cow · week) April to June. Target supplement intake for fall-calving cows was input 0.91 kg/(cow · day) January to April and 0.68 kg/(cow · day) during early lactation from August to December. A modification to the model was made to account for creep feed consumption by fall-born calves. The model was modified to substitute 45% of non-milk intake with creep feed while assuming the other 55% of non-milk intake consisted of forage and that the calf would consume the entire daily milk yield of the cow. The rate of 45% was chosen because it gave an average creep intake for the calf group that matched the target intake set by the ranch manager and accounted for variance in intake amount based on varying calf sizes. However, by replacing a lower nutritive value forage with a higher nutritive value creep feed, the model will iterate at a lesser peak milk yield of the cow to match the actual weaning weight of the calf. Target creep-feed intake was 1.81 kg/(calf · day) and was set to begin on day 23 of pregnancy and end on day 113 of pregnancy which was assumed to be the last 90 days of lactation. This model alteration

was only necessary for fall-calving cows since only fall calves were offered creep-feed. From performance and forage/feed inputs, the model calculated values for ME Maintenance (MEM), ME Pregnancy (MEP), ME Lactation (MEL), Total ME Required (MER), Cow EEI, Cow+calf EEI, PkM (kg/d), Energy Balance at Nadir (EBNadir), Days Pregnant at Nadir (DPNadir), and Days in Milk at Nadir (DIMNadir).

Additional alterations were made to the model to calculate monthly feed costs incurred per cow for hay and supplement/creep-feed. The modification allowed prices to be input per month per study year for hay, cow supplement, and calf creep individually. Hay prices used were gathered from USDA market report archives' Missouri Weekly Hay Summary as described in the Economic Analysis section. Hay price inputs ($/ton) for April were multiplied by 0.25 to emulate estimated hay:pasture consumption (25% hay, 75% pasture); months in which no hay was estimated to be consumed contained no price input. Cow supplement/creed-feed prices were similarly input ($/ton) using LJR invoice records from South Central MFA Agri Services (Mountain Grove, MO). Cow supplement and calf creep-feed were input separately to allow for the calf creep-feed modification previously described. Prices were only input for months in which cow supplement or creep-feed were fed. Additional model outputs resulting from price inputs were Cow Feed ($), Calf Feed ($), and Total Feed ($).

Statistical Analysis

Performance and economic data were analyzed using ANOVA Mixed Procedure in SAS statistical software (SAS Inst., Cary, NC). The model included the fixed effects of calving months and calf sex, when appropriate, and the random effect of calving year. There was no calving month x calf sex interaction ($P > 0.10$) for any dependent variable analyzed and so the

interaction term was removed from the model. The Tukey-Kramer Method was used to generate probabilities and standard errors for differences of least square means between calving months. Pregnancy rate was analyzed using PROC GLIMMIX procedure with a binary response distribution for least square means. Significance difference was set at $P < 0.05$.

RESULTS

Forage Data

Although statistical analysis was not performed on forage analysis results, nutritional content of forage varied by month. A direct relationship was observed between TDN and CP as well as between NDF and ADF (Figure 8). The change in TDN and CP content in forage samples appears to have an inverse relationship with changes in NDF and ADF content of forage. Crude protein and TDN content increased during spring and early fall months, whereas NDF and ADF decreased during these periods but increased during summer and winter months. Metabolizable energy followed a similar pattern to TDN and CP with ME being highest in spring and fall months (Table 8). Metabolizable energy content of hay and supplemental feed was relatively consistent year-round with only slight variation. Average monthly precipitation and temperature during the study are presented in Figure 9 and Figure 10, respectively (University of Missouri).

Calf Sex Effects

Estimates for cow and calf performance, values, and returns as affected by calf sex are represented in Table 9. Calf sex had a significant ($P<0.05$) effect on calf BW, actual and 205-d-adjusted-WW (Adj. WW), and value/hd with bull calves having heavier BW, WW, and Adj. WW and bringing greater returns/calf than heifer calves. Cow ME requirements during pregnancy (MEP) and lactation (MEL) and total ME requirements during the production cycle (MER) were significantly greater ($P<0.05$) for cows that birthed bulls calves than heifer calves. Energy efficiency indexes were significantly less for cows with bull calves ($P<0.05$), and PkM

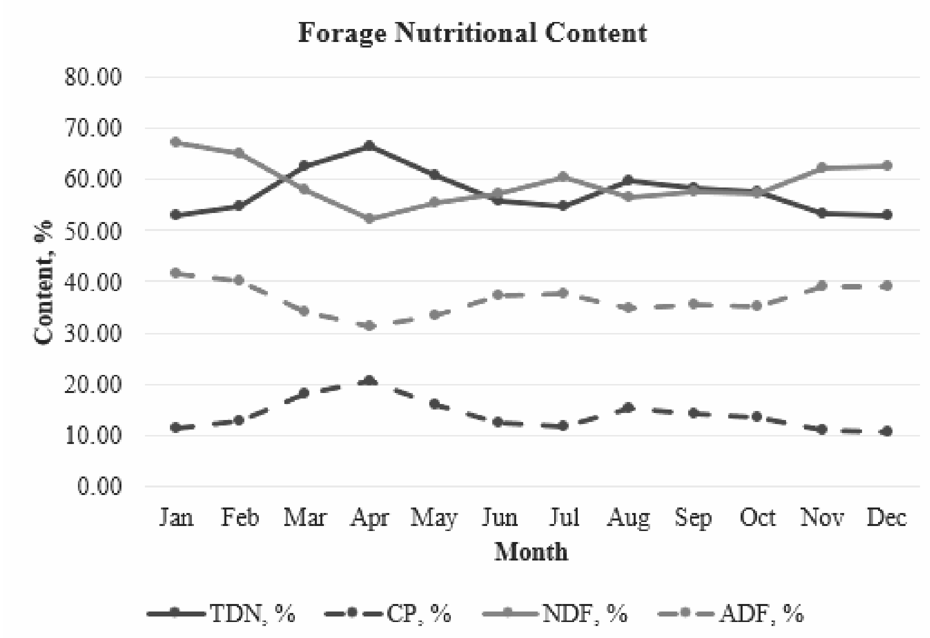

Figure 8: Mean forage sample TDN, CP, NDF, and ADF content from Journagan Ranch (36.993897, -92.258733) cow pastures during 2014-2018

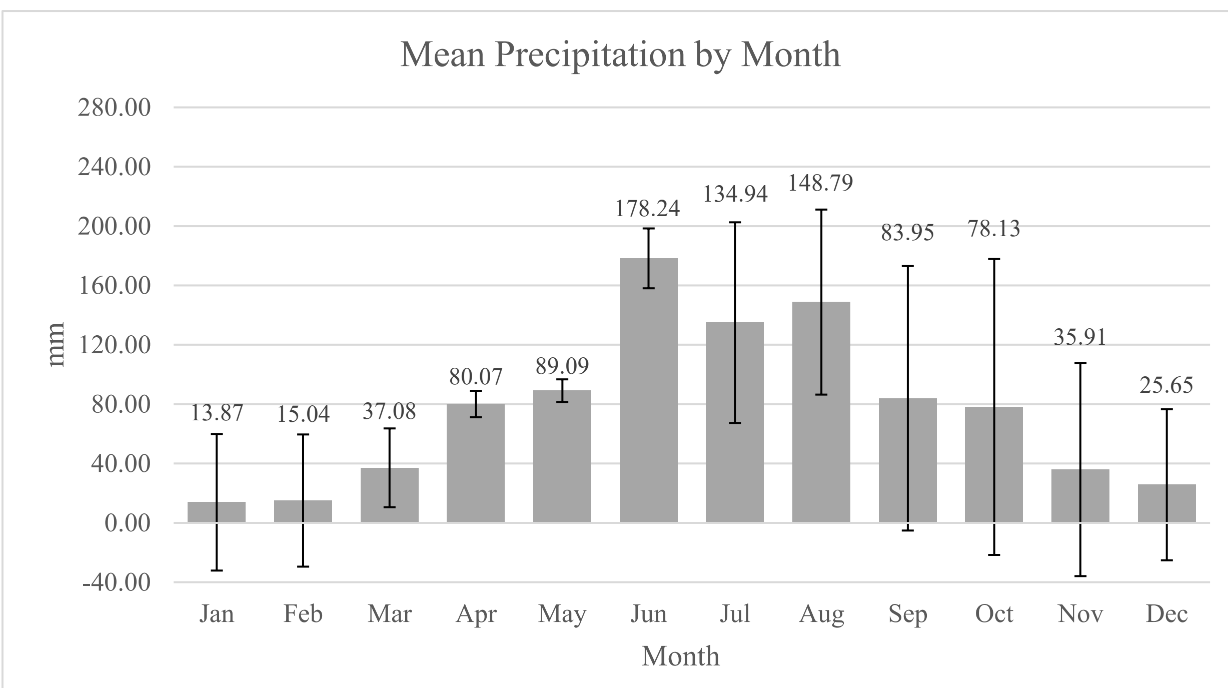

Figure 9. Mean (+/- SE) precipitation by month for years 2013-2019 recorded at Wright County Missouri State University Fruit Experiment Station 17.9 km north of Journagan Ranch (36.993897, -92.258733)

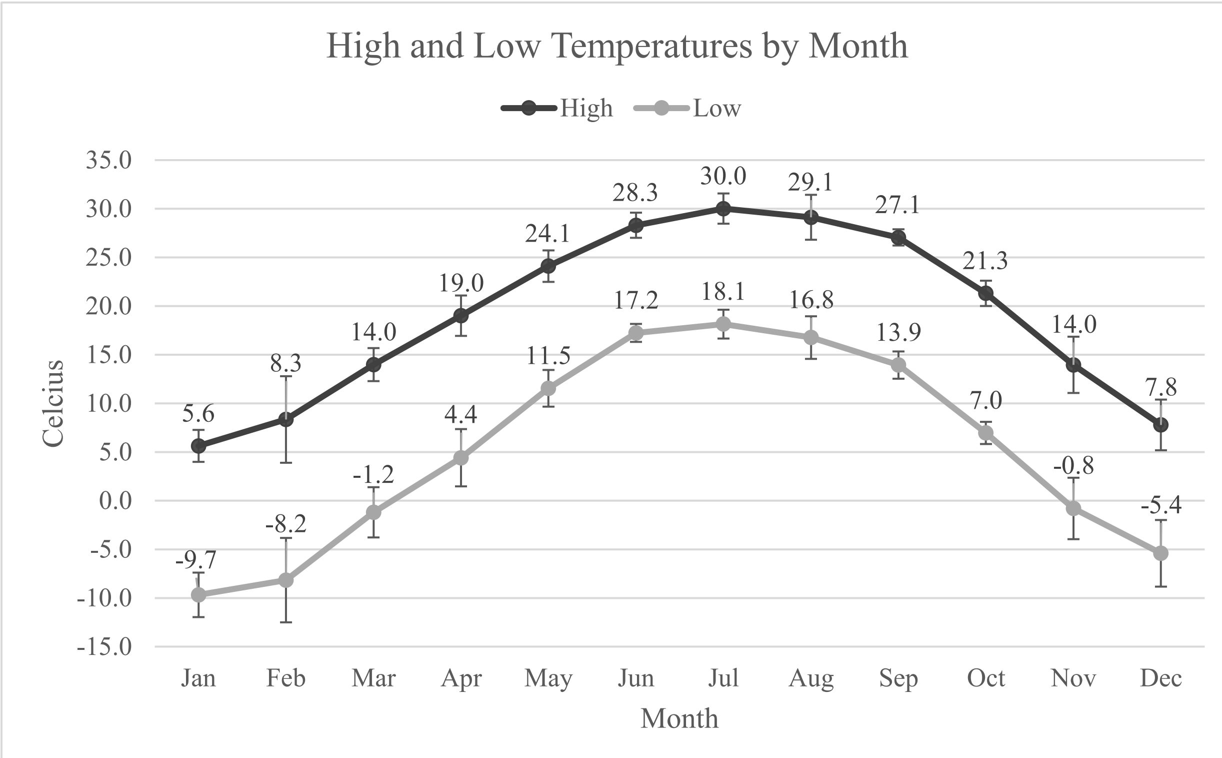

Figure 10. Mean (+/- SE) high and low temperatures by month for years 2013-2019 recorded at Wright County Missouri State University Fruit Experiment Station 17.9 km north of Journagan Ranch (36.993897, -92.258733)

produced was significantly greater for cows with bull calves (P<0.05). Net returns per calf were significantly greater for bull calves than heifer calves (P<0.05).

Calf Growth

The total number of calves born in each month during the study varied widely and is presented in Table 10. Due to wide variance in number of calves born each month, similarity of biological values was not always a consistent indicator of significant difference or similarity in variables. Least square means estimates for calf growth (BW, WW, and Adj WW) and Wean age by calving month are represented in Table 10. Calving month had a significant (P<0.05) effect on calf BW, WW, Wean age, and Adj. WW. Calves born in January through May had significantly heavier (P<0.05) BW than August and September (30.71 kg and 33.10 kg,

respectively) with other months being intermediate. Although the biological value of BW for calves born in July was numerically similar to those born in August, very few calves were born in July resulting in a large standard error for July compared with August. Thus, the mean BW for calves born in July was not significantly different ($P>0.05$) than any of the other months, whereas, the mean BW for calves born in August was lesser ($P<0.05$) than that for January through May and October.

Actual WW was significantly heavier ($P<0.05$) for calves born in January, August, and September (283.03 kg, 287.87 kg, and 294.68 kg, respectively) than calves born March through June and October through December with February and July being intermediate (263.81 kg and 224.26 kg, respectively). April and May-born calves (221.90 kg and 199.17 kg, respectively) had significantly lighter ($P<0.05$) WW than January through March and August through October. Wean ages were the greatest ($P<0.05$) for calves born in January, August, and September (259.65 d, 275.58 d, and 255.14 d, respectively) and least ($P<0.05$) for calves born in April, May, and June (185.17, 165.53 d and 186.92, respectively) with all other months intermediate. These results are consistent with the weaning practices for the spring and fall calving herds at LJR such that calves born earlier in the calving season were weaned at an older age than those born later in the season because all calves within a calving season were weaned at approximately the same time. Wean age for calves born in July and December varied some from this trend since some of these late-born calves were weaned with the group born in the following season. There were no significant differences (T-test $P>0.05$) between months for 205-d-adjusted WW, although calving month did account for a significant amount of the total variation (F-test $P<0.05$).

Cow Weight, Body Condition, and Re-breeding Ability

Cow weight, body condition, and re-breeding ability as affected by calving month are summarized in Table 11. Calving month had a significant effect on MCW, BCS at calving and weaning, calving interval, and pregnancy rate ($P<0.05$). Cows that gave birth in April had significantly heavier ($P<0.05$) MCW at weaning (582.48 kg) than cows that gave birth in February, August, and September (561.01 kg, 520.82 kg, and 554.32 kg, respectively) with all other months intermediate. The biological value for December MCW was the lowest numerically, but was not significantly different from April; this was due to December MCW's large SE (42.69 kg) which was likely caused by only 10 cows giving birth in that month over the duration of the study. Calving BCS for cows that calved in September and October (6.15 and 6.16, respectively) was significantly greater ($P<0.05$) than cows that calved in January through April. February cows (5.56) had significantly lesser ($P<0.05$) Calving BCS than March cows (5.73); and all other months were intermediate. Although there were no significant differences (T-test $P>0.05$) between months for Weaning BCS, calving month did account for a significant amount of the total variation (F-test $P<0.05$). Data records included neither Calving BCS or Weaning BCS for cows that calved in July nor Weaning BCS for December-calving cows.

Cows that calved in April and October (346.53 d and 347.53 d, respectively) had significantly shorter ($P<0.05$) Calving Intervals (CI) than cows that calved in January, February, August, and September; and other months were intermediate. January-calving cows' CI (404.48 d) was significantly longer ($P<0.05$) than February through May and September through November. Pregnancy Rate for cows that calved in February (0.85) was significantly greater ($P<0.05$) than cows that calved in June and September (0.40 and 0.71, respectively). June-

calving cow Pregnancy Rate was also lesser (P<0.05) than January and October (0.87 and 0.83, respectively). Pregnancy Rates for all other months were intermediate.

Cow ME Requirements and Energy Efficiency

Cow ME requirements for production are represented in Table 12. Metabolizable energy requirements for maintenance (MEM) were not significantly affected by calving month (P>0.05). Calving month had significant effect on ME requirements for pregnancy (MEP) and lactation (MEL) and total ME requirements (MER) (P<0.05). Metabolizable energy required for pregnancy (MEP) for cows that calved in August and September (459.30 Mcal and 499.60 Mcal, respectively) was significantly lesser (P<0.05) than cows that calved January through May and October, and all other months were intermediate. Metabolizable energy requirements for lactation (MEL) were significantly greater (P<0.05) for cows giving birth in January, February, and March (1018.59 Mcal, 990.82 Mcal, and 989.86 Mcal, respectively) than cows that gave birth in May, June, and August through November. Cows that calved in July (681.49 Mcal) had least biological value; however, as a result of a large SE (±109.69 Mcal), July MEL was not significantly different (P>0.05) from other months. Although MER was significantly affected by calving month (F test P<0.05), there were no significant differences between months (T test P>0.05).

Energy efficiency indexes (EEI) and Peak milk production are represented in Table 13. Cow EEI, Cow-calf EEI, and Peak milk production were significantly affected by calving month (P<0.05). Cows calving in August and September showed significantly more desirable (P<0.05) Cow EEI scores (26.13 Mcal/kg and 26.94 Mcal/kg) than other months except January and December. May calving cows (40.19 Mcal) had significantly greater (P<0.05) Cow EEI than

cows that calved in January through April and August through November, and all other months were intermediate. Scores for Cow+calf EEI were significantly more desirable ($P<0.05$) for cows calving in September (31.37 Mcal/kg) than in February through July. Cow+calf EEI was significantly worse ($P<0.05$) when cows calved in May and June (42.36 Mcal/kg and 44.19 Mcal/kg, respectively) than in January through April and August through November, and other months were intermediate. While there were significant differences between calving month EEI scores, numerical score was not a consistent predictor of statistical significant difference. Peak milk yields were significantly greater ($P<0.05$) for cows that calved in January through May than in August through October, and other months were intermediate.

Lowest energy balance and number of days pregnant and number of days in milk at the point of lowest energy balance during the production cycle were significantly affected by calving month ($P<0.05$) and are represented in Table 14. Cows giving birth in October had significantly greater ($P<0.05$) energy level at their point of lowest energy balance (1.04 Mcal) than cows that gave birth in January through June and August and September. Overall, cows that gave birth in January through May had significantly lesser ($P<0.05$) lowest energy balances than those that gave birth in August through December. At the point of lowest energy balance, cows that gave birth in January through July were at a significantly ($P<0.05$) earlier point in gestation at the point of lowest energy balance than cows that gave birth in August through December. Number of days in milk at lowest energy balance (DIMNadir) was significantly different ($P<0.05$) for cows that calved in October (181.93 d), being earlier than August and September but later than other months. Cows that calved in August and September (247.35 d and 232.28 d, respectively) had a significantly later ($P<0.05$) DIMNadir than cows that calved in other months. Cows that were part of the spring-calving group had lower energy balances and reached their lowest energy

balance earlier in pregnancy and lactation than cows in the fall-calving group (P<0.05). This pattern is likely the result of fall-calving cows receiving supplemental feed for a longer portion of the year (August through April) and not lactating during increased summer temperatures and while grazing forage of lesser quality resulting from advanced forage maturity.

Income and Costs

Yearly cost for hay and supplemental feed were significantly affected by calving month (P<0.05; Table 15). Cows giving birth in October ($194.69/cow) incurred significantly greater (P<0.05) feed costs than cows that gave birth in January and May ($184.33 and $179.28, respectively), and other months were intermediate. Calf feed costs were significantly greater (P<0.05) for calves born in August and September ($58.92/hd and $56.66/hd, respectively), and calves born in January through May incurred the least feed costs (P<0.05). The occurrence of negative costs incurred for calves born in March, April, and May was the result of model calculations as calves born in these months were not creep-fed nor required hay, thus not incurring actual feed costs. Total feed costs for both cow and calf were significantly greater (P<0.05) when calves were born in September ($244.70) than other months except August and October ($241.72 and $238.09, respectively; P>0.05). With the exception of July and December ($206.20 and $202.03, respectively; P>0.05), spring-group cows and calves (January through June) incurred significantly lesser (P<0.05) total feed costs than fall-group (August through November) cows and calves.

Value of weaned calves and cull cows and net return per calf born were significantly different (P<0.05) by calf month and are presented in Table 16. Calf value was the greatest (P<0.05) for calves born in September ($1,127.65). Calf value for each month for calves born

January through May were all significantly different (P<0.05) with January calf values being the greatest of these months ($1053.69; P<0.05) and values progressively decreasing with May calves ($819.12; P<0.05) having the least value of these months. With the exception of September, all other months were intermediate. Cow value was significantly affected by calving month; however cows that calved in August ($711.39) significantly differed (P<0.05) being valued less than other months except for cows that calved in July, November, and December ($796.17, $916.36, and $689.40, respectively; P>0.05). Net returns per calf were significantly greater (P<0.05) than other birth months (except August, P>0.05) when calves were born in September and January ($882.32 and $875.50, respectively). Net returns for each month for calves born January through May were all significantly different (P<0.05) with January net returns being the greatest of these months ($875.50; P<0.05) and net returns progressively decreasing with May calves ($640.84; P<0.05) having the least net returns of these months. All other months were intermediate.

Table 8. Mean (+/- SD) metabolizable energy (Mcal/kg) of pasture forage, supplemental feed, [1]hay, and [1]baleage provided to cows and calves at [2]Journagan Ranch by month for years 2016-2018

	Pasture forage[3]							Supplemental feed[4]		
Month	2016	SD	2017	SD	2018	SD	Avg. ME	2016	2017	2018
January			1.86	0.06	2.05	0.21	1.96	2.86	2.90	2.84
February			1.97	0.15	1.96	0.20	1.97	2.86	2.87	2.84
March			2.00	0.12	2.15	0.28	2.08	2.86	2.88	2.87
April			2.34	0.13	2.26	0.30	2.30	2.86	2.88	2.87
May	2.11	0.08	2.40	0.07	2.19	0.09	2.23	2.86	2.88	2.87
June	1.97	0.05	2.34	0.09	1.92	0.02	2.08	2.86	2.84	2.87
July[5]	1.97	0.11	2.03	0.04	2.00	0.17	2.00	-	-	-
August	2.04	0.10	2.00	0.09	1.98	0.12	2.01	2.86	2.84	2.88
September	2.18	0.08	1.96	0.06	2.18	0.25	2.11	2.86	2.84	2.88
October	2.24	0.18	2.21	0.06	2.22	0.12	2.22	2.86	2.84	2.88
November	2.10	-	2.13	0.06	2.18	0.09	2.14	2.86	2.84	2.88
December	1.90	0.09	1.99	0.04	2.14	0.09	2.01	2.86	2.84	2.88
Hay	1.83		1.83		1.91		1.86			
Baleage			1.91							

[1]Hay and baleage was harvested at Journagan Ranch
[2]Journagan Ranch located at 36.993897, -92.258733
[3]Forage sampling began May 2016
[4]Supplemental feed was purchased from MFA in Mountain Grove, MO
[5]No supplemental feed was offered in July

Table 9. Mean (+/- SE) calf performance[1] (kg, d) and value ($) and cow energy requirements[2] (Mcal), performance[3] (Mcal/kg), and returns over feed cost per calf ($) by calf sex for Journagan Ranch[4] calf crops of 2014-2018

	Bulls	Heifers	SE	P-value
Number of calves	1180	1042		
BW, kg	34.66	33.36	0.68	<0.0001
WW, kg	251.99	238.96	14.53	<0.0001
Wean age, d	218.22	216.26	2.88	0.0641
Adj. WW, kg	240.53	230.83	11.74	<0.0001
Calf Value, $/calf	$957.03	$919.70	114.91	<0.0001
MEM, Mcal[5]	6308.80	6257.99	74.08	0.0831
MEP, Mcal	520.39	499.43	5.06	<0.0001
MEL, Mcal	888.26	817.04	37.84	<0.0001
MER, Mcal	7717.49	7574.52	99.86	<0.0001
Cow EEI, Mcal/kg	33.15	34.11	0.62	<0.0001
Cow + Calf EEI, Mcal/kg	36.57	37.49	0.60	<0.0001
PkM, kg/d	5.67	5.27	0.23	<0.0001
Returns over feed costs, $/calf	$749.73	$714.93	106.63	<0.0001

[1]BW = Birth weight; WW = Weaning weight; Adj. WW = 205-day adjusted weaning weight
[2]MEM = cow metabolizable energy (ME) required for maintenance; MEP = cow ME required for pregnancy; MEL = cow ME required for lactation; MER = total cow ME required
[3]EEI = energy efficiency index; PkM = peak milk production
[4]Journagan Ranch located at 36.993897, -92.258733

Table 10. Mean (+/- SE) calf growth performance[1] (kg, d) results by calving month for Journagan Ranch[2] calf crops of 2014-2018

Birth Month	n	BW, kg	SE	WW, kg	SE	Wean age, d	SE	ADG, kg	Adj. WW, kg	SE
Total number of calves	2222	2186		1959		1974		12	1959	
January	152	34.87[ab]	0.37	283.03[ac]	6.96	259.65[ab]	3.16	0.96	233.26[a]	5.75
February	867	35.44[a]	0.24	263.81[be]	6.19	237.81[c]	2.55	0.96	234.19[a]	4.84
March	555	35.84[a]	0.26	244.89[df]	6.28	211.21[e]	2.62	0.99	241.17[a]	4.95
April	179	36.00[a]	0.35	221.90[g]	6.76	185.17[f]	3.02	1.00	242.85[a]	5.53
May	58	34.97[ab]	0.53	199.17[h]	8.11	165.63[g]	4.01	0.99	237.81[a]	7.06
June	15	34.22[abd]	1.03	211.62[fgh]	12.19	186.92[fg]	6.71	0.95	232.94[a]	11.38
July	5	30.93[abd]	1.70	224.26[cefgh]	18.70	204.80[cdef]	10.73	0.94	219.35[a]	17.97
August	32	30.71[d]	0.74	287.87[ab]	10.13	275.58[a]	5.29	0.93	222.86[a]	9.23
September	202	33.10[cd]	0.34	294.68[a]	6.86	255.14[b]	3.09	1.03	243.37[a]	5.64
October	124	33.61[bc]	0.40	251.05[de]	7.24	226.70[d]	3.37	0.96	230.21[a]	6.08
November	23	33.69[abd]	0.87	232.14[efgh]	12.16	194.72[ef]	6.69	1.02	243.02[a]	11.34
December	10	34.72[abd]	1.21	231.29[efgh]	16.11	203.58[def]	9.15	0.97	247.08[a]	15.37
P-value		<0.0001		<0.0001		<0.0001			0.0063	

[1]BW = Birth weight; WW = Weaning weight; Adj WW = 205-d adjusted weaning weight; Average Daily Gain (ADG) = (WW-BW)/Wean age; ADG was calculated from BW and WW estimates for each month

[2]Journagan Ranch located at 36.993897, -92.258733

Table 11. Mean (+/- SE) cow weight (MCW), body condition scores (BCS), calving interval, and pregnancy rate by calving month for Journagan Ranch[1] calf crops of 2014-2018

Birth Month	MCW, kg	SE	Calving BCS	SE	Weaning BCS	SE	ΔBCS	Calving interval, d	SE	Pregnancy rate
Total number of cows	1908		1214		806			1328		2206
January	560.35^{ab}	8.99	5.61^{bc}	0.11	5.22^{a}	0.16	0.39	404.48^{a}	4.92	0.87^{ab}
February	561.01^{b}	6.52	5.56^{c}	0.08	5.30^{a}	0.10	0.26	384.05^{c}	2.29	0.85^{b}
March	568.81^{ab}	6.80	5.73^{b}	0.09	5.50^{a}	0.11	0.23	364.64^{bd}	3.05	0.78^{bc}
April	582.48^{a}	8.28	5.69^{bc}	0.10	5.57^{a}	0.14	0.12	346.53^{d}	4.95	0.78^{bc}
May	578.03^{ab}	11.70	5.91^{abc}	0.14	5.70^{a}	0.29	0.21	354.54^{bd}	8.36	0.74^{bc}
June	564.15^{ab}	21.21	6.20^{abc}	0.24	6.16^{a}	0.79	0.04	405.22^{acd}	21.97	0.40^{c}
July[2]	539.02^{ab}	33.33	-	-	-	-	-	378.34^{acd}	34.71	0.56^{bc}
August	520.82^{b}	16.53	6.31^{abc}	0.29	5.40^{a}	0.46	0.91	393.81^{abc}	11.65	0.70^{bc}
September	554.32^{b}	8.56	6.15^{a}	0.10	5.50^{a}	0.13	0.65	380.74^{bc}	5.00	0.71^{ac}
October	564.04^{ab}	9.63	6.16^{a}	0.11	5.59^{a}	0.15	0.57	347.53^{d}	5.96	0.83^{ab}
November	535.25^{ab}	23.92	5.97^{abc}	0.21	5.42^{a}	0.31	0.55	324.38^{cd}	20.04	0.66^{bc}
December[3]	486.74^{ab}	42.69	5.92^{abc}	0.44	-	-	-	316.99^{acd}	28.33	0.51^{bc}
P-value	0.0009		<0.0001		0.025			<0.0001		<0.0001

[1]Journagan Ranch located at 36.993897, -92.258733
[2]No Calving BCS or Weaning BCS were recorded for July-calving cows
[3]No Weaning BCS were recorded for December-calving cows

Table 12. Mean (+/- SE) total cow metabolizable energy requirements for maintenance in a year (MEM) and during pregnancy (MEP) and lactation (MEL) by calving month for Journagan Ranch[1] calf crops of 2014-2018

Birth Month	MEM, Mcal	SE	MEP, Mcal	SE	MEL, Mcal	SE	MER, Mcal	SE
January	6447.01[a]	80.18	524.58[ab]	5.71	1018.59[b]	39.55	7992.29[a]	106.58
February	6409.20[a]	59.37	537.61[a]	3.33	990.82[ab]	34.16	7935.90[a]	84.76
March	6437.63[a]	61.69	541.33[a]	3.63	989.86[ab]	34.72	7965.44[a]	87.13
April	6496.26[a]	74.04	543.38[a]	5.08	952.92[abc]	37.88	7987.95[a]	100.01
May	6410.55[a]	102.62	528.96[ab]	7.98	875.03[cd]	46.11	7807.44[a]	131.41
June	6289.29[a]	183.93	518.59[abd]	15.43	761.55[cd]	72.88	7579.45[a]	225.31
July	6114.96[a]	288.07	467.20[abd]	24.62	681.49[bd]	109.69	7249.60[a]	348.47
August	6191.46[a]	146.72	459.30[d]	12.06	779.09[cd]	60.25	7435.09[a]	181.85
September	6395.88[a]	76.63	499.60[cd]	5.35	867.34[cd]	38.57	7759.93[a]	102.75
October	6442.97[a]	86.50	507.29[bc]	6.38	781.70[d]	41.33	7736.32[a]	113.47
November	6114.58[a]	207.16	509.02[abd]	17.50	749.45[ad]	80.94	7382.71[a]	252.60
December	5645.13[a]	368.66	482.09[abd]	31.66	783.99[bd]	138.75	6919.97[a]	444.26
P-value	0.1878		<0.0001		<0.0001		<0.0001	

[1]Journagan Ranch located at 36.993897, -92.258733

Table 13. Mean (+/- SE) calving unit energy efficiency indexes (EEI[1]) using cow ME intake (cow EEI) and cow and calf intakes (cow + calf EEI) and cow peak milk by calving month for Journagan Ranch[2] calf crops of 2014-2018

Birth Month	Cow EEI	SE	Cow + calf EEI	SE	Peak milk, kg/d	SE
January	28.65^{gh}	0.66	33.09^{eh}	0.64	5.94^{a}	0.24
February	30.69^{f}	0.52	34.63^{ef}	0.49	5.93^{a}	0.20
March	33.17^{ce}	0.53	36.43^{bd}	0.51	6.20^{a}	0.21
April	36.91^{bd}	0.62	39.56^{c}	0.60	6.31^{a}	0.23
May	40.19^{a}	0.83	42.36^{a}	0.80	6.11^{a}	0.29
June	41.50^{ab}	1.44	44.19^{a}	1.41	5.54^{ab}	0.47
July	39.90^{abc}	2.24	42.93^{abc}	2.19	5.09^{ab}	0.71
August	26.13^{h}	1.16	31.05^{gh}	1.13	4.47^{b}	0.38
September	26.94^{h}	0.64	31.37^{h}	0.62	5.07^{b}	0.24
October	31.79^{ef}	0.71	35.58^{df}	0.69	4.73^{b}	0.25
November	33.55^{cdfg}	1.62	36.64^{cdeg}	1.58	4.80^{ab}	0.52
December	34.11^{abefh}	2.86	36.58^{acdeh}	2.80	5.42^{ab}	0.90
P-value	<0.0001		<0.0001		<0.0001	

[1]EEI = ME intake/calf WW
[2]Journagan Ranch located at 36.993897, -92.258733

Table 14. Mean (+/- SE) cow lowest energy balance (EBNadir) and number of days pregnant (DPNadir) and number of days in milk (DIMNadir) when least energy balance occurred by calving month for Journagan Ranch[1] calf crops of 2014-2018

Birth Month	EBNadir, Mcal	SE	DPNadir, d[2]	SE	DIMNadir, d	SE
January	-1.47^{de}	0.12	34.86^{d}	3.01	114.28^{cd}	2.78
February	-1.45^{de}	0.10	32.33^{d}	2.14	112.02^{d}	2.10
March	-1.75^{f}	0.10	31.59^{d}	2.24	111.97^{d}	2.17
April	-1.89^{f}	0.11	33.52^{d}	2.76	111.28^{d}	2.58
May	-1.79^{ef}	0.14	31.75^{d}	3.92	111.62^{d}	3.53
June	-0.87^{cd}	0.23	53.94^{d}	7.17	104.84^{d}	6.25
July	-0.05^{abc}	0.35	32.80^{d}	11.29	112.23^{cd}	9.77
August	0.08^{b}	0.19	168.04^{a}	5.69	247.35^{a}	5.00
September	0.27^{b}	0.12	160.28^{a}	2.86	232.28^{a}	2.66
October	1.04^{a}	0.13	101.90^{c}	3.27	181.93^{b}	2.99
November	1.02^{ab}	0.26	128.81^{bc}	8.09	136.59^{c}	7.04
December	0.32^{abc}	0.45	155.05^{ab}	14.46	114.12^{cd}	12.49
P-value	<0.0001		<0.0001		<0.0001	

[1]Journagan Ranch located at 36.993897, -92.258733

Table 15. Mean (+/- SE) costs ($) incurred for hay[1] and supplemental feed[2] by an individual cow or calf and total feed cost incurred in a year by calving unit by calving month for Journagan Ranch[3] calf crops of 2014-2018

Birth Month	Cow feed cost, $	SE	Calf feed cost, $	SE	Total feed cost, $	SE
January	184.33[c]	12.09	1.43[e]	0.55	185.82[ef]	11.91
February	191.04[ab]	12.00	0.50[e]	0.34	191.65[d]	11.81
March	190.81[ab]	12.01	(0.01)[e]	0.36	190.77[df]	11.82
April	186.45[ac]	12.06	(0.10)[e]	0.49	186.33[ef]	11.88
May	179.28[c]	12.20	(0.11)[e]	0.75	179.15[e]	12.05
June	176.77[ac]	12.86	18.08[d]	1.43	194.83[de]	12.81
July	172.86[bc]	14.14	33.39[c]	2.27	206.20[cde]	14.27
August	182.90[bc]	12.52	58.92[a]	1.12	241.72[ab]	12.41
September	188.04[bc]	12.07	56.66[a]	0.51	244.70[a]	11.89
October	194.69[b]	12.12	43.38[b]	0.61	238.09[ab]	11.95
November	191.57[bc]	13.10	31.48[c]	1.62	223.07[bc]	13.09
December	178.08[bc]	15.40	24.00[cd]	2.92	202.03[cde]	15.69
P-value	<0.0001		<0.0001		<0.0001	

[1]Hay harvested from Journagan Ranch[3]
[2]Supplemental feed was custom mix from MFA in Mountain Grove, MO
[3]Journagan Ranch located at 36.993897, -92.258733

Table 16. Mean (+/- SE) value ($) of weaned calf, cull cow, and net return over feed cost per calf born by calving month for Journagan Ranch[1] calf crops of 2014-2018

Birth Month	Calf value, $	SE	Cull Cow value, $	SE	Net return/calf[2], $	SE
January	1,053.69[b]	115.18	903.30[a]	146.20	875.50[a]	106.84
February	1,008.88[c]	114.63	889.81[a]	145.59	815.98[b]	106.22
March	971.73[d]	114.69	900.78[a]	145.65	782.77[c]	106.28
April	898.85[e]	115.04	924.42[a]	146.00	717.03[d]	106.64
May	819.12[f]	116.12	951.65[a]	147.07	640.84[e]	107.70
June	837.11[ef]	120.49	890.46[a]	151.89	644.59[de]	112.50
July	795.90[def]	130.48	796.17[ab]	161.59	590.54[cde]	121.99
August	1,019.22[bcd]	118.08	711.39[b]	149.20	786.38[abcd]	109.99
September	1,127.65[a]	115.11	896.75[a]	146.21	882.32[a]	106.72
October	1,003.90[bcd]	115.40	926.88[a]	146.67	761.87[cd]	107.06
November	944.68[bcdef]	120.44	916.36[ab]	159.00	702.30[bcde]	114.31
December	799.63[ef]	126.10	689.40[ab]	183.03	587.81[bcde]	131.42
P-value	<0.0001		<0.0001		<0.0001	

[1]Journagan Ranch located at 36.993897, -92.258733

[2]Net return/calf = calf value – cow and calf feed costs

DISCUSSION

The goal of this study was to determine if an optimal time of year exists for beef cows to give birth in southwest Missouri based on performance and, ultimately, net returns. Income generated from cattle sales is generally the greatest concern of most beef producers. Income potential varies throughout the year as a result of supply and demand; therefore, since over 70% of calves are born in spring months and sold in the fall months, calf prices are generally lower than for fall-born calves (USDA, 2020). However, feed costs tend to be higher if a producer must provide hay and supplemental feed over the winter for a calf and lactating cow.

Net Return and Calf Growth

According to results from this study, September appears to be the most beneficial month to have calves be born. Although total feed costs were among the greatest when calves were born in September, calf value at weaning was also significantly greater than for other months. These calves were weaned with other fall-born calves and sold during the high price period in late spring. Since September is early in the breeding season, these calves were also the heaviest at weaning thus having the greatest sale value. Income for September-born calves surpassed feed costs to achieve net returns greater than other months except for calves born in January. It is also of note that September calves had not only the heaviest actual WW, but among the greatest ADG (1.03 kg/d), although 205-d adjusted WW were not significantly different between months. Rate of gain for September calves may have been positively influenced by a greater creep feed intake resulting from calves being older with more developed rumen capabilities when creep feed began to be offered (Anderson et al., 1987; Prichard et al., 1989). Calves born in January followed

September calves as the next best month for achieving optimal net returns. Like September calves, January calves were born at the beginning of the calving season and were older and heavier at weaning; and, although sold during the reduced-price period, achieved increased net returns due to decreased feed costs and heavy WW.

Alternatively, from a financial standpoint, the worst months to have cows calve were those toward the end of each breeding season. Calves born in these months were younger and generally lighter at weaning and, therefore, brought less income. Evidence of the effect of weaning age can be seen when observing the significant decrease in WW, calf value, and net returns for calves born in January through May. However, no significant differences were observed between months when WW were adjusted to a constant 205-days of age; but ADG did vary between months (although ADG was not statistically analyzed). Due to the weaning practices of this study, this data set may not give an accurate representation of monthly environmental effects on WW, and further study with lactation periods of equal length for all calves may be necessary.

Calves born in June and July did not follow the lessening trend for WW with the rest of the spring-group. However, few calves were born in June and July, which caused large SE (12.19 kg and 18.70 kg, respectively). Also, the ranch manager delayed weaning some June and July calves until late spring when fall-group calves were weaned; these calves were 10 to 11 months old at weaning. Average daily gains for calves born in July and August were lesser than other months. Dams of these calves were likely exposed to increased temperatures in the last couple months leading up to calving which has been shown to have a negative effect on both pre- and post-natal calf growth, putting these calves at a weight disadvantage in addition to being sold during decreased prices (Roman-Ponce et al., 1978; Collier et al., 1982; Tao et al., 2012;

Monteiro et al., 2016). Grings et al. (2005) also observed that calves born in June tended to have lighter weaning weight that those born in February or April although weaned at the same age (190 d).

Cow Performance

In addition to considering income and net returns, performance must be considered when deciding optimal calving time. Calving periods can be scheduled to minimize environmental effects, such as weather and forage quality, on feed efficiency which in turn affects reproductive performance. Excellent reproductive performance is paramount to a profitable cow-calf operation and preventing unnecessary expenditures from purchasing replacement cows or developing replacement heifers.

Re-breeding. Results for optimal month for achieving maximal re-breeding performance were mixed. Cows which calved in January, February, and October appeared to have the greatest pregnancy rates although they only significantly differed from June cows, and February cows' rates were only significantly greater than September. However, January and February had significantly longer CI than October as well as other spring-group cows, indicating that, while cows consistently conceived, they may have taken longer to resume estrous cycles or required more breedings to conceive than cows that calved later in the year. Results are consistent with White et al. (2002) who observed cows' estrus duration to be shorter in winter, and Buch et al. (1955) who found that the interval from parturition and first estrus is longer for cows that calved in winter. Burris and Priode (1958) observed that cows that calved early in the calving season had increased pregnancy rates. Having calved early in the season and, therefore, having an

extended breeding period may explain the better pregnancy rates of January and February-calving cows despite these negative effects on the estrous cycle.

Cows that gave birth in June had the worst pregnancy rate (0.40). June was near the end of the calving season, meaning the breeding period for these cows may have been cut short. Cows that calved in July and December also had biologically lesser pregnancy rates (0.56 and 0.51) although these were not significantly different from other months. December calving cows were likely prone to the estrous complications discussed previously for winter breeding and calved toward the end of the calving season. Cows that calved in June and July may have suffered from heat stress during the breeding season which has negative effects on estrus duration and follicular development and result in lower conception rates (Ingraham et al., 1974; Jordan, 2003). Since most cows in this study were bred via natural service, it is possible heat-stressed individuals did not participate in copulation as frequently, thus increasing the possibility of conception failure (White et al., 2002). Additionally, heat stress causes reduced spermatozoa motility and abnormal morphology which would have reduced sperm quality and negatively affected conception (Rahman et al., 2018).

Body Condition Changes. Body condition has a large influence on re-breeding ability Negative changes in body condition during lactation indicate a cow's nutritional requirements are not being met during this period of increased production. Change in BCS (ΔBCS) was calculated by subtracting Weaning BCS from Calving BCS and was negative for all calving months. In agreement with Story et al. (2000), loss of BCS during lactation decreased as calf age at weaning decreased; cows that calved early in the calving seasons lost the most BCS in their respective group (spring or fall) and late-calving cows lost the least BCS. Spring-group cows appear to have lost less BCS during lactation than fall-group cows, although ΔBCS was not

statistically analyzed. This is an interesting phenomenon considering cows in fall-group calving months were not calculated to have ever reached a negative energy balance (EBNadir) by the CVDS beef cow model, but EBNadir for spring-group cows were negative and significantly lower than for fall-group cows. This seeming may have been the result of an inaccuracy in the model's calculations. Fall-group cows may have produced more milk than the model calculated, which would have increased energy requirements and possibly cause a decreased EBNadir than the model predicted, resulting in the greater ΔBCS. Actual cow forage intake may also have differed from the that predicted by the model, and weather effects may have affected MEM but wasn't factored into the equation.

Cows that calved in September and October had significantly greater BCS at calving than most spring-group cows (January through April). This was likely caused by the increased energy requirement due to cold stress paired with decreased forage quality during late gestation of spring-calving cows, whereas September and October cows had access to forage of greater quality and availability in the summer months during late gestation. However, weaning BCS of fall cows did not differ from spring cows', possibly indicating a homeostatic BCS level typical to various lengths of lactation. These findings differed from Caldwell et al. (2013) who observed fall cows lost less BCS than spring cows during breeding, and BCS lost between breeding and weaning was slightly less for fall cows. In the study by Caldwell et al. (2013), fall cows had a greater BCS at weaning than spring cows. However, cows in Caldwell et al.'s (2013) study were grazed exclusively fescue, a cool-season grass, and the study was conducted about 130 miles south of the Journagan Ranch location. The growing season of cool-season grasses was possibly longer for Caldwell et al.'s study due to its southern location, providing fall-calving cows with better quality forage for a longer portion of the year and reducing BCS loss.

Cows with the least ΔBCS calved in June and April. Metabolizable energy requirements for cows that calved in June differed only from MEL of cows that calved in January, February, and March. June-calving cows likely experienced heat stress during the early lactation period which averaged 29.1°C for June, July, and August. Heat stress causes decreased milk yields which would lead to decreased MEL (Baumgard and Rhoads, 2013). However, this explanation cannot be applied to ME requirement differences in this study since weather conditions were not included in the equations for calculating ME requirements. However, the lactation period for calves born in June would have been shorter than other spring group calves, which were generally weaned in October. Consequently, the period of increased requirements for lactation was shortened, resulting in less time these cows may have been in a negative energy balance (which would have led to a greater ΔBCS) as a result of increased ME requirements for lactation. ME requirements during lactation for cows that calved in April significantly differed only from October; however, forage available to April-calving cows during lactation was of greater quality and lessened ΔBCS. Cows that calved in August had the greatest ΔBCS. Heat stress during late gestation and early lactation likely caused decreased intake which resulted in loss of BCS.

Energy Efficiency Index. For this study, energy efficiency was analyzed using the energy efficiency index (EEI) which compares cow ME requirements to calf weaning weight as a ratio. This method of analysis allows identification of cows able to produce more calf growth (through milk produced) while requiring less ME. While EEI scores are driven in part by genetics, environmental factors such as temperature, photoperiod, and forage quality also affect cow and calf requirements and growth.

More efficient cows with low EEI were those that calved in August and September, although January and December cows' EEI were not significantly different. Weaning weights for

calves born in both of these months were significantly greater than all months except January. Greater weaning weights could be attributed to calves being older at weaning, but when comparing to spring-group calves it should be noted that August- and September-born calves (as part of the fall-group) were creep fed which has positive effects on WW (Martin et al., 1981; Sexten et al., 2004). Metabolizable energy requirements for pregnancy and lactation for cows that calved in August and September were less than early spring months with August MEP being less than September. Although the CVDS model calculations for ME requirements do not account for temperature, the lighter BW of August- and September-born calves may evidence the occurrence of heat stress and the resulting effects on MEP in which less energy is allocated to the pregnancy as a result of reduced uterine blood flow (Roman-Ponce et al., 1978; Collier et al., 1982). As a result of lesser cow ME requirements and heavy actual WW, cows calving in August and September were calculated to have the most desirable EEI.

Cows that calved in late spring to early summer (April through Jun) tended to have the least desirable EEI. These months tended to result in lighter WW than most other months, despite April and May cows having greater Peak milk than late summer and early fall-calving cows which had lower EEI. These calves born at the beginning of the summer months were likely affected by heat stress which contributes to lighter WW (Broucek et al., 2008; Nabenishi and Yamazaki, 2017). The EEI is a ratio based on WW and ME requirements. Since MER were not significantly different regardless of WW, the effects of heat stress and a shorter lactation period led to decreased actual WW, which caused these months to have a lesser EEI.

Milk production. Peak milk production was greatest for early to mid spring-calving cows (January through May) which significantly differed from cows that calved in late summer and early fall months (August through October). This is consistent with studies that show

increased milk production resulting from cows being exposed to shorter photoperiods during the dry period before parturition (Miller et al., 2000; Auchtung et al., 2005). Peak milk production was calculated by the CVDS model from cow ME requirements and calf WW, but an allowance for photoperiod was not included in the peak milk equation and, therefore, cannot be considered as a direct influence in this study. However, if the study cows' milk production was influenced by photoperiod during the data gathering phase, calf WW may have been affected as well. Since the model uses calf WW to calculate peak milk production, photoperiod may still have had an indirect affect on final peak milk results calculated by the model.

Along with greater milk production, MEL tended to be greater for spring-group cows, specifically cows that calved in January through March. The dry period preceding parturition in August through October occurred during months with long photoperiods which has been shown to result in cows producing less milk than cows exposed to short photoperiods during the dry period (Dahl and Petitclerc, 2003; Dahl et al., 2012). Cows likely also experienced heat stress during the months of late gestation which negatively affects milk yield and could have resulted in lighter WW and affect peak milk calculations (Monteiro et al., 2016). However, actual WW of spring-group calves were not consistently heavier than fall-group calves, which may have been caused by decreased intake from heat stress during summer months. Neither were spring-group calves offered creep feed which may have given fall-group calves a growth advantage.

Summary

Superiority of calving season is widely dependent on location and climate. Northern locations usually experience greatest benefit from spring or early summer calving, but producers in southern locations have found fall calving seasons to be preferable (Bagley et al., 1987;

Morrison et al., 1992; Pruitt et al., 2003; Reisenauer Leesburg et al., 2007; Payne et al., 2009). Some studies, including a northern study, found that reproductive performance tends to be better for fall-calving cows (Schillo et al., 1983; King and Macloed, 1984; Smith et al., 2012).

Contrary to other similar calving-season studies reviewed, results of this study do not point toward fall-group cows having superior reproductive performance. Overall, spring-calving cows lost less BCS during lactation, but pregnancy rates did not consistently differ between cows calving in the spring or fall months. Caldwell et al. (2013) and Campbell et al. (2013) disagreed with this conclusion, observing fall to be superior. Other studies not performed in the Central United States also found that cows that calved during fall months had better reproductive performance with greater luteinizing hormone secretion and a faster return to estrus post-parturition (Schillo et al., 1983; King and Macleod, 1984; Smith et al., 2012).

As previously mentioned, the greatest concern for most local producers is net returns. Calf growth is the driver for income potential. Caldwell et al. (2013) reported fall calving produced heavier WW, but Campbell et al. (2013) and Henry et al. (2016) found spring calves to be heavier at weaning. In the current study, January, September, and August calves had a greater WW than calves born other months, indicating that calving early in the season and an older wean age increased WW and final calf value. Creep-feeding likely contributed to September and August WW; however, August Adj. WW was numerically lesser than September Adj. WW, suggesting September may have greater ADG, but they were not significantly different. Other studies performed in similar locales, however, reported spring calves had greater ADG than fall-born calves (McCarter et al., 1991; Campbell et al., 2013).

Based on results from this study, we conclude calving early in a calving season, but specifically September, to be the most beneficial time for beef producers in SW Missouri to

schedule cows to give birth. September calves had the greatest calf value and resulted in significantly greater net returns than calves born in other months except for January and August. However, although January calves were not creep-fed, Adj. WW for January calves did not significantly differ from September calves. January calves likely would have gained addition weight and value if creep-fed; however, the additional cost of feeding may have lessened net returns. Caldwell et al. (2013), Campbell et al. (2013), and Henry et al. (2016) found fall-calving to result in greater returns per weaned calf. Additional studies should be conducted with equal weaning ages to more definitely identify time of year effects on WW and, consequently, income for SW Missouri cow and calf operations.

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