EFFECTS OF GESTATION AND LACTATION ON DRY MATTER INTAKE, DRY MATTER DIGESTIBILITY, RUMINAL FERMENTATION, AND PASSAGE RATES OF PRIMIPAROUS BEEF HEIFERS

by

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B.S, THE OHIO STATE UNIVERSITY, 2000
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AN ABSTRACT OF A DISSERTATION

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Abstract

Two experiments were conducted to evaluate the effects of late gestation and early lactation on the nutritional status of beef heifers fed low-quality, warm-season grass hay. The first experiment compared DMI, DM digestibility, and ruminal dynamics of pregnant and lactating beef heifers to non-gestating, non-lactating heifers of a similar age and size. This study demonstrated that pregnant heifers ate less than non-pregnant heifers while maintaining similar digestibilities. Intake was similar between lactating and non-lactating, though DM digestibility increased postpartum in lactating heifers. Ruminoreticular fill was less for pregnant than for non-pregnant heifers; ruminoreticular fill was similar regardless of lactation status. Ruminal NH$_3$ increased with increasing intakes throughout the study. Lactating heifers had less ruminal NH$_3$ than non-lactating heifers. Total ruminal VFA concentration was similar from 10 wk prepartum through 10 wk postpartum except at 2 wk prepartum when gestating heifers had less total ruminal VFA concentration. The second experiment compared DMI, DM digestibility, passage rate, and plasma glucose and BHBA concentrations between pregnant heifers, pregnant cows, lactating heifers, and lactating cows which were fed low-quality, warm-season grass hay supplemented with 450 g/d of soybean meal. This study demonstrated that DMI increased with progressing gestation in heifers. Lactating heifers had greater intake than other groups postpartum. DM digestibility decreased with advancing gestation; gestating animals had greater digestibility than non-gestating animals. Lactation status did not influence DM digestibility, though lactating heifers had greater digestibility from 3 to 7 wk postpartum. Digestibility was not influenced by age. Pregnant animals had faster digesta passage rates than non-pregnant counterparts. Plasma glucose concentration increased during the prepartum period; pregnant and lactating animals had lesser plasma glucose concentrations than non-gestating, non-lactating animals. Plasma BHBA concentration was greater in pregnant and lactating animals than in non-pregnant and non-lactating animal; age was not an influence on BHBA concentration. Calves from mature cows grew faster than calves from heifers. These studies showed that beef heifers do not have the same patterns of intake as mature cows during late gestation. Heifers and their calves exhibited poorer performance when compared to mature cows when fed low-quality, warm-season grass hay.
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Dedication

To my beautiful bride and the woman that has been there throughout this entire crazy trip. The woman who packed up the house and moved half way across the country to support me when we all know she didn’t want to move to the wilderness of Kansas. The woman who worked three jobs to support our family when I was “working” at the school. The mother of my child and my better half. Erin. Thank you from the bottom of my heart. Without you, this would not have been possible.
CHAPTER 1 - A Review of Literature

Introduction

Replacement beef heifers are necessary for the continuation of beef cow/calf operations. However, beef heifers require more intensive management than mature beef cows due to the greater energy demands for growth in addition to their production requirements for calf growth and milk production. Additional management is especially important for heifers grazing native range tallgrass prairie. Tallgrass prairie forage is abundant and is an inexpensive source of feed for cattle throughout the central plains region of the United States. However, Olson et al. (2008) showed that prairie grass typically is of poor quality with low crude protein (< 7%) and high acid-detergent fiber (42%). Prairie grass has low digestibility when compared to cool-season grasses (Vona et al., 1984) and is of the lowest quality during the late winter and early spring when the plants are dormant.

The goal of most cow/calf producers is to produce a replacement heifer that breeds at 14 mo of age, calves, and rebreeds on a 12 month interval annually in synch with the mature cows (Bagley, 1993). To accomplish this, replacement beef heifers are typically bred 15 to 30 d earlier than mature cows to allow greater time from parturition to first estrus and to ensure a 12-mo calving interval for 2-yr-old cows (Banta et al., 2005). However, earlier calving may occur during seasonal dormancy for many grazed plants, especially for warm-season prairie grasses, resulting in less nutrient availability for heifers during late gestation and early lactation, which are periods of elevated nutrient requirements (NRC, 2000). Diets high in dietary fiber may limit the capacity of the rumen and therefore limit intake (Dado and Allen, 1995).

In addition to grazing low quality pasture during late gestation, gestation has been shown to decrease dry matter intake in ruminants (Campling, 1966; Weston, 1988; Stanley et al., 1993; Allen, 1996; Scheaffer et al., 2001). The lack of forage of adequate quality does not allow cows to reach their genetic potential for production (Bagley, 1993) resulting in suboptimal animal performance including decreased BW, decreased body condition, and an extended postpartum interval. A decrease in BW during mid- to late gestation resulted in cows with greater calving intervals, lower pregnancy rates, and lighter calves at weaning (Godfrey et al., 1988). In addition, primiparous cows had longer postpartum intervals when compared to multiparous cows.
(Wiltbank, 1970; Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000), and pregnancy rates for primiparous cows with a BCS of 4 were only 53% compared to 90% for primiparous cows with BCS 5 or greater (Rae et al., 1993). Matching postpartum nutrient supply to nutrient requirements is necessary to support milk production and to maintain a 12-mo calving interval. Lactating beef cows require 20 to 30% greater dietary NE to maintain BW when compared to non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000); moreover, milk production is usually associated with significantly increased intake (Wagner et al., 1986; Hatfield et al., 1989). Postpartum energy restriction decreased conception rate and increased postpartum interval of beef cows (Banta et al., 2005).

Although the effects of late gestation and early lactation on nutrition in mature beef cows has been addressed in recent years, it is currently unclear to what extent gestation and lactation affect intake, digestion, and ingesta passage rate in beef heifers. In addition, behavior differences exist between primiparous and multiparous cows. Dairy heifers eat more meals per day, but eat smaller meals when compared to multiparous cows (Bach et al., 2006), especially during the first 60 d postpartum. This may have an influence on management strategies needed to optimize production of both animal groups. Inferring that information pertaining to mature beef cows is relevant to heifers may lead to mismanagement of heifers during the periparturient period and increase the likelihood of reproductive failure during the second breeding season.

The purpose of this literature review is to examine the current information available regarding the effects of late gestation and early lactation on intake, digestion, and metabolism in ruminants and to compare these effects in primiparous and multiparous cattle.

Effects of Gestation

Effect of Gestation on Intake

Forage dry matter intake by ruminants has been shown to decrease during late pregnancy (Campling, 1966; Weston, 1988; Vanzant et al., 1991; Stanley et al., 1993; Allen, 1996; Scheafer et al., 2001; Dorshorst and Grummer, 2002; Hayirli and Grummer, 2004; French, 2006). The decrease in intake is associated with reduction in ruminal volume caused by the rapid increase in fetal size during late gestation creating a physical impingement on ruminal volume
This is because 60% of fetal growth occurs during the last 2 mo of gestation (Bauman and Currie, 1980). Inert fill in the rumen has been shown cause a decrease in intake (Dado and Allen, 1995). In addition, Dado and Allen (1995) observed an increase in the frequency of small meals when high-forage and rumen-inert fill was added. This may explain the decrease in intake often associated with animals on high-forage or high-fiber diets. Dry matter intake prediction models developed for growing cattle have not been accurate for animals on all forage diets (NRC, 2000).

Cattle during late gestation have been shown to have decreased dry matter intake when compared to non-pregnant cows and heifers (Campling, 1966; Jordan et al., 1973, Ingvartsen and Andersen, 2000; Patterson et al., 2003). Campling (1966) was one of the earliest to investigate the role of pregnancy on dry matter intake in ruminants. He determined using monozygotic twin cows that gestation resulted in 17% less voluntary dry matter intake of hay when compared to non-gestating cows. Dairy heifers showed a decrease in dry matter intake from wk 26 of pregnancy until calving (Ingvartsen and Andersen, 2000). They determined that the reduction in intake was greatest for cows and heifers that were fed energy dense diets. The reduction was less or insignificant for animals fed low energy density diets (Ingvartsen and Andersen, 2000).

This is in contrast to Scheaffer et al. (2001) who did not see a change in dry matter intake with advancing stage of gestation. However, they also noted an increase in diet quality with advancing gestation to meet their targeted weight gain throughout the trial (from 7.2% CP at d 40 of gestation to 12.7% CP at d 200 of gestation). An increase in dietary quality would result in greater diet digestibility and less ruminal fill than would be observed with a low-quality diet. This could easily explain their findings. Hunter and Seibert (1986) observed no differences in dry matter intake as a percent of BW between pregnant and non-pregnant cows during the last 3 mo of gestation.

Beef cows have been shown to have greater intake than heifers (Varel and Kreikemeier, 1999). Parity also has an influence on intake in dairy cattle. Cows had greater dry matter intake as a percent of BW than heifers (1.88 vs. 1.69% of BW daily; Hayirli et al., 2002). In addition, heifers had a more constant dry matter intake until the last week of gestation at which time it decreased rapidly, whereas cows had a gradual decrease in dry matter intake for the final 3 wk prepartum (Hayirli et al., 2002). Similarly, Marquardt et al. (1977) demonstrated that heifers had a decrease in intake of 25% from 14 d prepartum until parturition while mature cows had a 50%
decrease in dry matter intake during the same time period. Johnson et al. (2003) found that parity had an effect on dry matter intake (kg/d), but did not affect intake as a percent of BW.

Breed differences in intake have been shown in dairy and beef breeds. Intake was reduced in Jerseys when a less digestible diet was fed, but no difference was observed in Holstein cows (Aikman et al., 2008). Dry matter intake was greater for breeds of beef cattle that had greater milk production (Wagner et al., 1986).

Effect of Gestation on Digestion

Intake has been shown to influence dry matter digestibility. Limit-feeding has been shown to increase diet digestibility when compared to animals fed to ad libitum intake (Galyean et al., 1979; Murphy et al., 1994; Clark et al., 2007). However, the decrease in dry matter intake associated with late gestation does not seem to have a similar effect on DM digestibility. Dry matter digestibility tended to be lower for gestating ewes than for non-gestating ewes (Coffey et al., 1989). Organic matter digestibility decreased in ewes as pregnancy advanced (Faichney and White, 1988b).

Pregnancy status does not have an effect on dry matter digestibility in either limit fed beef cows or cows fed to ad libitum intake (Hanks et al., 1993; Stanley et al., 1993 respectively). Vanzant et al. (1991) determined that organic matter digestibility was greatest at 12 d prepartum for beef heifers grazing range consisting of mixed cool-season and warm-season grasses. They also stated that this was during the period when forage quality was at the greatest during their trial which would have had an influence on diet digestibility.

Pregnancy status did not affect ruminal pH or individual ruminal VFA proportions, except valerate in limit-fed beef cows (Hanks et al., 1993; Scheaffer et al., 2001).

Ruminal ammonia concentration decreased with advancing gestation in beef heifers (Scheaffer et al., 2001). Ruminal ammonia concentrations were less in pregnant cows at 10 d prepartum (6.9 mg/dL) when compared to non-pregnant cows (8.0 mg/dL), but did not differ at 96, 68, or 41 d prepartum (Hanks et al., 1993). This decrease could be attributed to increased passage rate or decreased dry matter intake during late gestation (Hanks et al., 1993).
Jejunum and ileum tissue cell number increases with advancing gestation in forage fed beef heifers; this is probably a response to increased energy demand in the pregnant heifers (Scheaffer et al., 2003).

**Effect of Gestation on Ruminal Fill and Passage Rate**

During late gestation, ruminants fed diets with high concentrations of forages have demonstrated a decrease in dry matter intake (Weston et al., 1983, Stanley et al., 1993). This decrease has largely been attributed to decreased ruminal capacity from the growing fetus. However, the decrease in intake is not as great as the decrease in ruminal volume that occurs at this time (Forbes, 1970; Forbes, 1987). This would indicate that an increase in passage rate must occur to account for this difference.

Passage rate of NDF increases with increasing dry matter intake (Okine and Mathison, 1991). Hanks et al. (1993) determined that limit-fed pregnant cows had increased particulate passage rate and decreased ruminal and total tract mean retention time when compared to non-pregnant cows, thus showing that an increase in passage rate occurs even when intake does not change. This is similar to results from Weston et al. (1983) and Faichney and White (1988a). Ruminal indigestible ADF passage rate increased from 61 d prepartum to 6 d prepartum in mature beef cows (Stanley et al., 1993). Hanks et al. (1993) speculated that circulating estradiol concentrations may increase passage rate as well.

In addition, particulate passage rate has been shown to increase with increasing forage content of diets and is correlated to dry matter intake when expressed as a percent of body weight in sheep (Evans, 1981a). Increases in dietary fiber and rumen inert fill have been shown to increase passage rate in dairy cows to compensate for rumen fill (Dado and Allen, 1995). Diets with high forage content, especially during the late transition period, for dairy cows have resulted in increased particulate passage rates (Park et al., 2010).

Dado and Allen (1995) also observed an increase in total time spent chewing with the addition of fiber and rumen-inert bulk to the diet and speculated that additional chewing times may have increased DM digestibility and passage rate. Aikman et al. (2008) observed that Jersey cows had greater passage rates prepartum than was observed postpartum. In contrast, Holstein cows had similar passage rates pre- and postpartum. These researchers observed that
ruminal mean retention time in Jersey cows was less than in Holstein cows, which coincided with increased chewing times in the Jersey cows.

Decreased dietary forage content has been shown to decrease ruminal liquid turnover rate (Evans, 1981a). In contrast, ruminal liquid turnover rate increases with increasing dry matter intake in both cattle and sheep (Evans, 1981a). Ruminal fluid turnover rate was greater in pregnant cows than in non-pregnant cows (Weston et al., 1983).

Ruminal fluid fill was not affected by pregnancy status in limit-fed cows (Hanks et al., 1993). However, Scheaffer et al. (2001) observed less fluid fill in pregnant beef heifers fed alfalfa hay and corn silage to ad libitum intake when compared to non-pregnant controls. This effect was not observed for ruminal dry matter fill.

Effect of Lactation

Effect of Lactation on Intake

Mammary demands for amino acids, glucose, and fatty acids increase several-fold within 4 d of parturition (Bell, 1995). Cows have shown a dry matter intake increase postpartum when compared to non-lactating cows (Campling, 1966; Hunter and Siebert, 1986; Ovenell et al., 1991). Increase in nutrient demand from lactation has been used to explain rapid increases in dry matter intake postpartum in dairy cattle. In addition, dry matter intake is positively correlated to increasing milk production (Hatfield et al., 1989). Even accounting for increasing milk production with increased cow age (Neville, 1971) beef cows have substantially less milk production when compared to dairy cows. Therefore, less of a response would be expected for beef cows and heifers than what is observed in dairy cows (Vanzant, 1991).

Rumen volume was similar between dairy cows fed a high-fiber diet and cows that were fed low-fiber diets with the addition of rumen inert fill, but was less in cows fed a low-fiber diet without inert rumen fill (Dado and Allen, 1995).

Cow dry matter intake increased postpartum when compared to non-lactating cows (Jordan et al., 1973; Overnell et al., 1991). Hunter and Siebert (1986) reported that Brahman-cross cows had 25% greater dry matter intake during the first month postpartum when compared to non-lactating cows and 35% greater dry matter intake in the third month postpartum. Vanzant et al. (1991) reported 17% greater dry matter intake in lactating heifers 26 d postpartum when compared to non-lactating heifers and estimated that the difference would be greater as the
lactating heifers approached peak milk yield. Rosiere et al. (1980) determined that lactating
heifers had 40% greater intake of warm-season grasses than non-lactating heifers at 90 d
postpartum.

Johnson et al. (2003) determined that multiparous beef cows had 19% greater forage dry
matter intake than primiparous cows (kg/d). However, when expressed as a percentage of BW,
intakes of primiparous and multiparous cows did not differ (Johnson et al., 2003; Galindo-
Gonzalez et al., 2007). Johnson et al. (2003) determined that multiparous Brangus cows had
66% more milk production than primiparous Brangus cows, with similar dry matter intake.

Intakes by lactating cows and heifers were decreased by 16% when calves were early weaned
(Galindo-Gonzalez et al., 2007). This shows that energy demand from milk production is a
driving force for dry matter intake.

A breed difference exists for intake of beef and beef-cross cows during lactation. Daily DE
intake during lactation was greater for Simmental-Angus cross cows and Charolais-Angus cross
cows than for Jersey-Angus cows and Hereford-Angus cows (23.9 Mcal, 23.9 Mcal, 22.5 Mcal,
and 21.8 Mcal, respectively; Bowden, 1981). Daily milk production at this time was 6.6 kg, 5.6
kg, 6.7 kg, and 5.9 kg for Simmental-Angus, Charolais-Angus, Jersey-Angus, and Hereford-
Angus cows respectively.

**Effect of Lactation on Digestion**

Vanzant et al. (1991) determined that lactating beef heifers tended to have greater NDF
digestibility, but not organic matter digestibility, at 26 d postpartum than non-gestating, non-
lactating heifers. This is consistent with studies in ewes (Coffey et al., 1989). In contrast, Ovenell
et al. (1991) determined that lactation did not influence DM digestibility for prairie hay. Vanzant
et al. (1991) found no difference in total VFA concentration between lactating and non-lactating
heifers.

**Effect of Lactation on Passage Rate**

Particulate passage rate increases with increasing DE intake and dry matter intake (Evans,
1981B; Okine and Mathison, 1991). Lactating ewes have faster passage rates than non-lactating
ewes (Coffey et al., 1989). This has been shown in lactating beef heifers as well. Vanzant et al.
(1991) demonstrated that lactating beef heifers had faster indigestible ADF passage rates when compared to non-pregnant, non-lactating heifers.

Postpartum particulate passage rate has been reported to be less than prepartum passage rate (Stanley et al., 1993). Ovenell et al. (1991) determined that lactating cows did not differ in particulate passage rate when compared to non-lactating counterparts.

**Effect of Gestation and Lactation on Metabolism**

Prepartum dry matter intake and the magnitude of decrease in dry matter intake may affect postpartum metabolic disorders (Hayirli and Grummer, 2004).

Beef heifers have a dramatic increase in energy demand during late gestation. Daily ME requirements for pregnancy increased from 257 kcal on d 100 of gestation to 3,264 kcal on d 220 and 8,336 kcal on d 280 of gestation in beef heifers (Ferrell et al., 1976).

During early gestation, dairy heifers have a low concentration of plasma NEFA, but a high concentration of plasma glucose (Ingvartsen and Andersen, 2000). During late gestation there is an increase in hepatic gluconeogenesis along with decreased glucose utilization by tissues (Bell, 1995). Glucose concentration increases during the last week of pregnancy and drops to its lowest at 1 to 3 wk postpartum (Ingvartsen and Andersen, 2000). This was also observed numerically by Dorshorst and Grummer (2002), but the effect was not statistically significant.

An increase in lipolysis, resulting in increased plasma NEFA would be expected during late gestation (Bell, 1995). Ingvartsen and Andersen (2000) demonstrated an increase in plasma NEFA approximately 2 to 3 wk prepartum with a peak 1 wk postpartum. This is similar to that reported by Dorshorst and Grummer (2002), who observed an increase in plasma NEFA as animals approached parturition. Increases in plasma NEFA may be due to a decrease in dry matter intake during this time. French (2006) claimed that a decline in dry matter intake was associated with an increase in plasma NEFA; however, there was not a causative relationship.

Lactation increases the demand for glucose, fatty acids, and amino acids that cannot be met by dietary intake in high producing dairy cows (Bell, 1995). The metabolic demand from colostrum production exceeds the metabolic demand from the fetus during late gestation (Goff and Horst, 1997). This results in a reduction in lipogenesis, an increase in lipolysis, and increase in gluconeogenesis (Bauman and Currie, 1980; Bell, 1995).
The most obvious metabolic factor that occurs during lactation is the mobilization of fat from adipose tissue to support synthesis of milk (Bauman and Currie, 1980). Dairy heifers fed energy dense diets during pregnancy have high concentrations of plasma NEFA postpartum but reduced concentrations of plasma glucose (Ingvartsen and Andersen, 2000). NEFA increased from 2 or 3 wk prepartum to a maximum 1 wk postpartum (Ingvartsen and Andersen, 2000). Plasma glucose increases 1 wk prepartum, but drops to a low at 1 to 3 wk postpartum (Ingvartsen and Andersen, 2000). This can be explained by the 9-fold increase in glucose uptake by the mammary tissue on d 9 postpartum compared to d 2 prepartum (Bell, 1995).

Age and parity influence metabolism. Primiparous dairy cows had greater concentrations of plasma NEFA than multiparous cows as well as greater incidence of elevated BHBA concentrations (Meikle et al., 2004). This coincided with greater postpartum interval for heifers. These changes are due to an increase in energy demand from the mammary gland and an increase in the amount of mobilized lipids required to meet energy demand.

Metabolic control of intake during the periparturient period has been proposed (Illius and Jessop, 1996; Ingvartsen and Anderson, 2000, Allen et al., 2009). The oxidation of fatty acids in the brain, liver, and whole body have been investigated. However, rate of oxidation has been linked inversely to changes in body fat and therefore body condition. Blocking fatty acid oxidation has been shown to increase intake, but only when fatty acid oxidation was already high (Allen et al., 2009). The degree and rate of fatty acid oxidation influences the hypophagic response in dairy cattle. Unsaturated fatty acids decrease intake to a greater extent than saturated fatty acids due to more rapid oxidation of unsaturated fatty acids (Allen et al., 2009). Similarly, medium-chain fatty acids decrease intake more than long-chain fatty acids (Allen et al., 2009).

**Effects of Late Gestation and Early Lactation on Reproduction**

Bellows et al. (2002) determined that the yearly cost of beef cow infertility and reproductive disease in the United States was $441 to $502 million. Three-fourths of this is attributed to female infertility. Short et al. (1990) stated that anestrus is the major component of postpartum infertility in beef cattle, with the two largest components of this being suckling response and nutrition.
Primiparous cows have longer postpartum intervals than multiparous cows (Wiltbank, 1970; Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000; Banta et al., 2005). Because of this, replacement beef heifers are typically bred 15 to 30 d before mature cows to allow greater time from parturition to first estrus and to allow for 2-yr-old cows to rebreed at the same time as older cows (Banta et al., 2005). Matching the nutrient supply to nutrient requirement is necessary to support milk production and to maintain the desired 12-mo calving interval (Bagley, 1993). However, earlier calving of heifers may occur during seasonal dormancy for many grazed plants resulting in less nutrient availability during late gestation. This reduction in nutrient availability takes place during a period of elevated nutrient requirements (NRC, 2000) making it difficult to maintain BW and BCS during late gestation while feeding low-quality forage diets.

Prepartum nutrient supply can effect rebreeding (Randel, 1990). Cows and heifers that were fed a low-TDN diet during gestation had longer postpartum intervals than cows and heifers fed a high-TDN diet (Bellows et al., 1982).

Postpartum anestrus is a major contributor to infertility (Short et al., 1990), and cow nutrition is an important factor in postpartum anestrus. Negative energy and protein balance, both together and separately, associated with late gestation and early lactation have negative impacts on cow fertility (Sasser et al., 1988). Heifers had postpartum intervals that were 29 to 33 d greater than mature cows (Bellows et al., 1982; Galindo-Gonzalez et al., 2007). Cows in moderate body condition had shorter postpartum intervals and greater pregnancy rates than thin cows (Lents et al., 2008). In addition, lactation increased postpartum interval in thin cows, but has little effect in cows with adequate body condition (Wettemann et al., 2003).

Postpartum energy restriction decreased conception rate and increased postpartum interval of beef cows (Banta et al., 2005), whereas an increase in energy intake decreased postpartum interval (Lalman et al., 2000). Maintaining prepartum body condition between 5 and 7 can decrease the severity of anestrus and infertility (Short et al., 1990). Cows that lost BW during mid- to late gestation had greater calving intervals, lower pregnancy rates, and lighter calves at weaning (Godfrey et al., 1988). Pregnancy rates for primiparous cows with a BCS of 4 were only 53% compared to 90% for primiparous cows with BCS 5 or greater (Rae et al., 1993). Lalman et al. (1997) showed a linear decrease in postpartum interval with a linear increase in ME fed to primiparous beef heifers. An increase of one unit of body condition results in a 23% increase in pregnancy rate (Lamb et al., 2001).
Primiparous cows that were fed a higher energy diet postpartum had shorter postpartum intervals and greater first estrus pregnancy rates than primiparous cows fed a lower energy diet (Ciccioli et al., 2003).

Amount of milk production has an effect on postpartum interval in cows fed chopped hay (Hansen et al., 1982). This is especially true for animals with high milk production potential fed diets with limited nutrients. Beef heifers with greater milk production at 30 d postpartum had increased postpartum interval when fed low-quality hay (Lalman et al., 2000). Because of this, heifers benefit from early weaning of their calves (Lusby et al., 1981; Banta et al., 2005; Galindo-Gonzalez et al., 2007). Early weaning calves resulted in a 16% decrease in dry matter intake in multiparous and primiparous cows when compared to conventionally weaning calves (Galindo-Gonzalez et al., 2007). Galindo-Gonzalez et al. (2007) showed that primiparous cows had greater BW, BCS, and pregnancy rates when calves were weaned at 90 d instead of following a traditional weaning. This is due to a decrease in energy demand from lactation. Early weaning primiparous heifers also increased pregnancy rates when compared to heifers with conventionally weaning calves. Normally weaned cows ate 58% more DM on average than early weaned cows (Arthington and Minton, 2004). Early weaned cows reached postpartum estrus 8 wk earlier than normal weaned cows (Arthington and Minton, 2004). This shows that increased energy demand from sustained milk production has a negative effect on rebreeding.

Use of Dairy Cattle and Sheep Models for Predicting Intake in Beef Cattle

Sheep as an intake model

Because of ease of handling and lesser costs of housing, sheep have often been used as a model of voluntary intake in cattle (Cushnahan et al., 1994). However, while sheep have some similarities to beef cows, sheep have several limitations that limit their usefulness as a model for beef cow intake.

One positive aspect of sheep nutrition is that sheep are commonly fed forage based diets similar to those fed to beef cows. However, grazing sheep consume more forage per metabolic BW than grazing cattle (76 vs. 63 g/MBW; Cordova et al., 1978). Reticulorumen volume, expressed as % BW, is similar between sheep and cattle (9-13%; Van Soest, 1994).
At high intakes, sheep have been shown to have greater diet digestibility (Colucci et al., 1989) and lesser digesta retention times than cows (Colucci et al., 1990). Sheep with multiple lambs have a marked decrease in dry matter intake during late gestation. This is due to decreased ruminal capacity from the growing fetuses and gravid uterus (Campling, 1966; Ferguson, 1956; Gordon and Tribe, 1951; Reid and Hinks, 1962). Beef cows typically only carry a single fetus. Therefore, less of a response during late gestation might be expected in beef cows than what has been observed in ewes carrying multiple fetuses.

**Dairy cows as an intake model**

Dairy cows make unique animal models for voluntary intake because of high energy demand and marginal nutritional status, which makes them very responsive to nutritional changes (Allen et al., 2005). However, it is this high energy demand that makes them an unacceptable comparison for beef cows and heifers. Increase in nutrient demand from lactation has been used to explain rapid increases in dry matter intake postpartum in dairy cattle. Net energy requirements increased to 26 Mcal/d for dairy cows producing 30 kg/d of milk (Ingvartsen and Andersen, 2000). However, beef cows have less milk production when compared to dairy cows. In addition, Johnson et al. (2003) reported beef heifer milk yield was 40% less than that by multiparous beef cows during early lactation. Beef heifer milk production ranges from 5.4 to 6.7 kg/d and generally peaked by 6 wk postpartum (Bowden, 1981; Lalman et al., 2000; Johnson et al., 2003). This is dramatically less production and a much earlier peak of lactation than is expected from a mature Holstein. Therefore, less of a nutritional response would be expected for beef cows and heifers than what is observed in dairy cows (Vanzant, 1991).

Ingvartsen and Andersen (2000) showed that changes in plasma NEFA and plasma glucose were influenced by energy density of the diet. If this is true, beef cows and heifers, which are fed diets that are much lower in energy density than those fed to dairy cows, may not exhibit the drastic changes seen in the dairy animals. Unlike energy dense diets fed to dairy cows, forage based diets for beef cattle do not provide enough digestible energy for physiological demand to control intake (NRC, 1987). Instead, intake is limited by gastrointestinal fill. Short et al. (1990) stated that beef cattle and dairy cattle differ in management, but not in physiology. Differing management between dairy cows and beef cows make beef cow research
more difficult than dairy cow research. Dairy cows are commonly and easily housed in individual stalls that allow for easier experimental sampling (Allen et al., 2005), whereas beef cows are seldom housed individually. Occasionally dairy cows are housed similarly to beef cows. An example of this would be loose housing cows with automatic milking units as described by Bach et al. (2006). In this study cows were housed in a loose barn with access to an automatic milking unit. This allowed the cows to be milked as needed at random times throughout the day, similar to what would be seen with beef cows with suckling calves. Though the diets for the dairy cows would have greater energy density than most beef rations, it does allow for some more similar comparisons. Bach et al. (2006) observed that primiparous cows had a greater number of meals, but spent less total time eating than multiparous cows.

**Summary of Findings on the Effects of Gestation and Lactation on Beef Cow and Beef Heifer Nutrition**

Several generalizations can be made regarding the effects of gestation and lactation on nutritional status of beef cattle.

Advancing gestation leads to a decrease in ruminoreticular volume due to the growing fetus displacing the rumen. Some correction for this can be made by stretching of the rumen wall, which has been demonstrated in studies with inert material placed in the rumen to limit rumen capacity. However, during the last several months of gestation there is not enough space in the abdomen for the rumen to expand into because of the size of the rapidly growing fetus and gravid uterus. Therefore, based on simple first order rate equations several things may occur. The first is a decrease in dry matter intake. It has been well established that dry matter intake, especially of high forage diets, is decreased in ruminants with advancing gestation. However, the decrease in intake does not account for all of the decrease in ruminal volume observed meaning that another factor must be present as well. Particulate passage rate and ruminal fluid turnover rate have been demonstrated to increase with advancing gestation. The increase in ruminal particulate and fluid passage rate in conjunction with a decrease in intake may account for the difference in decreased ruminal volume. In addition, there is a 40 fold increase in ME demand from the growing fetus from the third month of gestation to the last month of gestation. The dramatic increase in energy demand results in a negative energy balance. This is characterized by
high concentrations of plasma NEFA due to increased lipolysis. The rapid oxidation of fatty acids in the liver further contributes to a decrease in intake during late gestation.

Following parturition the fetus no longer has an inhibition on ruminal capacity. This allows for an increase in intake to occur because of reduced physical impingement from the gravid uterus and fetus. At parturition, energy demand increases with increasing milk production. These factors contribute to an increase in postpartum DMI. DMI has been observed to be up to 40% greater in lactating beef cows within 3 months postpartum compared to non-lactating cows. In conjunction with increased DMI, lactating cows have greater passage rates when compared to non-lactating cows. However, postpartum passage rate is less than prepartum passage rate even though DMI is greater postpartum. In addition, energy demand from lactation exceeds the energy that can be obtained from a low-quality forage diet. This results in increasing lipolysis to meet energy demand and a subsequent increase in plasma NEFA concentration.

These findings show that late gestation and early lactation place constraints on the nutritional status of beef cows and heifers that must be corrected for by altering intake, passage rate, and changes occurring in metabolism to ensure rebreeding while maintaining yearly calf production.


CHAPTER 2 - EFFECTS OF GESTATION AND LACTATION ON DRY MATTER INTAKE, DRY MATTER DIGESTION, AND RUMINAL DYNAMICS OF PRIMIPAROUS BEEF HEIFERS FED TALLGRASS PRAIRIE HAY

Abstract

Ruminally-cannulated, Angus-cross heifers were individually fed chopped, warm-season grass hay (6.5% CP and 36.8% ADF) ad libitum for 68 d prepartum (n = 12; 7 pregnant and 5 non-pregnant; initial BW = 525 ± 53 kg) and 68 d postpartum (n = 11; 6 lactating and 5 non-lactating; initial BW = 504 ± 40 kg). Total tract DM digestibility (DMD), ruminoreticular fill, ruminal VFA, ruminal NH₃, particulate passage, and fluid dilution rate were measured every 14 d. Intake of DM by both pregnant (PREG) and non-pregnant (OPEN) heifers increased (main effect of period - P < 0.01) during the prepartum period; however, PREG ate less (P = 0.05) DM than OPEN. The DMI of both lactating (LACT) and non-lactating (NL) heifers increased (main effect of period - P < 0.01) during the postpartum period; however, DMI was similar (P = 0.39) between LACT and NL. Ruminoreticular fill (RRF) tended to increase over time prepartum (main effect of period - P = 0.07) but RRF of PREG was less (P = 0.03) than that of OPEN. Following parturition, RRF was relatively constant (main effect of period - P = 0.23) and heifers had similar RRF regardless of lactation status (P = 0.82). Prepartum DMD was similar (P = 0.14) between PREG and OPEN and generally decreased (main effect of period - P < 0.01) as intake increased. Postpartum DMD generally increased over time but the magnitude of the response was influenced by lactation status (treatment x period - P < 0.01). Ruminal NH₃ generally increased (treatment x period - P = 0.04) during the prepartum period. Ruminal NH₃ increased (main effect of period - P < 0.01) postpartum; moreover, LACT had less (P = 0.03) ruminal NH₃ than NL. Total ruminal VFA concentration was similar (P > 0.10) between treatments at 10, 8, 6,
and 4 wk prior to parturition; however, PREG had less (treatment x period, $P < 0.01$) total ruminal VFA than OPEN 2 wk before parturition. Postpartum total ruminal VFA concentrations were similar ($P = 0.97$) between LACT and NL. Particulate passage rate was similar ($P \geq 0.55$) between PREG and OPEN and between LACT and NL. Ruminal fluid dilution rate of PREG tended to be less ($P = 0.10$) than that of OPEN; however, it was similar ($P = 0.52$) between LACT and NL. Changes to intake, passage rate, and ruminal fermentation that are characteristic of beef cows during late gestation may not occur in beef heifers maintained on low-quality, warm-season grass hay diets.

Keywords: fermentation, gestation, heifers, intake, lactation

**Introduction**

Replacement beef heifers are typically bred 15 to 30 d before mature cows to allow more time from parturition to first estrus and to ensure a 12-mo calving interval for 2-yr-old cows (Banta et al., 2005). Earlier calving may occur during seasonal dormancy for many grazed plants resulting in less nutrient availability for heifers during late gestation and body condition loss prior to lactation. This takes place during a period of elevated nutrient requirements (NRC, 2000).

Forage DMI by beef cows typically decreases during late pregnancy (Campling, 1966; Weston, 1988; Stanley et al., 1993; Allen, 1996; Scheaffer et al., 2001). The decrease in DMI is associated with a reduction in ruminal volume caused by a rapid increase in fetal size during the final 45 to 60 d of gestation (Forbes, 1968). Maintaining BW during late gestation can be a challenge under these conditions. Cows that lost BW during mid- to late gestation had greater calving intervals, lower pregnancy rates, and lighter calves at weaning (Godfrey et al., 1988). In addition, primiparous cows had longer postpartum intervals when compared to multiparous cows (Wiltbank, 1970; Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000) and pregnancy rates for primiparous cows with a BCS of 4 were only 53% compared to 90% for primiparous cows with BCS 5 or greater (Rae et al., 1993).

Matching nutrient supply to nutrient requirement is necessary to support milk production and to maintain a 12-mo calving interval. Lactating beef cows require 20 to 30% more dietary energy
when compared to non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000); moreover, milk production is usually associated with significantly increased intake (Wagner et al., 1986; Hatfield, et al., 1989). Postpartum energy restriction decreased conception rate and increased postpartum interval of beef cows (Banta et al., 2005).

While much is known about pre- and postpartum nutrition of mature beef cows fed low-quality forages, similar information about primiparous heifers is scarce. This dearth of information contributes to mismanagement of heifers during the periparturient period and increases the likelihood of reproductive failure during the second breeding season. The objective of our study was to measure the effects of late gestation and early lactation on DMI, DMD, ruminal fermentation, and passage rates by primiparous beef heifers fed low-quality forages.

**Materials and Methods**

All procedures used in the care and management of animals in our study were approved by the Kansas State University Institutional Animal Care and Use Committee.

**Prepartum Phase**

Ruminally-cannulated Angus-cross heifers (n = 12; average initial BW 525 ± 53 kg) were housed indoors in individual tie-stalls (2 x 1.2 m) in an environmentally controlled barn (average temperature 25°C; average humidity 72%; 12 h light, 12 h dark) for an average of 68 d prepartum. Treatment assignments were based on pregnancy status. Twelve heifers were inseminated by transcervical AI approximately 213 d before the study began. Ovulation was synchronized before AI using the 7-11 Co-Synch protocol described by Eborn and Grieger (2007).

Eleven heifers were verified pregnant and one heifer was verified non-pregnant via transrectal ultrasonography approximately 150 d before the study began. Pregnancies of 4 randomly-selected pregnant heifers were terminated at that time by a veterinarian (25 mg Lutalyse, Pfizer Animal Health, New York, NY; 20 mg Dexamethasone, Agrilabs, St. Joseph, MO) to obtain a total of 5 non-pregnant controls (OPEN). Seven heifers began the study pregnant (PREG; calculated average initial day of gestation = 213 ± 14.5). One of the pregnant heifers became ill and was removed from the study on d 28 of the prepartum period.
Postpartum Phase

The heifers (n = 11; average initial BW 504 ± 40 kg) from the prepartum portion of the study were housed under the same conditions described previously for an average of 68 d postpartum. Treatment assignments were based on lactation status. Postpartum data collection was initiated on 6 heifers immediately after parturition (LACT). In addition, 5 heifers served as non-pregnant, non-lactating controls (NL). Calves were removed permanently from dams at 24 h of age. Lactating heifers were milked by machine twice daily (0500 h and 1500 h) thereafter to approximate the energy demand created by a nursing calf. Oxytocin injections (1 mL IM; VetOne, MWI Veterinary Supply, Meridian, ID) were given 1 min prior to milking to facilitate milk let down.

Feed

Botanical composition, chemical composition, and energy content of tallgrass prairie hay was described by Olson et al. (2008). Heifers were fed chopped tallgrass prairie hay (approximate particle length = 10 cm; 6.5 % CP, 36.8% ADF, 0.42% Ca, and 0.18% P) ad libitum in individual feed bunks (87 cm long x 152 cm high x 85 cm wide). Hay was kept in a covered barn before and after chopping; it was offered once daily (0700) at approximately 115% of the previous 5-d average voluntary intake. Daily hay refusals were weighed immediately prior to feeding the following morning (0630). Clean drinking water and trace-mineralized salt were available ad libitum.

Vanzant et al. (1991) reported that OMI of tallgrass prairie forage by British-type beef heifers was approximately 2% of BW during the final 55 d of gestation and 2.6% of BW 30 d after parturition. At these forage intakes, our hay exceeded minimum requirements of beef heifers (544 kg mature weight, 4.5 kg d⁻¹ peak milk) for NEm during the pre- and postpartum portions of our study (NRC, 2000; Olson et al., 2008). Conversely, our hay was slightly deficient in CP during the last 60 d of gestation but adequate in CP during the first 60 d of lactation (NRC, 2000).

Data Collection

The prepartum period and postpartum periods were each divided into 5 data-collection periods that were 14 d in length. Intake was measured on d 1-14 of each period and reported as the arithmetic mean for each animal. Fecal output was measured on d 9 to 12 of each period.
Fecal grab samples were collected every 4 h, with sample collection times advanced 1 h each day. Using this scheme, 1 sample was collected at each hour of the day (i.e., a total of 24 fecal samples over 4 d), in order to account for diurnal changes in composition. Fecal samples were dried for 72 h in a forced-air oven at 55°C to determine DM. Total tract nutrient digestion coefficients were calculated using ADIA as an internal marker according to Cochran and Galyean (1994). Stafford et al. (1996) reported that fecal recovery of ingested ADIA from beef cattle consuming hay of the type used in this study was quantitative.

Heifer BW were measured every 14 d throughout the study; BCS were determined at the time BW were measured as the average score assigned by 3 trained observers using a 9-point scale (1 = emaciated, 9 = obese; Neumann and Lusby, 1986).

Ruminal fermentation and fluid dilution rates were characterized on d 13 of each collection period. Cobalt-EDTA was used as an external marker of the fluid phase of ruminal digesta (Uden et al. 1980). The marker was infused via ruminal cannulae at a rate of 6.5 g Co-EDTA / heifer at 0800 h. Ruminal fluid samples were obtained from 3 randomly-selected areas of the ventral rumen just prior to marker dosing (0 h) and 4, 8, 12, 16, and 20 h after marker dosing. Ruminal fluid was strained through 4 layers of cheesecloth and separated into 2 aliquots: 10 mL for Co analysis and 10 mL for VFA and NH₃ analyses. The latter aliquot was combined with 2 mL of 25% (wt/vol) metaphosphoric acid. Ruminal fluid aliquots were frozen immediately after collection.

Ruminoreticular fill (RRF) and ruminal ADIA passage rates were measured on d 14 of each collection period. The RRF was measured by complete manual evacuation of digesta (fluid and solid fractions) from the rumen and reticulum immediately prior to and 4 h after the daily feeding (Olson et al., 1999). Ruminoreticular contents were completely removed, weighed, and mixed by hand; 4 subsamples of digesta were collected. After sampling, all contents were replaced via the ruminal fistula. Fill was calculated by averaging the RRF from the pre-feeding and post-feeding periods. Ruminal digesta DM was determined by drying samples in a forced-air oven at 55°C for 72 h. Ruminal DM fill was estimated by multiplying ruminal digesta DM by the total weight of ruminal digesta. Ruminal fluid fill was estimated as the difference between total ruminal fill and ruminal DM fill. Ruminal particulate passage rate was calculated as ADIA ingestion rate divided by ADIA concentration in ruminal digesta.
**Laboratory Analyses**

Forage, ort, fecal, and ruminal samples were dried for 72 h in a forced-air oven at 55°C and ground to pass through a 1-mm screen (Model 4 Wiley mill; Thomas Scientific, Swedesboro, NJ). Crude protein was determined by combustion (AOAC, 1980). Neutral-detergent fiber and ADF were determined using an Ankom Fiber Analyzer (Ankom200, Macedon, NY).

Ruminal fluid samples were thawed at room temperature for 2 h and centrifuged at 39,000 x g for 20 min. Ruminal NH$_3$ concentration in the supernatant was determined by colorimetry using an autoanalyzer (Seal Analytical, Mequon, WI; Broderick and Kang, 1980). Ruminal VFA concentrations were determined by GLC (column temperature = 130°C, injection and detector temperature = 250°C; column = 2 m x 4 mm i.d. glass packed with GP 10%; carrier gas = helium).

Cobalt content of ruminal fluid was determined by atomic absorption (Perkin Elmer Atomic Absorption Spectrometer 3110, Waltham, MA). The natural logarithm of cobalt concentration was regressed against sampling time to calculate fluid dilution rates (Warner and Stacey, 1968).

**Statistical Analyses**

All data were expressed relative to the average date of parturition for the pregnant heifers in our study. Pre- and postpartum data sets were each analyzed as 6-period, 2-treatment completely random repeated measure designs using the MIXED procedure of SAS (version 9.1, SAS Inst. Inc., Cary, NC). The model statements included terms for treatment, period, and treatment x period. Animal within treatment was included as a random effect. Period was the repeated effect with animal (treatment) as the subject.

Data describing ruminal fermentation and passage rates were analyzed as split-plot arrangements of completely random designs using the MIXED procedure of SAS. Whole plot effects included animal, period, and treatment. Subplot effects were time and treatment x time. Whole plot effects were tested using animal x period x treatment. Residual error was used to test subplot effects.

When significant $F$-tests ($P \leq 0.05$) were observed, pair-wise $t$-tests were used to separate means. Least-Squares Means were considered different when $P \leq 0.05$; trends and tendencies were discussed when $P > 0.05$ and $< 0.10$. 
Results and Discussion

**Body Weight and Body Condition Score**

Initial BW was similar ($P = 0.16$) between pregnant and non-pregnant heifers and BW was maintained throughout the gestation and lactation phases of the study (main effect of period - $P = 0.99$; Table 2-1). In contrast, Scheaffer et al. (2001) reported greater BW for pregnant heifers then for non-pregnant heifers. Pregnant heifers experienced a decrease in BW at parturition (Table 1). The decrease in BW at parturition in our study is accounted for by the weight of the calf and gravid uterus (average calf weight = 29 ± 13 kg). Body condition decreased over time for both PREG and OPEN (period main effect - $P < 0.001$); however, BCS was not influenced by pregnancy status ($P = 0.71$). Scheaffer et al. (2001) reported a decrease in carcass weight of pregnant heifers with advancing pregnancy indicating a loss of body mass to meet mammary development and to support the growing fetus.

During the postpartum period LACT had lower (treatment main effect; $P = 0.03$) BW from 4 wk postpartum until the end of the study (Table 2-2) when compared to NL. Non-lactating heifers had a general increase in BW throughout the postpartum period (period main effect – $P < 0.0001$), whereas lactating heifers did not increase BW. An increase in BW for NL implies an increase in body size towards mature BW during the study. A lack of BW increase in LACT indicates that energy demands for both lactation and growth were not being met.

Body condition score was influenced by lactation status and period (treatment x period effect – $P = 0.01$). NL increased BCS throughout the study (period main effect - $P < 0.001$), while lactating heifers showed a quadratic response with a decrease until 6 wk postpartum followed by an increase from 6 wk through the end of the study (data not shown). LACT had lower BCS when compared to NL (treatment main effect – $P < 0.001$). Lesser BCS in LACT shows that energy demands for lactation and growth were not being met due to the high energy demands relative to nutrient consumption.

**DMI and DM Digestion**

Both treatment groups generally increased (main effect of period - $P < 0.01$) DMI during the prepartum period (Figure 2-1); however, PREG ate less ($P = 0.02$) DM than OPEN (Figure 2-1). There is little agreement in published literature on the effects of late gestation on intake by beef cows or heifers. Similar to our research, Campling (1966) reported that pregnant dairy cows ate
less forage than their non-pregnant monozygotic twins. Conversely, Stanley et al. (1993) indicated pregnant mature beef cows ate more alfalfa than non-pregnant counterparts, whereas Scheaffer et al. (2001) reported no difference in DMI of a total mixed ration composed of alfalfa and corn silage between pregnant and non-pregnant beef heifers. Both Stanley et al. (1993) and Scheaffer et al. (2001) were feeding a diet that was more digestible and would potentially cause less ruminal fill than the warm-season hay that was fed during this study. Vanzant et al. (1991) reported greater intake of tallgrass prairie forage by pregnant heifers than by non-pregnant heifers 55 d prepartum; however, there was no difference in DMI 12 d prepartum. This may be in part because of the addition of alfalfa pellet supplementation and the greater passage rates that were present in the pregnant and lactating beef heifers in their study.

Increases in DMI that occur early during the final trimester of pregnancy have classically been attributed to increased nutrient requirements driven by the fetus and gravid uterus. In contrast, decreased DMI in the weeks immediately prior to parturition was usually associated with the rapidly-growing fetal tissues creating a physical impingement on the rumen (Forbes, 1986). Dry matter intake by pregnant heifers in our study sharply declined 2 wk prepartum, possibly because of a decrease in ruminal volume.

Lack of consensus on the effects of late-term pregnancy on DMI may have been caused by differences in the timing of intake measurements, differences in the classes of cattle, and differences in the nutrient density and digestibility of diets that occurred from study to study. Dry matter digestibility (DMD) was similar (\( P = 0.30 \)) between PREG and OPEN and generally decreased over time (main effect of period - \( P < 0.01 \)) as intake increased (Figure 2-1). Hanks et al. (1993) reported no difference in DMD between pregnant and non-pregnant cows, whereas Beharka et al. (1988) reported decreased DMD during late gestation. Vanzant et al. (1991) and Scheaffer et al. (2001) reported poorer DMD in pregnant heifers when compared to non-pregnant heifers. Increased DMI was usually associated with decreased DMD (Okine and Mathison, 1991). Additionally, increased DMI was usually accompanied by more rapid fluid and particulate passage (Allen, 1996). Mean ruminal retention time and the extent of DMD generally decrease under these conditions (Allen, 1996).

Lactating beef cows require 20 to 30% greater metabolizable energy than non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000); any postpartum increase in DMI may be explained by the increase in energy requirements associated with milk production.
(Vanzant et al., 1991; Johnson et al., 2003). Both lactating and non-lactating heifers generally increased (main effect of period - \( P < 0.01 \)) DMI as the postpartum portion of our study advanced but DMI was similar (\( P = 0.39 \)) between treatments (Figure 2-2). Most published research reported contrasting results. Rosiere et al. (1980) found that lactating heifers had greater DMI at 90 d and 150 d postpartum than non-lactating heifers when grazing low-quality forage. Rosiere et al. (1980) estimated DMI based on 24-hr fecal output divided by in vitro indigestibility of OM at 90 d and 150 d postpartum. It was suggested that some of the variation in intakes could be from inherent errors in the estimation technique. Forage intake should have overcome any restrictions in rumen fill from the fetus and gravid uterus by this stage of lactation. Ovenell et al. (1991) and Hatfield et al. (1989) reported greater DMI by lactating, mature beef cows than by non-lactating, mature beef cows when fed hay along with protein supplements. Campling (1966) and Hunter and Siebert (1986) reported 29% and 25% greater DMI by cows, respectively, following parturition. Both studies fed diets that were much greater in protein concentration than that in our study and greater digestibility would be expected. Marston and Lusby (1995) also reported that beef heifers increased DMI from late gestation until 6 wk postpartum. Vanzant et al. (1991) reported a 17% increase in DMI by lactating heifers over non-lactating heifers when measured 26 d postpartum. However, Vanzant et al. (1991) fed alfalfa pellets as a supplement and reported data from a single time point postpartum.

Apparent total-tract DMD in lactating heifers generally increased during the postpartum period but did not follow a consistent pattern in non-lactating heifers (treatment x period - \( P < 0.01 \); Figure 2-2). Diet digestibility was similar to that reported by Johnson et al. (2003) for primiparous beef heifers during early lactation and less than that reported for mature cows (Hatfield et al., 1989). Hatfield et al. (1989) evaluated diets that included dehydrated alfalfa pellets as well as hay; therefore, greater DMD would be expected. Marston and Lusby (1995) reported no differences in DMD of beef heifers based on lactation status; Ovenell et al. (1991) reported similar observations for mature cows. Vanzant et al. (1991) reported also that OM digestibility did not differ between lactating and non-lactating heifers 26 d post-partum. Conversely, Colucci et al. (1982) and Okine and Mathison (1991) reported that mature dairy cows experienced a post-partum depression in DMD concomitant with increased DMI. Classically, DMD and DMI have been inversely related (Clark et al., 2007). Increased rates of digesta passage and shorter digesta residence times in the gut are characteristic of both high
relative DMI and low relative diet digestibility (Moe et al., 1965; Colucci et al., 1982; Edionwe and Owen, 1989); mastication and rumination time per kg of DM decrease also with increased intake and may contribute to decreased DMD (Deswysen et al., 1987).

**Ruminoreticular Fill**

Total ruminoreticular fill (RRF) for PREG and OPEN tended to increase (main effect of period - $P = 0.07$) slightly during the prepartum period (Figure 2-3). This is in contrast to Stanley et al. (1993) who reported a general increase in ruminal fill in mature beef cows from d 61 until d 34 prepartum that was followed by a decrease in ruminal fill from d 34 to d 6 prepartum. Pregnant heifers had less ($P = 0.03$) RRF than OPEN. Weston, et al. (1983) made similar conclusions when comparing pregnant and open mature beef cows. In contrast, Beharka et al. (1988) reported no difference in rumen fill between pregnant and non-pregnant cows. Scheaffer et al. (2001) reported greater ruminal fill in pregnant heifers when compared to non-pregnant heifers during early gestation but less ruminal fill in pregnant heifers compared to non-pregnant heifers during late gestation. Hanks et al. (1993) reported less estimated gastrointestinal fill for pregnant than for non-pregnant beef cows. Less ruminal fill for pregnant heifers in our study as early as 10 wk prepartum may indicate a decrease in ruminal capacity earlier than what has been shown in mature beef cows. These factors may drive a change in digesta flow through the gastrointestinal tract of primiparous beef heifers that differs from that reported for mature beef cows.

Ruminal fluid fill did not change with advancing gestation (main effect of period - $P = 0.25$; Figure 2-3); however, PREG had less ($P = 0.04$) ruminal fluid fill when compared to OPEN. Vanzant et al. (1991) and Hanks et al. (1993) reported similar results in pregnant beef heifers and cows, respectively. Stanley et al. (1993) reported an increase in ruminal fluid fill in mature beef cows from 61 d to 34 d prepartum that was followed by a decrease in ruminal fluid fill from 34 d until 6 d prepartum. They attributed the late-term decrease to an increase in fetal size during late pregnancy. Scheaffer et al. (2001) reported greater ruminal fluid fill in pregnant heifers during early gestation compared to non-pregnant heifers but no difference during late gestation.

Ruminal solid fill increased with advancing gestation (main effect of period - $P < 0.01$; Figure 2-3). Pregnant heifers had less ($P = 0.02$) ruminal solids than OPEN. Vanzant et al. (1991) and Stanley et al. (1993) reported also that pregnant heifers and pregnant cows,
respectively, had less fill of ruminal solids than non-pregnant females. In contrast, Scheaffer et al. (2001) reported no difference in ruminal DM fill in pregnant and non-pregnant beef heifers. Total RRF did not change over time following parturition (main effect of period - \( P = 0.23 \); Figure 2-4). In addition, total RRF was similar (\( P = 0.82 \)) in lactating and non-lactating heifers. Stanley et al. (1993) reported an increase in ruminal fill in pregnant mature cows from parturition to 22 d postpartum. We speculated that greater gut capacity and appetite in mature cows compared to the heifers in our study contributed to these contrasting results.

Effects of lactation status on ruminal-fluid fill varied (treatment x period - \( P < 0.01 \)) over time. Vanzant et al. (1991) reached similar conclusions with fewer measurements of ruminal fluid fill than were made in our study. More precise characterization of ruminal fill during the 10 wk following parturition is probably not necessary.

Ruminal-solid fill of lactating and non-lactating heifers tended to increase (main effect of period - \( P = 0.06 \)) during the 10 wk following parturition but there was no difference (\( P = 0.57 \)) based on lactation status (Figure 2-4). Vanzant et al. (1991) indicated also that ruminal IADF fill was similar in pregnant and non-pregnant heifers.

**Milk Production**

Average milk production for lactating heifers peaked at 5.7 kg/d at 16 d postpartum (data not shown). The amount of milk at peak lactation was expected given the genetic potential for milk production of our heifers; however, peak milk was reached about 5 wk earlier than predicted by NRC (2000) for mature cows nursing calves. Peak milk production observed was 1.1 kg/d less than that reported by Bowden (1981) for primiparous heifers 6 wk postpartum owing to the fact that heifers in that study were of a different biological type and were supplemented with concentrates. Johnson et al. (2003) reported milk yield by beef heifers (i.e., 5.4 kg/d) that were similar to ours; they also reported that milk yield by heifers was 40% less than that by multiparous beef cows during early lactation.

**Ruminal Fermentation**

Ruminal NH\(_3\) was similar between pregnant and non-pregnant heifers during the prepartum period and the magnitude of response was influenced by period (treatment x period - \( P = 0.04 \); Figure 2-5). Ruminal NH\(_3\) concentrations were generally below the level recommended by Satter and Slyter (1974) as necessary to support maximal microbial cell protein production.
Weston (1983) and Scheaffer et al. (2001) reported a decrease in ruminal NH$_3$ in pregnant sheep and heifers, respectively, compared to non-pregnant counterparts. In contrast, Vanzant et al. (1991) reported an increase in ruminal NH$_3$ early in pregnancy followed by a decrease in ruminal NH$_3$ during late pregnancy. Hanks et al. (1993) likewise reported no difference in NH$_3$ until 10 d prepartum, at which time pregnant cows had less NH$_3$ than non-pregnant cows. A decrease in ruminal NH$_3$ concentration is often associated with an increase in ruminal passage rate or an increase in DMI (Adams and Kartchner, 1984). Scheaffer et al. (2001) suggested that increased nutrient demand by the fetus may drive greater absorption of ruminal NH$_3$.

Total ruminal VFA concentration was generally similar between pregnant and non-pregnant heifers during the prepartum period and the magnitude of response was influenced by period (treatment x period - $P < 0.01$; Figure 2-5). Similarly, Scheaffer et al. (2001) and Vanzant et al. (1991) reported no differences in total VFA concentration between pregnant and non-pregnant beef heifers. Hanks et al. (1993) reported inconsistent temporal differences between pregnant and lactating cows. Sharply decreased total VFA we observed in pregnant heifers 2 wk prepartum coincided with decreased DMI. Decreased DMI likely resulted in decreased substrate availability for ruminal microbes and a decrease in the products of fermentation.

Ruminal NH$_3$ was relatively static in lactating heifers postpartum but generally increased in non-lactating heifers (treatment x period - $P = 0.01$; Figure 2-6). Differences in ruminal NH$_3$ may have been resulted from less urea recycling in lactating heifers; amino acids may have been used for milk synthesis, making less NH$_3$ available to produce urea.

Total ruminal VFA concentration in lactating and non-lactating heifers was generally similar and generally increased (treatment x period - $P < 0.01$) during the postpartum portion of our study (Figure 2-6). Vanzant et al. (1991) likewise reported no differences in total ruminal VFA concentration between lactating and non-lactating heifers.

Pregnant heifers had greater ($P < 0.03$) ruminal molar proportions of acetate and lesser ($P < 0.01$) ruminal molar proportions of butyrate and minor VFA when compared with non-pregnant heifers (Table 2-1). An increase in molar proportion of acetate is generally associated with a decrease in other VFA. Vanzant et al. (1991) and Scheaffer et al. (2001) reported no differences in ruminal molar proportion of acetate between pregnant and non-pregnant heifers. Similarly, Scheaffer et al. (2001) reported no difference in molar proportion of butyrate between pregnant and non-pregnant cows.
Ruminal molar proportions of acetate, propionate, and butyrate in pregnant and non-pregnant heifers were influenced by both treatment and time relative to parturition ($P < 0.01$; Table 2-2). In contrast, the collective ruminal molar proportion of isobutyrate, valerate, and isovalerate (i.e., minor VFA) were greater ($P < 0.01$) in non-pregnant than pregnant heifers. Although branched-chain VFA and valerate are thought to stimulate microbial protein synthesis in vitro, Gunter et al. (1990) suggested the effect was of questionable in-vivo significance.

Ruminal acetate generally increased (period main effect - $P < 0.01$) following parturition, but was similar (treatment main effect - $P = 0.21$) between lactating and non-lactating heifers (Table 2-3). Vanzant et al. (1991) reported lesser proportions of acetate in lactating heifers compared with non-lactating heifers.

Ruminal molar proportions of acetate and propionate varied over time (main effect of period - $P < 0.01$) during the postpartum portion of our study but were not influenced ($P \geq 0.21$) by lactation status (Table 2-3). In contrast, Vanzant et al. (1991) reported that lactating heifers had greater ruminal molar proportions of propionate than non-lactating heifers. Ruminal molar proportions of butyrate were inconsistent (treatment x time – $P < 0.01$) over time and lactation status, although decreased molar proportions of ruminal butyrate have been reported in lactating compared to non-lactating cows (Ingvartsen, 2006). The interaction between treatment and time was significant ($P < 0.01$) for the collective molar proportions of isobutyrate, valerate, and isovalerate during the postpartum portion of our study (Table 2-3). Treatments did not change relative ranks during the postpartum data collection period and the numerical differences between treatments during each data collection period were greater than $3 \times$ the SE for treatment. We interpreted this interaction to be due to the magnitude of difference between treatments. It appeared that non-lactating heifers had greater ($P < 0.01$) ruminal molar proportions of these minor VFA than lactating heifers; however, we were unsure of the biological significance of this difference.
**Passage Rate**

Ruminal particulate passage rates were similar ($P = 0.55$) between pregnant and non-pregnant heifers, whereas ruminal fluid dilution rates of pregnant heifers tended to be less ($P = 0.09$) than that of non-pregnant heifers (Figure 7). This was contradictory to the reports by Weston (1983), Beharka et al. (1988), Vanzant et al. (1991), and Hanks et al. (1993), in which pregnant cattle had greater fluid and particulate passage rates compared with non-pregnant cattle. The tendency for lower fluid dilution rate by pregnant heifers in our study was associated with lower DMI by pregnant heifers relative to non-pregnant heifers. Okine and Mathison (1991) indicated that ruminal passage rates increased concomitantly with intake and that mean retention time in the lower gastrointestinal tract increased as ruminal mean retention time decreased. Evans (1981) reported that fluid dilution rate was influenced by saliva production, lesser DMI and presumably less rumination would lead to less saliva production and may have slowed fluid dilution rates. Forbes (1986) postulated that decreased retention time was the result of increased estrogen during late gestation. This idea was supported by Hanks et al. (1993) who reported increased circulating estrogen in pregnant vs. non-pregnant cows.

Both ruminal particulate passage rates and fluid dilution rates were similar ($P \geq 0.52$) in lactating and non-lactating heifers (Figure 2-8). Vanzant et al. (1991) reported lactating heifers had greater particulate passage rates and fluid dilution rates when compared with non-lactating heifers. Ovenell et al. (1991) reported a trend for lactating beef cows to have greater particulate passage rate compared to non-lactating beef cows. These effects were concomitant with greater DMI by lactating females (Okine and Mathison, 1991). Equal DMI ($P = 0.39$) between lactating and non-lactating heifers in our study was probably the reason for similarities in particulate passage and fluid dilution rates.

**Conclusion**

Our data were interpreted to suggest that the changes in intake, passage rate, and ruminal fermentation that are characteristic of beef cows during late gestation may not be as pronounced in beef heifers. In addition, our data demonstrated that pregnant and lactating beef heifers have decreased intake of low-quality forage with similar dry matter digestibility when compared to non-pregnant, non-lactating heifers. This is contrary to other studies comparing pregnant and non-pregnant cows and heifers. However, in each of these studies the diets contained either
alfalfa hay or concentrates in addition to the forage. Increased diet quality would lead to increased diet digestibility and increased dry matter intake thus reducing the effect of decreasing rumen volume from physical impingement of the growing fetus. This shows that beef heifers fed low-quality, warm-season grass hay require additional supplementation to maintain growth and reproduction.

References


Figure 2-1 Dry matter intake and digestibility by primiparous beef heifers from 10 wk prepartum to parturition.

PREG denotes pregnant primiparous beef heifers. OPEN denotes non-pregnant, non-lactating beef heifers. DMI: treatment P = 0.02; period P = <0.01; treatment x period interaction P = 0.12. DM digestibility: treatment P = 0.30; period P = <0.01; treatment x period interaction P = 0.18.
LACT denotes lactating primiparous beef heifers. NL denotes non-pregnant, non-lactating beef heifers. DMI: treatment $P = 0.39$; period $P = <0.01$; treatment x period interaction $P = 0.11$. DM digestibility: treatment $P = 0.08$; period $P = <0.01$; treatment x period interaction $P < 0.01$. 

Figure 2-2: Dry matter intake and digestibility by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk postpartum.
Figure 2-3 Total ruminal fill, ruminal liquid fill, and ruminal solid fill by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

PREG denotes pregnant primiparous beef heifers. OPEN denotes non-pregnant, non-lactating beef heifers. Ruminal total fill: treatment P = 0.03; period P = 0.07; treatment x period P = 0.28. Ruminal fluid fill: treatment P = 0.04; period P = 0.25; treatment x period P = 0.25. Ruminal solid fill: treatment P = 0.02; period P < 0.01; treatment x period P = 0.47.
LACT denotes lactating primiparous beef heifers. NL denotes non-pregnant, non-lactating beef heifers. Ruminal total fill: treatment $P = 0.82$; period $P = 0.23$; treatment x period $P < 0.01$. Ruminal fluid fill: treatment $P = 0.73$; period $P = 0.26$; treatment x period $P < 0.01$. Ruminal solid fill: treatment $P = 0.57$; period $P = 0.06$; treatment x period $P = 0.11$. 

Figure 2-4 Total ruminal fill, ruminal liquid fill, and ruminal solid fill by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk.
Figure 2-5 Ruminal NH$_3$ and total ruminal VFA concentration by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

PREG denotes pregnant primiparous beef heifers. OPEN denotes non-pregnant, non-lactating beef heifers. Ruminal NH$_3$: treatment $P = 0.96$; period $P = <0.01$; treatment x period $P = 0.04$. Total ruminal VFA treatment $P = 0.29$; period $P = <0.01$; treatment x period $P < 0.01$. 
LACT denotes lactating primiparous beef heifers. NL denotes non-pregnant, non-lactating beef heifers. Ruminal NH$_3$: treatment $P = 0.03$; period $P = <0.01$; treatment x period $P = 0.01$. Total ruminal VFA: treatment $P = 0.97$; period $P = <0.01$; treatment x period $P < 0.01$. 

Figure 2-6 Ruminal NH$_3$ and total ruminal VFA concentration by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk.
Figure 2-7 Ruminal particulate passage and fluid passage rates by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

PREG denotes pregnant primiparous beef heifers. OPEN denotes non-pregnant, non-lactating beef heifers. Ruminal particulate passage rate: treatment $P = 0.55$; period $P = 0.27$; treatment x period $P = 0.18$. Ruminal fluid dilution rate: treatment $P = 0.09$; period $P = 0.02$; treatment x period $P = 0.35$. 
LACT denotes lactating primiparous beef heifers. NL denotes non-pregnant, non-lactating beef heifers. Ruminal particulate passage rate: treatment $P = 0.71$; period $P < 0.01$; treatment x period $P = 0.48$. Ruminal fluid dilution rate: treatment $P = 0.52$; period $P = 0.02$; treatment x period $P = 0.66$. 

Figure 2-8 Ruminal particulate passage and fluid passage rates by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk.
Table 2-1 Body weight and BCS of primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

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<th>Week prepartum</th>
<th>PREG</th>
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<th>P – trt</th>
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<th>&lt;0.01</th>
<th>0.21</th>
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<td>8</td>
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<tr>
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</tbody>
</table>
| PREG denotes pregnant primiparous beef heifers
| OPEN denotes non-pregnant, non-lactating beef heifers
Table 2-2 Body weight and BCS of primiparous beef heifers fed low-quality, warm-season grass hay from parturition to 10 wk postpartum.

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<th>Week postpartum</th>
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<th>6</th>
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<th>10</th>
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<th>P - Period</th>
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</table>

LACT denotes lactating primiparous beef heifers
NL denotes non-pregnant, non-lactating beef heifers
Table 2-3 Ruminal concentration of acetate, propionate, butyrate, and minor VFA* as percentage of total VFA by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

<table>
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<th>Butyrate</th>
<th>Minor VFA*</th>
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<td>0</td>
<td>P - trt</td>
<td>0.03</td>
<td></td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

SE denotes standard error

P - Period

P - P - Period interaction

PREG denotes pregnant primiparous beef heifers

OPEN denotes non-pregnant, non-lactating beef heifers

* Minor VFA consists of isobutyrate, valerate and isovalerate
Table 2-4 Ruminal concentration of acetate, propionate, butyrate, and minor VFA* as percentage of total VFA by primiparous beef heifers fed low-quality, warm-season grass hay from parturition to 10 wk postpartum.

<table>
<thead>
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<th>Week postpartum</th>
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<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>SE -</th>
<th>P - period</th>
<th>P - period interaction</th>
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<td>Acetate</td>
<td>LACT</td>
<td>69.86</td>
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<td></td>
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<td></td>
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<td>Propionate</td>
<td>LACT</td>
<td>17.42</td>
<td>18.05</td>
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<td>Butyrate</td>
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<td>Minor VFA*</td>
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<td>2.17</td>
<td>2.31</td>
<td>2.42</td>
<td>2.45</td>
<td>2.10</td>
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</tbody>
</table>

LACT denotes lactating primiparous beef heifers
NL denotes non-lactating, non-pregnant beef heifers
* Minor VFA consists of Isobutyrate, valerate and isovalerate
CHAPTER 3 - COMPARISON OF EFFECTS OF GESTATION AND LACTATION ON DRY MATTER INTAKE, DRY MATTER DIGESTIBILITY, AND PASSAGE RATES BETWEEN PRIMIPAROUS BEEF HEIFERS AND BEEF COWS

Abstract

Angus-cross cows (n = 13; 8 pregnant, BW 610 ± 24 kg and 5 non-pregnant, BW 571 ± 23 kg) and heifers (n = 13; 8 pregnant, BW 511 ± 40 kg and 5 non-pregnant, BW 451 ± 60 kg) were individually fed chopped warm-season grass hay (5.5% CP, 67% NDF, and 40% ADF) for ad libitum intake and soybean meal (46% CP) at 450 g/d. Intake was measured daily, and DM digestibility, passage rate, and plasma glucose and BHBA concentrations were measured every 14 d from 49 d prepartum to 49 d postpartum. Prepartum DMI (% of BW) tended to increase over time for pregnant heifers until 2 wk prepartum before declining, but did not change over time for pregnant cows (pregnancy status x time; \( P = 0.03 \); age x pregnancy status x time; \( P = 0.06 \)). However, prepartum intake (% of BW) was not influenced by age (cow vs. heifer; \( P = 0.34 \)), pregnancy status (\( P = 0.29 \)), or time (\( P = 0.33 \)). Dry matter digestibility decreased with advancing gestation (\( P < 0.001 \)); pregnant animals had greater digestibility than non-pregnant cows and heifers (\( P = 0.02 \)). Digestibility was not influenced by age (\( P = 0.99 \)). Pregnant cows and heifers had faster digesta passage rates than non-pregnant counterparts (\( P = 0.02 \)). Plasma glucose concentration increased during the prepartum period (\( P = 0.02 \)) and pregnant animals had lower plasma glucose (\( P < 0.001 \)). Plasma BHBA concentration was greater in pregnant animals than in non-pregnant animals (\( P < 0.0001 \)), but was not influenced by age (\( P = 0.27 \)) or time prepartum (\( P = 0.98 \)). Postpartum DMI (% of BW) increased over (time \( P < 0.001 \)); lactating heifers had greater intakes than other groups (age x lactation status; \( P = 0.05 \)). Diet digestibility increased with time postpartum (\( P < 0.001 \)), but lactation status did not influence digestibility (\( P = 0.62 \)). Heifers had greater digestibility than cows from 3 to 7 wk postpartum, but not at 1 wk postpartum (age x time; \( P = 0.02 \)). Passage rate was not influenced by age or
lactation status \((P > 0.23)\). Lactating animals had lesser plasma glucose concentrations postpartum \((P < 0.001)\), but age did not influence glucose concentration \((P = 0.37)\). Lactating cows and heifers had greater plasma BHBA concentrations than non-lactating animals \((P < 0.0001)\), but age did not influence BHBA concentration \((P = 0.37)\). Calves from mature cows grew faster than calves from heifers \((age \times time; P < 0.001)\). These data show that though primiparous beef heifers have similar DM digestibility, passage rates, and plasma glucose and BHBA concentrations, intake patterns differ between heifers and cows. These result in decreased animal performance of primiparous beef heifers and their calves. Care must be taken when comparing nutritional data from mature beef cows and beef heifers. Primiparous beef heifers require additional nutritional management to ensure body weight and condition are maintained for optimal calf performance and ensuring an optimal return to breeding.

**Key words:** Beef, Cow, Gestation, Heifer, Lactation, Nutrition

**Introduction**

Replacement beef heifers require more intensive management than mature beef cows due to the greater energy demands for growth in addition to their production requirements. This is especially true of heifers grazing native-range tallgrass prairie, which is an abundant and inexpensive source of feed for cattle throughout the central plains region of the United States. Prairie grass has low digestibility when compared to cool-season grasses (Vona et al., 1984). Olson et al. (2008) showed that prairie grass typically is of poor quality with low crude protein \((< 7\%)\) and high fiber content \((ADF: 42\%)\).

Replacement beef heifers are typically bred 15 to 30 d earlier than mature cows to allow more time from parturition to first estrus and to allow rebreeding to be more synchronous with that of older cows (Banta et al., 2005). However, earlier calving may occur during seasonal dormancy for many grazed plants, especially for warm-season prairie grasses, resulting in less nutrient availability for heifers during late gestation and early lactation, which are periods of elevated nutrient requirements (NRC, 2000).

Gestation has been shown to decrease DMI in ruminants (Campling, 1966; Weston, 1988; Stanley et al., 1993; Allen, 1996; Scheaffer et al., 2001). This, in conjunction with grazing low
quality pasture during late gestation, results in suboptimal animal performance including decreased BW, decreased BCS, and extended postpartum interval. Cows that lost BW during mid- to late-gestation had greater calving intervals, lower pregnancy rates, and lighter calves at weaning (Godfrey et al., 1988). In addition, primiparous cows had longer postpartum intervals when compared to multiparous cows (Wiltbank, 1970; Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000) and pregnancy rates for primiparous cows with a BCS of 4 were only 53% compared to 90% for primiparous cows with BCS 5 or greater (Rae et al., 1993).

Postpartum energy restriction decreased conception rate and increased postpartum interval of beef cows (Banta et al., 2005). Matching nutrient supply to nutrient requirement is necessary to support milk production and to maintain a 12-mo calving interval.

Lactating beef cows require 20 to 30% more energy than non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000); moreover, milk production is usually associated with increased intake (Wagner et al., 1986; Hatfield et al., 1989). Although the effects of late gestation and early lactation on nutrition of mature beef cows has been addressed, it is unclear to what extent gestation and lactation affect intake, digestion, and ingesta passage rate in beef heifers. Applying information from mature beef cows to heifers may lead to mismanagement of heifers during the periparturient period and could increase the likelihood of reproductive failure during the second breeding season.

Our objective was to determine the effects of pregnancy and lactation on nutritive status of forage-fed beef heifers in comparison to mature beef cows. We hypothesized that heifers would consume no more forage than cows and thus demonstrate nutrition-impaired performance.

Materials and Methods

All procedures used in the care and management of animals were approved by the Kansas State University Institutional Animal Care and Use Committee.

Prepartum Phase

Treatment assignments were based on pregnancy status. Eight Angus-cross cows (PRC; n = 8, average initial BW 610 ± 24 kg) and 8 heifers (PRH; n = 8, average initial BW 511 ± 40 kg) heifers were bred by natural service following ovarian synchronization approximately 245 d before the study began and were verified pregnant via transrectal ultrasonography approximately
60 d before the study began. In addition, 5 cows (NPC; n = 5, average initial BW 571 ± 23 kg) and 5 heifers (NPH; n = 5; average initial BW 451 ± 60 kg) served as non-pregnant, non-lactating controls. Cattle were group housed in an open lot for an average of 49 d prepartum.

**Postpartum Phase**

Treatment assignments were based on pregnancy status from the previous study. Angus-cross cows that were lactating (LAC; n = 7, average initial BW 526 ± 27 kg) or non-lactating (NPC; n = 5, average initial BW 570 ± 25 kg) and heifers that were lactating (LAH; n = 8, average initial BW 423 ± 33 kg) or non-lactating (NPH; n = 5; average initial BW 443 ± 58 kg) from the prepartum portion of the study were housed in an open lot for an average of 49 d postpartum. One lactating cow was removed from this portion of the study due to illness unrelated to the study. Calves remained with their dams throughout the postpartum period.

**Feed**

Cows and heifers were fed chopped, warm-season grass hay (approximate particle length = 10 cm; DM basis: 5.5 ± 0.28% CP, 66.8 ± 2.2% NDF, and 40.4 ± 0.88% ADF) for ad libitum intake and 450 g soybean meal daily to meet rumen degradable protein requirement (DM basis: 46.4 ± 5.0% CP, 10.8 ± 1.5% NDF, 7.1 ± 0.8% ADF) in individual feed bunks approximately 90 cm long x 90 cm high x 75 cm wide (American Calan, Northwood, NH). Hay was offered once daily (0900 h) at 115% of the previous 3-d average voluntary intake. SBM was fed daily immediately prior to hay feeding. Daily hay refusals were removed and weighed 1 h prior to feeding. Clean drinking water, salt, and trace-mineralized salt blocks (Table 3-1) were available for ad libitum intake. Hay was kept in a covered barn after chopping.

**Data Collection**

The prepartum and postpartum phases were each divided into 4 data-collection periods that were each 14 d in length. Total fecal output was estimated on d 10 to 13 of each sample period using acid detergent insoluble ash (ADIA) as an indigestible marker. Fecal grab samples were collected every 12 h, with sample collection times advanced 3 h each day to provide samples for each 3 h period of the day. Total tract nutrient digestion coefficients were calculated using ADIA as an internal marker according to Cochran and Galyean (1994). Stafford et al. (1996) reported that fecal recovery of ingested ADIA from beef cattle consuming hay of the type used in this
study was quantitative. Digesta passage rate was determined using ytterbium chloride (YbCl₃) as the marker. A solution of 8 g of YbCl₃ per 100 ml H₂O was mixed with the soybean meal and fed on d 8 of each sample period. Fecal samples collected at 48, 75, 102, and 129 h following YbCl₃ administration were maintained separately for use in assessing passage rate.

Blood samples were collected via jugular venipuncture using an 18-gauge needle on d 14 of each sample period. Samples were collected into Vacutainer tubes containing sodium heparin (BD, Franklin Lakes, NJ) to prevent coagulation and placed on ice immediately. Blood was centrifuged at 500 x g for 20 min. Plasma was removed by pipette and frozen until use.

Cattle BW were measured on d 14 of each sample period throughout the study; BCS were determined at the same time as the average score of 3 trained observers using a 9-point scale (1 = emaciated, 9 = obese; Neumann and Lusby, 1986). Hip heights were measured using a hip height measuring stick across the hip bones with cattle standing level. Calf BW were measured on the same days as cows and heifers.

**Laboratory Analyses**

Forage samples pooled by period and fecal samples pooled by cow and period were dried for 72 h in a forced-air oven at 55°C and ground to pass a 1-mm screen (Model 4 Wiley mill; Thomas Scientific, Swedesboro, NJ). Crude protein was determined by Keldahl analysis. Concentrations of NDF and ADF were determined using an Ankom 200 Fiber Analyzer (Ankom Technologies, Macedon, NY).

Feces (0.5 g) used for Yb concentration were dried, ground, and ashed at 450°C for 8 h in a screw-cap tube; ash was solubilized in 10 mL of acid reagent (3 M HNO₃ + 3 M HCl) with gentle agitation for 12 h, then allowed to settle for 12 h. Ytterbium content of the liquid was determined by atomic absorption with a nitrous oxide/acetylene flame (Perkin Elmer Atomic Absorption Spectrometer 3110, Waltham, MA). The natural logarithm of ytterbium concentration was regressed against sampling time to calculate passage rate (Warner and Stacy, 1968).

Plasma samples for glucose were analyzed by BioTek PowerWave XS plate reader with a Wako Glucose Autokit (Richmond, VA). Samples (10 μL) were pipetted into the plate wells along with 250 μL of the working reagent. Absorbance was read at 505 nm. Plasma samples for BHBA were analyzed by BioTek PowerWave XS plate reader with a BHBA reagent set (Pointe
Samples (10 μL) were pipetted into the plate wells along with 250 μL of the working reagent. Absorbance was read at 505 nm.

Plasma samples for progesterone were analyzed by DPC Coat-A-Count kit (Siemens Medical Solutions, Malvern, PA; Assay sensitivity = 0.003 ng/mL; inter assay CV = 4.2%; intra assay CV = 4.7%). Animals with plasma progesterone concentrations greater than 1 ng/mL were considered to be ovulating.

**Calculations and Statistical Analyses**

Cattle calving date was set as d 0 for DMI data. To account for variable calving dates, calves born from d 1 to 14 in relation to a data collection period were designated as wk 1; all other collection times were then staged accordingly. Data collected during the pre- and postpartum periods were analyzed for repeated measures completely random design with a 2 x 2 factorial treatment structure using the MIXED procedure of SAS (version 9.1, SAS Inst. Inc., Cary, NC). The model statement included terms for age (cow vs. heifer), pregnancy or lactation status, age x pregnancy or lactation status, time, age x time, pregnancy or lactation status x time, and age x pregnancy or lactation status x time. Time was the repeated effect with animal as the subject. When significant F-tests \((P < 0.05)\) were observed, pair-wise t-tests were used to separate means. Outliers were removed when \(|\text{student residuals}| > 3\). Digestion, plasma glucose, plasma BHBA, and Yb passage rate data are reported as the means for each 2-wk data collection period, whereas DMI is reported on a weekly basis.

**Results and Discussion**

**Prepartum Phase**

**Body Weight and BCS.** As expected, mature cows weighed more \((P < 0.001)\) than heifers at the beginning and at the end of the study (Figure 3-1). Pregnant animals weighed more \((P < 0.001)\) than non-pregnant animals. Body weight of non-pregnant cattle was relatively constant throughout the prepartum period, whereas BW of pregnant cattle decreased slightly with advancing gestation (pregnancy x time; \(P = 0.02\)). This is similar to a reported decrease in carcass weight in pregnant heifers with advancing pregnancy indicating a loss of body mass to support the growing fetus and meet mammary development (Scheaffer et al., 2001). A decrease
in BW with advancing gestation shows that the low-quality forage did not meet energy demands of the pregnant cattle even with the supplementation of protein from SBM.

Prepartum BCS (Figure 3-2) for heifers tended to decrease over time while cows increased BCS over time (age x time; \( P = 0.10 \)). A general decrease in BCS demonstrates that energy demands of heifers were not met by the diet provided, which could result in inadequate body reserves for optimal rebreeding. Prepartum BCS < 5 has been shown to increase postpartum interval (Randel, 1990, Lents et al., 2008). Insufficient prepartum energy intake can decrease pregnancy rates even if adequate dietary energy is supplied postpartum (Randel, 1990).

**Hip Height.** As anticipated, cows had greater \( (P < 0.001) \) hip height than heifers (Figure 3-3). Heifers tended to increase in hip height over time more than cows (age x time; \( P = 0.08 \)). Based on hip height, beef cows do not reach physical maturity until 4 years of age (Neville, 1971). The pregnant 2-yr old heifers in this study were still growing, thus requiring energy and protein for growth in addition to maintenance and pregnancy (NRC, 2000). Cows had minimal change in hip height, indicating that they were through growing.

**Dry Matter Intake and Digestibility.** Prepartum DMI, as kg d\(^{-1}\) (DMIkg; Figure 3-4), tended to increase for pregnant heifers while pregnant cows did not differ over time (age x pregnancy x time; \( P = 0.12 \)). DMIkg was less for pregnant animals until 4 wk prepartum at which time pregnant heifers exceeded the intake of non-pregnant heifers. Prepartum DMI, as a percentage of BW (DMI%BW; Figure 3-5), was less for pregnant cows and heifers when compared to non-pregnant cows and heifers until 3 wk prepartum. Pregnant heifers increased intake until peaking at 2 wk prepartum at which point it surpassed the DMI%BW of non-pregnant cows and heifers (pregnancy status x time \( P = 0.03 \)). DMI%BW tended to demonstrate an age x pregnancy status x time interaction \( (P = 0.06) \). Pregnant animals had lesser intake than non-pregnant animals until 2 wk prepartum at which time intake of pregnant heifer exceeded that of pregnant cows and non-pregnant animals. The general increase in intake by pregnant heifers can be attributed to an increase in nutritional demand from the growing fetus and is similar to that observed previously (See Chapter 2 of this thesis). Lesser DMI for pregnant cattle compared to non-pregnant cattle is similar to findings by others (Campling, 1966; Jordan, et al., 1973) and is usually explained by a physical impingement on ruminal volume from the growing fetus (Forbes, 1986).

Johnson et al. (2003) demonstrated that mature cows ate more than heifers (kg d\(^{-1}\)), but similar to our data they found no difference when intake was expressed on a BW basis.
Similarly, Varel and Kreikemeier (1999) determined that age had no influence on OM intake of alfalfa and brome hay expressed relative to BW. Marquardt et al. (1977) demonstrated that dairy heifers had a decrease in DMI of 25% from 14 d prepartum until parturition, whereas mature dairy cows had a 50% decrease in DMI during the same time period. Vanzant et al. (1991) reported greater intake of tallgrass prairie forage by pregnant heifers than by non-pregnant heifers at 55 d prepartum; however, there was no difference in DMI 12 d prepartum. In contrast, Scheaffer et al. (2001) reported no difference between pregnant and non-pregnant beef heifers in DMI of a total mixed ration composed of alfalfa and corn silage, and Stanley et al. (1993) indicated that pregnant mature beef cows ate more alfalfa than non-pregnant counterparts. However, the alfalfa and corn silage in those diets would be more digestible than the diet offered in the current study and is less likely to exhibit as much rumen fill as a low-quality warm-season hay (Ovenell et al., 1991). It is difficult to compare many of the studies found in the literature because of the wide variation in sampling days and in the nutritional composition of the diets offered.

Dry matter digestibility decreased with advancing gestation (time main effect $P < 0.0001$; Figure 3-6) which is an effect difficult to separate from changes in forage quality, environment, or both that may have occurred over time. Digestibility was greater for pregnant cows and heifers than non-pregnant cows and heifers (pregnancy status; $P = 0.02$) and decreased more over time for non-pregnant animals than for pregnant animals (pregnancy x time; $P = 0.02$). However, age did not influence digestibility ($P = 0.99$). A decrease in digestibility with advancing gestation has been observed by others (Faichney and White, 1988b; Beharka et al., 1988; Scheaffer et al., 2001). The greater digestibility for pregnant cows and heifers is in contrast to other published data. Hanks et al. (1993) found no difference in DM digestibility in pregnant and non-pregnant cows fed tall fescue hay. However, cows in that trial were limit-fed to 80% of their previous 30 d average intake. Vanzant et al. (1991) and Scheaffer et al. (2001) reported less DMD in pregnant heifers when compared to non-pregnant heifers. Coffey et al. (1989) observed lower digestibility in gestating ewes compared to non-gestating ewes.

**Passage Rate.** Prepartum passage rate (Figure 3-7) did not differ by age or by time in relation to parturition (age $P = 0.16$; time $P = 0.12$). In contrast, cows have been shown to have greater fluid dilution rate than heifers (11.6% vs. 8.8%; Varel and Kreikemeier, 1999), but parity did not influence particulate passage rate in prepartum dairy cows (Dorshorst and Grummer, 2002).
Pregnant females had greater passage rate than non-pregnant females (pregnancy $P = 0.02$). Similarly, particulate passage rate was greater for pregnant than for non-pregnant ewes at 3 wk and 1 wk prepartum (Coffey et al., 1989) and for pregnant beef cows than non-pregnant compatriots (Hanks et al., 1993). Ruminal mean retention time decreases with advancing gestation in ewes (Faichney and White, 1988a). Hanks et al. (1993) suggested that pregnancy status did not affect ruminal fluid kinetics in beef cows. In addition, increased DMI has been shown to increase passage rate of NDF from the reticulo-rumen (Okine and Mathison, 1991) and ruminal liquid turnover rate increases with increasing DMI in sheep and cattle (Evans, 1981a). Increasing passage rates in pregnant heifers from 5 wk to 1 wk prepartum coincides with increasing DMI. However, the increase in passage rate over time for pregnant cows occurred independent of changes in DMI.

**Plasma Glucose and BHBA Concentration.** Plasma glucose concentrations (Figure 3-8) were less in pregnant cows and heifers than in non-pregnant cows and heifers (pregnancy $P < 0.001$), which is likely due to an increase in glucose use by the fetus. Glucose concentration was not influenced by age (age main effect $P = 0.13$). In contrast, prepartum plasma glucose was greater in dairy heifers compared to mature cows (Dorshorst and Grummer, 2002). Dorshorst and Grummer (2002) speculated that less energy demand from mammary tissue in heifers compared to mature cows would allow for greater plasma glucose concentrations. This effect would not be as dramatic in beef cows and heifers due to less mammary tissue demand compared to dairy cows. Plasma glucose increased over time (time main effect $P = 0.02$), but the increase over time was similar between pregnant and non-pregnant animals.

Prepartum plasma BHBA concentrations (Figure 3-9) were greater in pregnant cows and heifers than in non-pregnant cows and heifers (pregnancy $P < 0.0001$). However, BHBA concentration was not affected by age (age $P = 0.27$). BHBA concentration was not different over time ($P = 0.37$). In contrast, Dorshorst and Grummer (2002) observed an increase in BHBA concentration with increasing time of gestation (from 21 d prepartum), but similar to our work did not observe an effect of parity. Insufficient energy from the diet during pregnancy would result in increased lipolysis. Bell (1995) determined that increases in BHBA can be accounted by incomplete oxidation of NEFA.
Postpartum Phase

**Body Weight.** There was a general decrease in BW during the postpartum period (time $P < 0.001$; Figure 3-10) while DMI was increasing. This can be attributed to the low ME concentration of the warm-season hay fed during the study. Postpartum BW differed between age groups (age main effect $P < 0.001$) with mature cows being heavier than heifers. However BW did not differ by lactation status (lactation status $P = 0.31$) nor were BW losses different between pregnant and non-pregnant animals (lactation x time $P = 0.63$). In contrast, Jordan et al. (1973) observed that despite an increase in DMI postpartum, lactating beef cows continued to lose BW in relation to non-lactating cows. The difference in BW in the lactating cows and heifers from the prepartum period to the postpartum period is predominantly attributed to the loss of the fetus and gravid uterus (average calf birth weight was 35.6 kg for heifers and 36.4 kg for cows).

**Calf Body Weight.** Calf BW increased over time ($P < 0.0001$; Figure 3-11). Though calf birth weight was similar for calves from mature cows and from heifers, calf BW was greater for calves from mature cows than for calves from heifers from 3 wk postpartum through the end of the study (age $P = 0.02$; age x time $P < 0.01$). This is due to greater milk production by mature cows compared to first-calf heifers (NRC, 2000). Johnson et al. (2003) reported 66% greater milk production by mature Brangus cows compared to heifers. Based on predictive equations for calves fed milk, calves from mature cows consumed 20% greater ME than calves from heifers (2.99 vs. 2.44 Mcal/d; NRC, 2001). In addition, it has been shown that heifer milk production peaks much earlier than predicted for mature beef cows (Chapter 2 of this thesis).

**Body Condition.** Postpartum BCS increased with time following parturition (time main effect $P < 0.01$; Figure 3-12). The increase in BCS over time coincides with increases in DMI, although BW did not increase at the same time the BCS demonstrated increases. Postpartum BCS was influenced by age ($P = 0.03$) with cows having greater BCS than heifers and by lactation status ($P < 0.001$) with lactating cows and heifers having lesser BCS when compared to non-lactating cows and heifers. Interactions of treatments with time were not present ($P \geq 0.48$) suggesting that any treatment effects were largely preexisting at calving. Maintaining cow BCS between 5 and 7 can reduce the incidence of anestrus and infertility (Short et al., 1990). This may be a concern for the lactating heifers which did not exceed BCS 4.5 throughout the postpartum phase.
**Hip Height.** Postpartum hip height (Figure 3-13) was greater for cows than for heifers (age $P < 0.01$), but was not influenced by lactation status ($P = 0.46$) or time ($P = 0.88$). Lack of growth for lactating heifers during the postpartum phase indicates that energy was partitioned for energy for lactation rather than for growth.

**Dry Matter Intake and Digestibility.** Lactating beef cows require 20 to 30% more ME than non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000). Intakes (DMIkg) generally increased over time for cows and for lactating heifers (time $P = 0.02$). DMIkg (Figure 3-15) did not differ between cows and heifers (age $P = 0.35$) and lactation status did not influence intake ($P = 0.24$). Postpartum DMI%BW generally increased over time ($P < 0.001$) and the increases over time tended ($P = 0.13$) to be more for lactating animals than for non-lactating animals. This is in agreement with studies in which heifers have been shown to increase DMI following parturition (Rosiere et al., 1980; Vanzant et al., 1991; Marston and Lusby, 1995). Mature beef cows generally have greater DMI while lactating when compared to non-lactating mature cows (Campling, 1966; Hunter and Siebert, 1986; Ovenell et al., 1991; Hatfield et al., 1989), which can be explained by the energy requirements necessary for milk production (Vanzant et al., 1991; Johnson et al., 2003). Postpartum DMI was greatest for lactating heifers throughout the postpartum period (age x lactation status; $P = 0.05$). In contrast, Galindo-Gonzalez et al. (2007) observed no difference between cow and heifer DMI on a BW basis. Postpartum DMI for lactating heifers in the current study was greater than that reported for beef heifers grazing warm-season grasses (Rosiere et al., 1980), although Rosiere et al. (1980) did not obtain intake data until 90 and 150 d postpartum when intake may have been less than at earlier stages of lactation.

Dry matter digestibility (Figure 3-16) increased with time after calving ($P < 0.0001$). The increase in diet digestibility at wk 7 may be a result of better forage quality. Though hay was stored and handled similarly, variation in hay quality was possible. There was a trend for greater digestibility for heifers than for cows (age main effect $P = 0.14$) and an age x time interaction ($P = 0.02$) wherein heifers had greater DMD with greater increase over time when compared to cows. Johnson et al. (2003) showed lactating heifers had 5% greater OM digestibility than lactating multiparous cows with similar DMI%BW. However, lactation did not affect diet digestibility ($P = 0.62$). Similarly, Marston and Lusby (1995) reported that lactation did not affect dry matter digestibility in beef heifers; Vanzant et al. (1991) also reported that OM
digestibility did not differ between lactating and non-lactating heifers 26 d post-partum. Ovenell et al. (1991) reported similar observations for mature cows. Conversely, Colucci et al. (1982) and Okine and Mathison (1991) reported that mature dairy cows experienced a post-partum depression in DM digestibility concomitant with increased DMI, although DMI increases more dramatically in dairy cattle than it did for our beef cattle.

**Passage Rate.** Postpartum passage rate (Figure 3-17) was not influenced by age, lactation status, or time after calving ($P > 0.19$). Ruminal liquid turnover rate increases with increasing DMI in sheep and cattle (Evans, 1981a). Particle passage rate was greater for lactating ewes than for non-lactating ewes (Coffey et al., 1989), likely due to greater DMI (Okine and Mathison, 1991); differences in DMI%BW among groups in our study may not have been great enough to impact passage.

**Plasma Glucose and BHBA Concentrations.** Postpartum plasma glucose concentration (Figure 3-18) was less in lactating cows and heifers than in non-lactating cows and heifers ($P < 0.001$), probably reflecting a greater glucose demand by mammary tissue. Glucose concentration was not influenced by age ($P = 0.37$). This is similar to findings of no difference in plasma insulin concentrations between parities in dairy cows (Meikle et al., 2004). Plasmas glucose generally increased over time ($P < 0.001$). The increase in plasma glucose at 7 wk postpartum could be from an increase in forage quality as demonstrated by greater diet digestibility at that time point.

Postpartum plasma BHBA concentration (Figure 3-19) was greater for lactating cows and heifers than for non-lactating cows and heifers ($P < 0.0001$), but parity did not affect BHBA concentration (age $P = 0.37$). In contrast, Meikle et al. (2004) found that primiparous dairy cows had an increased incidence of elevated BHBA postpartum than multiparous cows. However, dairy cows would have greater lipolysis due to greater milk production. Plasma BHBA appeared to increase at 5 wk postpartum and then decrease at 7 wk postpartum (time main effect $P < 0.0001$). Postpartum, decreasing BHBA generally coincides with an increase in DMI and a subsequent decrease in negative energy balance during the postpartum period. However, the increase in BHBA at 5 wk postpartum does not match what would be expected from DMI. The decrease in BHBA between 5 and 7 wk postpartum might reflect a pattern of decreasing BHBA concentrations with time postpartum, or this might reflect the apparently better hay quality fed at 7 wk postpartum that was better digested. Because BHBA concentrations demonstrated a similar
pattern for lactating and non-lactating animals, it is difficult to attribute all of the effects of time to stage of lactation.

**Plasma Progesterone Concentration.** Plasma progesterone concentration was used to determine time to first ovulation postpartum. By 49 d postpartum, a single heifer was ovulating and none of the cows were ovulating (data not shown). Galindo-Gonzalez et al. (2007) demonstrated that multiparous cows had a shorter calving interval compared to primiparous cows along with a trend for a greater number of multiparous cows to reach first estrus postpartum when compared to primiparous cows. The lack of estrus at 7 wk postpartum may be due to the lack of energy in the diet. It has been shown that cows with body condition below 5 have increased postpartum interval (Short et al., 1990). This is evident in the lactating animals which had BCS < 5 throughout the postpartum phase. Lactating heifers had a low point of 4.1 at 3 wk postpartum. These animals are thin enough to possibly have lengthened postpartum intervals.

Lack of dietary protein increases postpartum interval in beef heifers (Sasser et al., 1988). The diet in our study supplied adequate dietary MP for maintenance of cows and for maintenance and growth in heifers (422 g MP d\(^{-1}\) and 467 g MP d\(^{-1}\) respectively; NRC 2000). However, there was an inadequate supply of MP for lactation (771 g MP d\(^{-1}\) for cows; 816 g MP d\(^{-1}\) for heifers; NRC, 2000).

**General Discussion**

Pregnant heifers fed prairie hay for ad libitum intake with 450 g SBM daily demonstrated increased DMI during late gestation until 2 wk prepartum. Over the same time, pregnant cows maintained near constant DMI. The diet provided adequate MP for maintenance in cows and maintenance and growth in heifers (422 g MP d\(^{-1}\) and 467 g MP required for cows and heifers respectively; NRC, 2000). However, there was inadequate MP for fetal growth during late gestation (672 g MP d\(^{-1}\) for cow maintenance and gestation and 718 g MP d\(^{-1}\) for heifer maintenance, growth, and gestation; NRC, 2000). Despite the increase in DMI in pregnant heifers and an increase in DM digestibility in pregnant animals compared to non-pregnant animals, pregnant heifers were unable to ingest enough ME or MP from the diet to meet requirements for growth and production as evidenced by the decrease in BW and BCS.
Lactation resulted in decreased BW and lower BCS in heifers, even though DMI%BW was greater than for lactating cows and non-lactating cows and heifers. Calves from heifers had ME intakes that were 20% less than the ME consumed by calves from mature cows. The diet provided adequate MP for maintenance in cows and maintenance and growth in heifers, but there was inadequate MP to meet lactation demands, indicating that heifers are unable to ingest enough ME and MP from the prairie hay diet to meet maintenance and lactation demands.

**Conclusion**

Together, these data show that even with an increase in DMI during late gestation and early lactation, pregnant and lactating heifers fed a low-quality, warm-season grass hay with the addition of 454 g of soybean meal daily are unable to meet energy and protein demands for maintenance, growth, and reproduction. A deficiency in energy and protein can result in increased postpartum interval and more difficulty in rebreeding while trying to maintain yearly calf production. This suggests that beef heifers will require additional supplementation to maintain growth, lactation, and reproduction and to maintain a 12-mo production cycle as 3-yr old cows.
Literature Cited


Table 3-1 Mineral block content

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Content</th>
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<tr>
<td>Salt (NaCl)</td>
<td>96 to 99 %</td>
</tr>
<tr>
<td>Manganese</td>
<td>≥2400 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>≥ 2400 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>260 to 380 ppm</td>
</tr>
<tr>
<td>Zinc</td>
<td>≥ 320 ppm</td>
</tr>
<tr>
<td>Iodine</td>
<td>≥ 70 ppm</td>
</tr>
<tr>
<td>Cobalt</td>
<td>≥ 40 ppm</td>
</tr>
</tbody>
</table>

North American Salt Company, Overland Park, KS
Figure 3-1 Body weight of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P < 0.0001$; pregnancy status $P < 0.01$; age x pregnancy status interaction $P = 0.49$; time $P < 0.0001$; age x time interaction $P = 0.53$; pregnancy status x time interaction $P = 0.02$; pregnancy x age x time interaction $P = 0.48$. n = 5 for non-pregnant cow; n = 8 for pregnant cows; n = 5 for non-pregnant heifers; n = 8 for pregnant heifers. SEM = 18.46.
Figure 3-2 Body condition of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.84$; gestation status $P = 0.99$; age x gestation status interaction $P = 0.96$; time $P = 0.12$; age x time interaction $P = 0.10$; gestation status x time interaction $P = 0.79$; age x gestation status x time interaction $P = 0.67$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 8$ for pregnant heifers. SEM = 0.25.
Figure 3-3 Hip height of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P < 0.001$; pregnancy status $P = 0.14$; age x pregnancy status interaction $P = 0.05$; time $P < 0.0001$; age x time interaction $P = 0.08$; pregnancy status x time interaction $P = 0.41$; age x pregnancy status x time interaction $P = 0.55$. n = 5 for non-pregnant cow; n = 8 for pregnant cows; n = 5 for non-pregnant heifers; n = 8 for pregnant heifers. SEM = 1.84.
Figure 3-4 Dry matter intake, kg d$^{-1}$, of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.88$; pregnancy status $P = 0.52$; age x pregnancy status interaction $P = 0.70$; time $P = 0.35$; age x time $P = 0.87$; pregnancy status x time interaction $P = 0.27$; age x pregnancy status x time $P = 0.12$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 8$ for pregnant heifers. SEM = 2.14.
Figure 3-5 Dry matter intake, %BW, by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.34$; pregnancy status $P = 0.29$; age x pregnancy status interaction $P = 0.88$; time $P = 0.33$; age x time $P = 0.86$; pregnancy status x time interaction $P = 0.03$; age x pregnancy status x time $P = 0.06$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 8$ for pregnant heifers. SEM = 0.40.
Figure 3-6 Dry matter digestibility by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.99$; pregnancy status $P = 0.02$; age x pregnancy status interaction $P = 0.38$; time $P < 0.0001$; age x time interaction $P = 0.22$; pregnancy status x time interaction $P = 0.02$; age x pregnancy status x time interaction $P = 0.35$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 8$ for pregnant heifers. SEM = 5.87.
Figure 3-7 Digesta passage rate by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.16$; pregnancy status $P = 0.02$; age x pregnancy status interaction $P = 0.95$; time $P = 0.12$; age x time interaction $P = 0.28$; pregnancy status x time interaction $P = 0.63$; age x pregnancy status x time interaction $P = 0.38$. n = 5 for non-pregnant cow; n = 8 for pregnant cows; n = 5 for non-pregnant heifers; n = 8 for pregnant heifers. SEM = 0.47.
Figure 3-8 Plasma glucose concentration of pregnant and non-pregnant cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.13$; gestation status $P < 0.0001$; age x gestation status interaction $P = 0.74$; time $P = 0.02$; age x time interaction $P = 0.53$; gestation status x time interaction $P = 0.90$; age x pregnancy status x time interaction $P = 0.86$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 8$ for pregnant heifers. SEM = 3.1.
Figure 3-9 Plasma beta-hydroxybutyrate concentration of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

Age (heifer vs. cow) $P = 0.27$; pregnancy status $P < 0.0001$; age x pregnancy status interaction $P = 0.37$; time $P = 0.98$; age x time interaction $P = 0.16$; pregnancy status x time interaction $P = 0.08$; age x pregnancy status x time interaction $P = 0.14$. $n = 5$ for non-pregnant cow; $n = 8$ for pregnant cows; $n = 5$ for non-pregnant heifers; $n = 7$ for pregnant heifers. SEM = 48.7.
Figure 3-10 Body weight of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P < 0.0001$; lactation status $P = 0.31$; age x lactation status interaction $P = 0.88$; time $P < 0.0001$; age x time interaction $P = 0.21$; lactation status x time interaction $P = 0.63$; age x lactation status x time interaction $P = 0.93$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 15.82.
Figure 3-11 Calf body weight from lactating beef cows and heifers from birth to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.02$; time $P < 0.001$; age x time interaction $P < 0.001$. n = 7 for cows; n = 7 for heifers. SEM = 2.63.
Figure 3-12 Body condition of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.03$; lactation status $P < 0.0001$; age x lactation status interaction $P = 0.77$; time $P < 0.01$; age x time interaction $P = 0.74$; lactation status x time interaction $P = 0.48$; age x lactation status x time interaction $P = 0.65$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 0.26.
Figure 3-13 Hip height of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P < 0.01$; lactation status $P = 0.46$; age x lactation status interaction $P = 0.26$; time $P = 0.88$; age x time interaction $P = 0.75$; lactation status x time interaction $P = 0.50$; age x lactation status x time interaction $P = 0.26$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 1.80.
Figure 3-14 Dry matter intake, kg d$^{-1}$, by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.35$; lactation status $P = 0.24$; age x lactation status interaction $P = 0.09$; time $P = 0.02$; age x time interaction $P = 0.32$; lactation status x time interaction $P = 0.25$; age x lactation status x time interaction $P = 0.45$. n = 5 for non-lactating cows; n = 7 for lactating cows; n = 5 for non-lactating heifers; n = 8 for lactating heifers. SEM = 1.11.
Figure 3-15 Dry matter intake, % BW, by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.07$; lactation status $P = 0.07$; age x lactation status interaction $P = 0.05$; time $P < 0.0001$; age x time interaction $P = 0.42$; lactation status x time interaction $P = 0.13$; age x lactation status x time interaction $P = 0.19$. n = 5 for non-lactating cows; n = 7 for lactating cows; n = 5 for non-lactating heifers; n = 8 for lactating heifers. SEM = 0.23.
Figure 3-16 Dry matter digestibility by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.14$; lactation status $P = 0.62$; age x lactation status interaction $P = 0.95$; time $P < 0.0001$; age x time $P = 0.02$; lactation status x time interaction $P = 0.26$; age x lactation status x time interaction $P = 0.64$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 4.7.
Figure 3-17 Digesta passage rate by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.23$; lactation status $P = 0.80$; age x lactation status interaction $P = 0.45$; time $P = 0.19$; age x time interaction $P = 0.73$; lactation status x time interaction $P = 0.10$; age x lactation status x time interaction $P = 0.43$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 0.34.
Figure 3-18 Plasma glucose concentration of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.37$; lactation status $P < 0.001$; age x lactation status interaction $P = 0.92$; time $P < 0.0001$; lactation status x time interaction $P = 0.55$; age x lactation status x time interaction $P = 0.02$. n = 5 for non-lactating cows; n = 7 for lactating cows; n = 5 for non-lactating heifers; n = 8 for lactating heifers. SEM = 3.3.
Figure 3-19 Plasma beta-hydroxybutyrate concentration of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

Age (heifer vs. cow) $P = 0.37$; lactation status $P < 0.0001$; age x lactation status interaction $P = 0.15$; time $P < 0.0001$; age x time interaction $P = 0.51$; lactation status x time interaction $P = 0.13$; age x lactation status x time interaction $P = 0.58$. $n = 5$ for non-lactating cows; $n = 7$ for lactating cows; $n = 5$ for non-lactating heifers; $n = 8$ for lactating heifers. SEM = 57.1.