

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
M.S, THE OHIO STATE UNIVERSITY, 2004

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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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

31 (Wiltbank, 1970; Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000), and
32 pregnancy rates for primiparous cows with a BCS of 4 were only 53% compared to 90% for
33 primiparous cows with BCS 5 or greater (Rae et al., 1993).

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

41 Although the effects of late gestation and early lactation on nutrition in mature beef cows has
42 been addressed in recent years, it is currently unclear to what extent gestation and lactation affect
43 intake, digestion, and ingesta passage rate in beef heifers. In addition, behavior differences exist
44 between primiparous and multiparous cows. Dairy heifers eat more meals per day, but eat
45 smaller meals when compared to multiparous cows (Bach et al., 2006), especially during the first
46 60 d postpartum. This may have an influence on management strategies needed to optimize
47 production of both animal groups. Inferring that information pertaining to mature beef cows is
48 relevant to heifers may lead to mismanagement of heifers during the periparturient period and
49 increase the likelihood of reproductive failure during the second breeding season.

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

53

54 **Effects of Gestation**

55 *Effect of Gestation on Intake*

56 Forage dry matter intake by ruminants has been shown to decrease during late pregnancy
57 (Campling, 1966; Weston, 1988; Vanzant et al., 1991; Stanley et al., 1993; Allen, 1996;
58 Scheaffer et al., 2001; Dorshorst and Grummer, 2002; Hayirli and Grummer, 2004; French,
59 2006). The decrease in intake is associated with reduction in ruminal volume caused by the rapid
60 increase in fetal size during late gestation creating a physical impingement on ruminal volume

61 (Forbes, 1968). This is because 60% of fetal growth occurs during the last 2 mo of gestation
62 (Bauman and Currie, 1980). Inert fill in the rumen has been shown cause a decrease in intake
63 (Dado and Allen, 1995). In addition, Dado and Allen (1995) observed an increase in the
64 frequency of small meals when high-forage and rumen-inert fill was added. This may explain the
65 decrease in intake often associated with animals on high-forage or high-fiber diets. Dry matter
66 intake prediction models developed for growing cattle have not been accurate for animals on all
67 forage diets (NRC, 2000).

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

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

85 Beef cows have been shown to have greater intake than heifers (Varel and Kreikemeier,
86 1999). Parity also has an influence on intake in dairy cattle. Cows had greater dry matter intake
87 as a percent of BW than heifers (1.88 vs. 1.69% of BW daily; Hayirli et al., 2002). In addition,
88 heifers had a more constant dry matter intake until the last week of gestation at which time it
89 decreased rapidly, whereas cows had a gradual decrease in dry matter intake for the final 3 wk
90 prepartum (Hayirli et al., 2002). Similarly, Marquardt et al. (1977) demonstrated that heifers had
91 a decrease in intake of 25% from 14 d prepartum until parturition while mature cows had a 50%

92 decrease in dry matter intake during the same time period. Johnson et al. (2003) found that parity
93 had an effect on dry matter intake (kg/d), but did not affect intake as a percent of BW.

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

98

99 *Effect of Gestation on Digestion*

100 Intake has been shown to influence dry matter digestibility. Limit-feeding has been shown to
101 increase diet digestibility when compared to animals fed to ad libitum intake (Galyean et al.,
102 1979; Murphy et al., 1994; Clark et al., 2007). However, the decrease in dry matter intake
103 associated with late gestation does not seem to have a similar effect on DM digestibility. Dry
104 matter digestibility tended to be lower for gestating ewes than for non-gestating ewes (Coffey et
105 al., 1989). Organic matter digestibility decreased in ewes as pregnancy advanced (Faichney and
106 White, 1988b).

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

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

115 Ruminal ammonia concentration decreased with advancing gestation in beef heifers
116 (Scheaffer et al., 2001). Ruminal ammonia concentrations were less in pregnant cows at 10 d
117 prepartum (6.9 mg/dL) when compared to non-pregnant cows (8.0 mg/dL), but did not differ at
118 96, 68, or 41 d prepartum (Hanks et al., 1993). This decrease could be attributed to increased
119 passage rate or decreased dry matter intake during late gestation (Hanks et al., 1993).

120 Jejunum and ileum tissue cell number increases with advancing gestation in forage fed beef
121 heifers; this is probably a response to increased energy demand in the pregnant heifers (Scheaffer
122 et al., 2003).

123

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

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

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

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

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

150 ruminal mean retention time in Jersey cows was less than in Holstein cows, which coincided
151 with increased chewing times in the Jersey cows.

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

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

160 **Effect of Lactation**

161 *Effect of Lactation on Intake*

162 Mammary demands for amino acids, glucose, and fatty acids increase several-fold within 4 d
163 of parturition (Bell, 1995). Cows have shown a dry matter intake increase postpartum when
164 compared to non-lactating cows (Campling, 1966; Hunter and Siebert, 1986; Overnell et al.,
165 1991). Increase in nutrient demand from lactation has been used to explain rapid increases in dry
166 matter intake postpartum in dairy cattle. In addition, dry matter intake is positively correlated to
167 increasing milk production (Hatfield et al., 1989). Even accounting for increasing milk
168 production with increased cow age (Neville, 1971) beef cows have substantially less milk
169 production when compared to dairy cows. Therefore, less of a response would be expected for
170 beef cows and heifers than what is observed in dairy cows (Vanzant, 1991).

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

174 Cow dry matter intake increased postpartum when compared to non-lactating cows (Jordan et
175 al., 1973; Overnell et al., 1991). Hunter and Siebert (1986) reported that Brahman-cross cows
176 had 25% greater dry matter intake during the first month postpartum when compared to non-
177 lactating cows and 35% greater dry matter intake in the third month postpartum. Vanzant et al.
178 (1991) reported 17% greater dry matter intake in lactating heifers 26 d postpartum when
179 compared to non-lactating heifers and estimated that the difference would be greater as the

180 lactating heifers approached peak milk yield. Rosiere et al. (1980) determined that lactating
181 heifers had 40% greater intake of warm-season grasses than non-lactating heifers at 90 d
182 postpartum.

183 Johnson et al. (2003) determined that multiparous beef cows had 19% greater forage dry
184 matter intake than primiparous cows (kg/d). However, when expressed as a percentage of BW,
185 intakes of primiparous and multiparous cows did not differ (Johnson et al., 2003; Galindo-
186 Gonzalez et al., 2007). Johnson et al. (2003) determined that multiparous Brangus cows had
187 66% more milk production than primiparous Brangus cows, with similar dry matter intake.

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

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

197

198 *Effect of Lactation on Digestion*

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

205

206 *Effect of Lactation on Passage Rate*

207 Particulate passage rate increases with increasing DE intake and dry matter intake (Evans,
208 1981B; Okine and Mathison, 1991). Lactating ewes have faster passage rates than non-lactating
209 ewes (Coffey et al., 1989). This has been shown in lactating beef heifers as well. Vanzant et al.

210 (1991) demonstrated that lactating beef heifers had faster indigestible ADF passage rates when
211 compared to non-pregnant, non-lactating heifers.

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

215

216 *Effect of Gestation and Lactation on Metabolism*

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

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

222 During early gestation, dairy heifers have a low concentration of plasma NEFA, but a high
223 concentration of plasma glucose (Ingvarlsen and Andersen, 2000). During late gestation there is
224 an increase in hepatic gluconeogenesis along with decreased glucose utilization by tissues (Bell,
225 1995). Glucose concentration increases during the last week of pregnancy and drops to its lowest
226 at 1 to 3 wk postpartum (Ingvarlsen and Andersen, 2000). This was also observed numerically by
227 Dorshorst and Grummer (2002), but the effect was not statistically significant.

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

235 Lactation increases the demand for glucose, fatty acids, and amino acids that cannot be met
236 by dietary intake in high producing dairy cows (Bell, 1995). The metabolic demand from
237 colostrum production exceeds the metabolic demand from the fetus during late gestation (Goff
238 and Horst, 1997). This results in a reduction in lipogenesis, an increase in lipolysis, and increase
239 in gluconeogenesis (Bauman and Currie, 1980; Bell, 1995).

240 The most obvious metabolic factor that occurs during lactation is the mobilization of fat from
241 adipose tissue to support synthesis of milk (Bauman and Currie, 1980). Dairy heifers fed energy
242 dense diets during pregnancy have high concentrations of plasma NEFA postpartum but reduced
243 concentrations of plasma glucose (Ingvarsten and Andersen, 2000). NEFA increased from 2 or 3
244 wk prepartum to a maximum 1 wk postpartum (Ingvarsten and Andersen, 2000). Plasma glucose
245 increases 1 wk prepartum, but drops to a low at 1 to 3 wk postpartum (Ingvarsten and Andersen,
246 2000). This can be explained by the 9-fold increase in glucose uptake by the mammary tissue on
247 d 9 postpartum compared to d 2 prepartum (Bell, 1995).

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

253 Metabolic control of intake during the periparturient period has been proposed (Illius and
254 Jessop, 1996; Ingvarsten and Anderson, 2000; Allen et al., 2009). The oxidation of fatty acids in
255 the brain, liver, and whole body have been investigated. However, rate of oxidation has been
256 linked inversely to changes in body fat and therefore body condition. Blocking fatty acid
257 oxidation has been shown to increase intake, but only when fatty acid oxidation was already high
258 (Allen et al., 2009). The degree and rate of fatty acid oxidation influences the hypophagic
259 response in dairy cattle. Unsaturated fatty acids decrease intake to a greater extent than saturated
260 fatty acids due to more rapid oxidation of unsaturated fatty acids (Allen et al., 2009). Similarly,
261 medium-chain fatty acids decrease intake more than long-chain fatty acids (Allen et al., 2009).
262

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

264 Bellows et al. (2002) determined that the yearly cost of beef cow infertility and reproductive
265 disease in the United States was \$441 to \$502 million. Three-fourths of this is attributed to
266 female infertility. Short et al. (1990) stated that anestrus is the major component of postpartum
267 infertility in beef cattle, with the two largest components of this being suckling response and
268 nutrition.

269 Primiparous cows have longer postpartum intervals than multiparous cows (Wiltbank, 1970;
270 Bellows et al., 1982; Triplett et al., 1995; Yavas and Walton, 2000; Banta et al., 2005). Because
271 of this, replacement beef heifers are typically bred 15 to 30 d before mature cows to allow
272 greater time from parturition to first estrus and to allow for 2-yr-old cows to rebreed at the same
273 time as older cows (Banta et al., 2005). Matching the nutrient supply to nutrient requirement is
274 necessary to support milk production and to maintain the desired 12-mo calving interval (Bagley,
275 1993). However, earlier calving of heifers may occur during seasonal dormancy for many grazed
276 plants resulting in less nutrient availability during late gestation. This reduction in nutrient
277 availability takes place during a period of elevated nutrient requirements (NRC, 2000) making it
278 difficult to maintain BW and BCS during late gestation while feeding low-quality forage diets.

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

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

290 Postpartum energy restriction decreased conception rate and increased postpartum interval of
291 beef cows (Banta et al., 2005), whereas an increase in energy intake decreased postpartum
292 interval (Lalman et al., 2000). Maintaining prepartum body condition between 5 and 7 can
293 decrease the severity of anestrus and infertility (Short et al., 1990). Cows that lost BW during
294 mid- to late gestation had greater calving intervals, lower pregnancy rates, and lighter calves at
295 weaning (Godfrey et al., 1988). Pregnancy rates for primiparous cows with a BCS of 4 were only
296 53% compared to 90% for primiparous cows with BCS 5 or greater (Rae et al., 1993). Lalman et
297 al. (1997) showed a linear decrease in postpartum interval with a linear increase in ME fed to
298 primiparous beef heifers. An increase of one unit of body condition results in a 23% increase in
299 pregnancy rate (Lamb et al., 2001).

300 Primiparous cows that were fed a higher energy diet postpartum had shorter postpartum
301 intervals and greater first estrus pregnancy rates than primiparous cows fed a lower energy diet
302 (Ciccioli et al., 2003).

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

318

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

320

320 Sheep as an intake model

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

325 One positive aspect of sheep nutrition is that sheep are commonly fed forage based diets
326 similar to those fed to beef cows. However, grazing sheep consume more forage per metabolic
327 BW than grazing cattle (76 vs. 63 g/MBW; Cordova et al., 1978). Reticulorumen volume,
328 expressed as % BW, is similar between sheep and cattle (9-13%; Van Soest, 1994).

329 At high intakes, sheep have been shown to have greater diet digestibility (Colucci et al.,
330 1989) and lesser digesta retention times than cows (Colucci et al., 1990).

331 Sheep with multiple lambs have a marked decrease in dry matter intake during late gestation.
332 This is due to decreased ruminal capacity from the growing fetuses and gravid uterus (Campling,
333 1966; Ferguson, 1956; Gordon and Tribe, 1951; Reid and Hinks, 1962). Beef cows typically only
334 carry a single fetus. Therefore, less of a response during late gestation might be expected in beef
335 cows than what has been observed in ewes carrying multiple fetuses.

336 *Dairy cows as an intake model*

337 Dairy cows make unique animal models for voluntary intake because of high energy demand
338 and marginal nutritional status, which makes them very responsive to nutritional changes (Allen,
339 et al., 2005). However, it is this high energy demand that makes them an unacceptable
340 comparison for beef cows and heifers.

341 Increase in nutrient demand from lactation has been used to explain rapid increases in dry
342 matter intake postpartum in dairy cattle. Net energy requirements increased to 26 Mcal/d for
343 dairy cows producing 30 kg/d of milk (Ingvartsen and Andersen, 2000). However, beef cows
344 have less milk production when compared to dairy cows. In addition, Johnson et al. (2003)
345 reported beef heifer milk yield was 40% less than that by multiparous beef cows during early
346 lactation. Beef heifer milk production ranges from 5.4 to 6.7 kg/d and generally peaked by 6 wk
347 postpartum (Bowden, 1981; Lalman et al., 2000; Johnson et al., 2003). This is dramatically less
348 production and a much earlier peak of lactation than is expected from a mature Holstein.
349 Therefore, less of a nutritional response would be expected for beef cows and heifers than what
350 is observed in dairy cows (Vanzant, 1991).

351 Ingvartsen and Andersen (2000) showed that changes in plasma NEFA and plasma glucose
352 were influenced by energy density of the diet. If this is true, beef cows and heifers, which are fed
353 diets that are much lower in energy density than those fed to dairy cows, may not exhibit the
354 drastic changes seen in the dairy animals. Unlike energy dense diets fed to dairy cows, forage
355 based diets for beef cattle do not provide enough digestible energy for physiological demand to
356 control intake (NRC, 1987). Instead, intake is limited by gastrointestinal fill.

357 Short et al. (1990) stated that beef cattle and dairy cattle differ in management, but not in
358 physiology. Differing management between dairy cows and beef cows make beef cow research

359 more difficult than dairy cow research. Dairy cows are commonly and easily housed in
360 individual stalls that allow for easier experimental sampling (Allen et al., 2005), whereas beef
361 cows are seldom housed individually. Occasionally dairy cows are housed similarly to beef
362 cows. An example of this would be loose housing cows with automatic milking units as
363 described by Bach et al. (2006). In this study cows were housed in a loose barn with access to an
364 automatic milking unit. This allowed the cows to be milked as needed at random times
365 throughout the day, similar to what would be seen with beef cows with suckling calves. Though
366 the diets for the dairy cows would have greater energy density than most beef rations, it does
367 allow for some more similar comparisons. Bach et al. (2006) observed that primiparous cows had
368 a greater number of meals, but spent less total time eating than multiparous cows.

369

370 **Summary of Findings on the Effects of Gestation and Lactation on Beef Cow** 371 **and Beef Heifer Nutrition**

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

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

389 high concentrations of plasma NEFA due to increased lipolysis. The rapid oxidation of fatty
390 acids in the liver further contributes to a decrease in intake during late gestation.

391 Following parturition the fetus no longer has an inhibition on ruminal capacity. This
392 allows for an increase in intake to occur because of reduced physical impingement from the
393 gravid uterus and fetus. At parturition, energy demand increases with increasing milk production.
394 These factors contribute to an increase in postpartum DMI. DMI has been observed to be up to
395 40% greater in lactating beef cows within 3 months postpartum compared to non-lactating cows.
396 In conjunction with increased DMI, lactating cows have greater passage rates when compared to
397 non-lactating cows. However, postpartum passage rate is less than prepartum passage rate even
398 though DMI is greater postpartum. In addition, energy demand from lactation exceeds the energy
399 that can be obtained from a low-quality forage diet. This results in increasing lipolysis to meet
400 energy demand and a subsequent increase in plasma NEFA concentration.

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

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**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,

607 and 4 wk prior to parturition; however, PREG had less (treatment x period, $P < 0.01$) total
608 ruminal VFA than OPEN 2 wk before parturition. Postpartum total ruminal VFA concentrations
609 were similar ($P = 0.97$) between LACT and NL. Particulate passage rate was similar ($P \geq 0.55$)
610 between PREG and OPEN and between LACT and NL. Ruminal fluid dilution rate of PREG
611 tended to be less ($P = 0.10$) than that of OPEN; however, it was similar ($P = 0.52$) between
612 LACT and NL. Changes to intake, passage rate, and ruminal fermentation that are characteristic
613 of beef cows during late gestation may not occur in beef heifers maintained on low-quality,
614 warm-season grass hay diets.

615 Keywords: fermentation, gestation, heifers, intake, lactation

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Introduction

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619 Replacement beef heifers are typically bred 15 to 30 d before mature cows to allow more
620 time from parturition to first estrus and to ensure a 12-mo calving interval for 2-yr-old cows
621 (Banta et al., 2005). Earlier calving may occur during seasonal dormancy for many grazed plants
622 resulting in less nutrient availability for heifers during late gestation and body condition loss
623 prior to lactation. This takes place during a period of elevated nutrient requirements (NRC,
624 2000).

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

635 Matching nutrient supply to nutrient requirement is necessary to support milk production and
636 to maintain a 12-mo calving interval. Lactating beef cows require 20 to 30% more dietary energy

637 when compared to non-lactating cows (Neville, 1971; Montano-Bermudez et al., 1990; NRC,
638 2000); moreover, milk production is usually associated with significantly increased intake
639 (Wagner et al., 1986; Hatfield, et al., 1989). Postpartum energy restriction decreased conception
640 rate and increased postpartum interval of beef cows (Banta et al., 2005).

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

647

648 **Materials and Methods**

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

652 *Prepartum Phase*

653 Ruminally-cannulated Angus-cross heifers (n = 12; average initial BW 525 ± 53 kg) were
654 housed indoors in individual tie-stalls (2 x 1.2 m) in an environmentally controlled barn (average
655 temperature 25°C; average humidity 72%; 12 h light, 12 h dark) for an average of 68 d
656 prepartum. Treatment assignments were based on pregnancy status. Twelve heifers were
657 inseminated by transcervical AI approximately 213 d before the study began. Ovulation was
658 synchronized before AI using the 7-11 Co-Synch protocol described by Eborn and Grieger
659 (2007).

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

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Postpartum Phase

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

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Feed

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

686 Vanzant et al. (1991) reported that OMI of tallgrass prairie forage by British-type beef
687 heifers was approximately 2% of BW during the final 55 d of gestation and 2.6% of BW 30 d
688 after parturition. At these forage intakes, our hay exceeded minimum requirements of beef
689 heifers (544 kg mature weight, 4.5 kg d⁻¹ peak milk) for NEm during the pre- and postpartum
690 portions of our study (NRC, 2000; Olson et al., 2008). Conversely, our hay was slightly deficient
691 in CP during the last 60 d of gestation but adequate in CP during the first 60 d of lactation (NRC,
692 2000).

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Data Collection

694 The prepartum period and postpartum periods were each divided into 5 data-collection
695 periods that were 14 d in length. Intake was measured on d 1-14 of each period and reported as
696 the arithmetic mean for each animal. Fecal output was measured on d 9 to 12 of each period.

697 Fecal grab samples were collected every 4 h, with sample collection times advanced 1 h each
698 day. Using this scheme, 1 sample was collected at each hour of the day (i.e., a total of 24 fecal
699 samples over 4 d), in order to account for diurnal changes in composition. Fecal samples were
700 dried for 72 h in a forced-air oven at 55°C to determine DM. Total tract nutrient digestion
701 coefficients were calculated using ADIA as an internal marker according to Cochran and
702 Galyean (1994). Stafford et al. (1996) reported that fecal recovery of ingested ADIA from beef
703 cattle consuming hay of the type used in this study was quantitative.

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

707 Ruminal fermentation and fluid dilution rates were characterized on d 13 of each collection
708 period. Cobalt-EDTA was used as an external marker of the fluid phase of ruminal digesta (Uden
709 et al. 1980). The marker was infused via ruminal cannulae at a rate of 6.5 g Co-EDTA / heifer at
710 0800 h. Ruminal fluid samples were obtained from 3 randomly-selected areas of the ventral
711 rumen just prior to marker dosing (0 h) and 4, 8, 12, 16, and 20 h after marker dosing. Ruminal
712 fluid was strained through 4 layers of cheesecloth and separated into 2 aliquots: 10 mL for Co
713 analysis and 10 mL for VFA and NH₃ analyses. The latter aliquot was combined with 2 mL of
714 25% (wt/vol) metaphosphoric acid. Ruminal fluid aliquots were frozen immediately after
715 collection.

716 Ruminoreticular fill (RRF) and ruminal ADIA passage rates were measured on d 14 of each
717 collection period. The RRF was measured by complete manual evacuation of digesta (fluid and
718 solid fractions) from the rumen and reticulum immediately prior to and 4 h after the daily feeding
719 (Olson et al., 1999). Ruminoreticular contents were completely removed, weighed, and mixed by
720 hand; 4 subsamples of digesta were collected. After sampling, all contents were replaced via the
721 ruminal fistula. Fill was calculated by averaging the RRF from the pre-feeding and post-feeding
722 periods. Ruminal digesta DM was determined by drying samples in a forced-air oven at 55°C for
723 72 h. Ruminal DM fill was estimated by multiplying ruminal digesta DM by the total weight of
724 ruminal digesta. Ruminal fluid fill was estimated as the difference between total ruminal fill and
725 ruminal DM fill. Ruminal particulate passage rate was calculated as ADIA ingestion rate divided
726 by ADIA concentration in ruminal digesta.

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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 NH₃ 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 .

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Results and Discussion

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Body Weight and Body Condition Score

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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.

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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.

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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.

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DMI and DM Digestion

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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

787 less forage than their non-pregnant monozygotic twins. Conversely, Stanley et al. (1993)
788 indicated pregnant mature beef cows ate more alfalfa than non-pregnant counterparts, whereas
789 Scheaffer et al. (2001) reported no difference in DMI of a total mixed ration composed of alfalfa
790 and corn silage between pregnant and non-pregnant beef heifers. Both Stanley et al. (1993) and
791 Scheaffer et al. (2001) were feeding a diet that was more digestible and would potentially cause
792 less ruminal fill than the warm-season hay that was fed during this study. Vanzant et al. (1991)
793 reported greater intake of tallgrass prairie forage by pregnant heifers than by non-pregnant
794 heifers 55 d prepartum; however, there was no difference in DMI 12 d prepartum. This may be in
795 part because of the addition of alfalfa pellet supplementation and the greater passage rates that
796 were present in the pregnant and lactating beef heifers in their study.

797 Increases in DMI that occur early during the final trimester of pregnancy have classically
798 been attributed to increased nutrient requirements driven by the fetus and gravid uterus. In
799 contrast, decreased DMI in the weeks immediately prior to parturition was usually associated
800 with the rapidly-growing fetal tissues creating a physical impingement on the rumen (Forbes,
801 1986). Dry matter intake by pregnant heifers in our study sharply declined 2 wk prepartum,
802 possibly because of a decrease in ruminal volume.

803 Lack of consensus on the effects of late-term pregnancy on DMI may have been caused by
804 differences in the timing of intake measurements, differences in the classes of cattle, and
805 differences in the nutrient density and digestibility of diets that occurred from study to study.

806 Dry matter digestibility (DMD) was similar ($P = 0.30$) between PREG and OPEN and
807 generally decreased over time (main effect of period - $P < 0.01$) as intake increased (Figure 2-1).
808 Hanks et al. (1993) reported no difference in DMD between pregnant and non-pregnant cows,
809 whereas Beharka et al. (1988) reported decreased DMD during late gestation. Vanzant et al.
810 (1991) and Scheaffer et al. (2001) reported poorer DMD in pregnant heifers when compared to
811 non-pregnant heifers. Increased DMI was usually associated with decreased DMD (Okine and
812 Mathison, 1991). Additionally, increased DMI was usually accompanied by more rapid fluid and
813 particulate passage (Allen, 1996). Mean ruminal retention time and the extent of DMD generally
814 decrease under these conditions (Allen, 1996).

815 Lactating beef cows require 20 to 30% greater metabolizable energy than non-lactating cows
816 (Neville, 1971; Montano-Bermudez et al., 1990; NRC, 2000); any postpartum increase in DMI
817 may be explained by the increase in energy requirements associated with milk production

818 (Vanzant et al., 1991; Johnson et al., 2003). Both lactating and non-lactating heifers generally
819 increased (main effect of period - $P < 0.01$) DMI as the postpartum portion of our study
820 advanced but DMI was similar ($P = 0.39$) between treatments (Figure 2-2). Most published
821 research reported contrasting results. Rosiere et al. (1980) found that lactating heifers had greater
822 DMI at 90 d and 150 d postpartum than non-lactating heifers when grazing low-quality forage.
823 Rosiere et al. (1980) estimated DMI based on 24-hr fecal output divided by in vitro
824 indigestibility of OM at 90 d and 150 d postpartum. It was suggested that some of the variation
825 in intakes could be from inherent errors in the estimation technique. Forage intake should have
826 overcome any restrictions in rumen fill from the fetus and gravid uterus by this stage of lactation.
827 Ovenell et al. (1991) and Hatfield et al. (1989) reported greater DMI by lactating, mature beef
828 cows than by non-lactating, mature beef cows when fed hay along with protein supplements.
829 Campling (1966) and Hunter and Siebert (1986) reported 29% and 25% greater DMI by cows,
830 respectively, following parturition. Both studies fed diets that were much greater in protein
831 concentration than that in our study and greater digestibility would be expected. Marston and
832 Lusby (1995) also reported that beef heifers increased DMI from late gestation until 6 wk
833 postpartum. Vanzant et al. (1991) reported a 17% increase in DMI by lactating heifers over non-
834 lactating heifers when measured 26 d postpartum. However, Vanzant et al. (1991) fed alfalfa
835 pellets as a supplement and reported data from a single time point postpartum.

836 Apparent total-tract DMD in lactating heifers generally increased during the postpartum
837 period but did not follow a consistent pattern in non-lactating heifers (treatment x period - $P <$
838 0.01 ; Figure 2-2). Diet digestibility was similar to that reported by Johnson et al. (2003) for
839 primiparous beef heifers during early lactation and less than that reported for mature cows
840 (Hatfield et al., 1989). Hatfield et al. (1989) evaluated diets that included dehydrated alfalfa
841 pellets as well as hay; therefore, greater DMD would be expected. Marston and Lusby (1995)
842 reported no differences in DMD of beef heifers based on lactation status; Ovenell et al. (1991)
843 reported similar observations for mature cows. Vanzant et al. (1991) reported also that OM
844 digestibility did not differ between lactating and non-lactating heifers 26 d post-partum.
845 Conversely, Colucci et al. (1982) and Okine and Mathison (1991) reported that mature dairy
846 cows experienced a post-partum depression in DMD concomitant with increased DMI.
847 Classically, DMD and DMI have been inversely related (Clark et al., 2007). Increased rates of
848 digesta passage and shorter digesta residence times in the gut are characteristic of both high

849 relative DMI and low relative diet digestibility (Moe et al., 1965; Colucci et al., 1982; Edionwe
850 and Owen, 1989); mastication and rumination time per kg of DM decrease also with increased
851 intake and may contribute to decreased DMD (Deswysen et al., 1987).

852 *Ruminoreticular Fill*

853 Total ruminoreticular fill (RRF) for PREG and OPEN tended to increase (main effect of
854 period - $P = 0.07$) slightly during the prepartum period (Figure 2-3). This is in contrast to Stanley
855 et al. (1993) who reported a general increase in ruminal fill in mature beef cows from d 61 until d
856 34 prepartum that was followed by a decrease in ruminal fill from d 34 to d 6 prepartum.
857 Pregnant heifers had less ($P = 0.03$) RRF than OPEN. Weston, et al. (1983) made similar
858 conclusions when comparing pregnant and open mature beef cows. In contrast, Beharka et al.
859 (1988) reported no difference in rumen fill between pregnant and non-pregnant cows. Scheaffer
860 et al. (2001) reported greater ruminal fill in pregnant heifers when compared to non-pregnant
861 heifers during early gestation but less ruminal fill in pregnant heifers compared to non-pregnant
862 heifers during late gestation. Hanks et al. (1993) reported less estimated gastrointesintestinal fill
863 for pregnant than for non-pregnant beef cows. Less ruminal fill for pregnant heifers in our study
864 as early as 10 wk prepartum may indicate a decrease in ruminal capacity earlier than what has
865 been shown in mature beef cows. These factors may drive a change in digesta flow through the
866 gastrointestinal tract of primiparous beef heifers that differs from that reported for mature beef
867 cows.

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

876 Ruminal solid fill increased with advancing gestation (main effect of period - $P < 0.01$;
877 Figure 2-3). Pregnant heifers had less ($P = 0.02$) ruminal solids than OPEN. Vanzant et al.
878 (1991) and Stanley et al. (1993) reported also that pregnant heifers and pregnant cows,

879 respectively, had less fill of ruminal solids than non-pregnant females. In contrast, Scheaffer et
880 al. (2001) reported no difference in ruminal DM fill in pregnant and non-pregnant beef heifers.

881 Total RRF did not change over time following parturition (main effect of period - $P = 0.23$;
882 Figure 2-4). In addition, total RRF was similar ($P = 0.82$) in lactating and non-lactating heifers.
883 Stanley et al. (1993) reported an increase in ruminal fill in pregnant mature cows from parturition
884 to 22 d postpartum. We speculated that greater gut capacity and appetite in mature cows
885 compared to the heifers in our study contributed to these contrasting results.

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

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

894 ***Milk Production***

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

904 ***Ruminal Fermentation***

905 Ruminal NH_3 was similar between pregnant and non-pregnant heifers during the
906 prepartum period and the magnitude of response was influenced by period (treatment x period -
907 $P = 0.04$; Figure 2-5). Ruminal NH_3 concentrations were generally below the level recommended
908 by Satter and Slyter (1974) as necessary to support maximal microbial cell protein production.

909 Weston (1983) and Scheaffer et al. (2001) reported a decrease in ruminal NH_3 in pregnant sheep
910 and heifers, respectively, compared to non-pregnant counterparts. In contrast, Vanzant et al.
911 (1991) reported an increase in ruminal NH_3 early in pregnancy followed by a decrease in ruminal
912 NH_3 during late pregnancy. Hanks et al. (1993) likewise reported no difference in NH_3 until 10 d
913 prepartum, at which time pregnant cows had less NH_3 than non-pregnant cows. A decrease in
914 ruminal NH_3 concentration is often associated with an increase in ruminal passage rate or an
915 increase in DMI (Adams and Kartchner, 1984). Scheaffer et al. (2001) suggested that increased
916 nutrient demand by the fetus may drive greater absorption of ruminal NH_3 .

917 Total ruminal VFA concentration was generally similar between pregnant and non-pregnant
918 heifers during the prepartum period and the magnitude of response was influenced by period
919 (treatment x period - $P < 0.01$; Figure 2-5). Similarly, Scheaffer et al. (2001) and Vanzant et al.
920 (1991) reported no differences in total VFA concentration between pregnant and non-pregnant
921 beef heifers. Hanks et al. (1993) reported inconsistent temporal differences between pregnant and
922 lactating cows. Sharply decreased total VFA we observed in pregnant heifers 2 wk prepartum
923 coincided with decreased DMI. Decreased DMI likely resulted in decreased substrate availability
924 for ruminal microbes and a decrease in the products of fermentation.

925 Ruminal NH_3 was relatively static in lactating heifers postpartum but generally increased in
926 non-lactating heifers (treatment x period - $P = 0.01$; Figure 2-6). Differences in ruminal NH_3
927 may have been resulted from less urea recycling in lactating heifers; amino acids may have been
928 used for milk synthesis, making less NH_3 available to produce urea.

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

933 Pregnant heifers had greater ($P < 0.03$) ruminal molar proportions of acetate and lesser ($P <$
934 0.01) ruminal molar proportions of butyrate and minor VFA when compared with non-pregnant
935 heifers (Table 2-1). An increase in molar proportion of acetate is generally associated with a
936 decrease in other VFA. Vanzant et al. (1991) and Scheaffer et al. (2001) reported no differences
937 in ruminal molar proportion of acetate between pregnant and non-pregnant heifers. Similarly,
938 Scheaffer et al. (2001) reported no difference in molar proportion of butyrate between pregnant
939 and non-pregnant cows.

940 Ruminal molar proportions of acetate, propionate, and butyrate in pregnant and non-pregnant
941 heifers were influenced by both treatment and time relative to parturition ($P < 0.01$; Table 2-2).
942 In contrast, the collective ruminal molar proportion of isobutyrate, valerate, and isovalerate (i.e.,
943 minor VFA) were greater ($P < 0.01$) in non-pregnant than pregnant heifers. Although branched-
944 chain VFA and valerate are thought to stimulate microbial protein synthesis *in vitro*, Gunter et al.
945 (1990) suggested the effect was of questionable *in-vivo* significance.

946 Ruminal acetate generally increased (period main effect - $P < 0.01$) following parturition, but
947 was similar (treatment main effect - $P = 0.21$) between lactating and non-lactating heifers (Table
948 2-3). Vanzant et al. (1991) reported lesser proportions of acetate in lactating heifers compared
949 with non-lactating heifers.

950 Ruminal molar proportions of acetate and propionate varied over time (main effect of period
951 - $P < 0.01$) during the postpartum portion of our study but were not influenced ($P \geq 0.21$) by
952 lactation status (Table 2-3). In contrast, Vanzant et al. (1991) reported that lactating heifers had
953 greater ruminal molar proportions of propionate than non-lactating heifers. Ruminal molar
954 proportions of butyrate were inconsistent (treatment x time - $P < 0.01$) over time and lactation
955 status, although decreased molar proportions of ruminal butyrate have been reported in lactating
956 compared to non-lactating cows (Ingvarlsen, 2006). The interaction between treatment and time
957 was significant ($P < 0.01$) for the collective molar proportions of isobutyrate, valerate, and
958 isovalerate during the postpartum portion of our study (Table 2-3). Treatments did not change
959 relative ranks during the postpartum data collection period and the numerical differences
960 between treatments during each data collection period were greater than $3 \times$ the SE for treatment.
961 We interpreted this interaction to be due to the magnitude of difference between treatments. It
962 appeared that non-lactating heifers had greater ($P < 0.01$) ruminal molar proportions of these
963 minor VFA than lactating heifers; however, we were unsure of the biological significance of this
964 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.

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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.

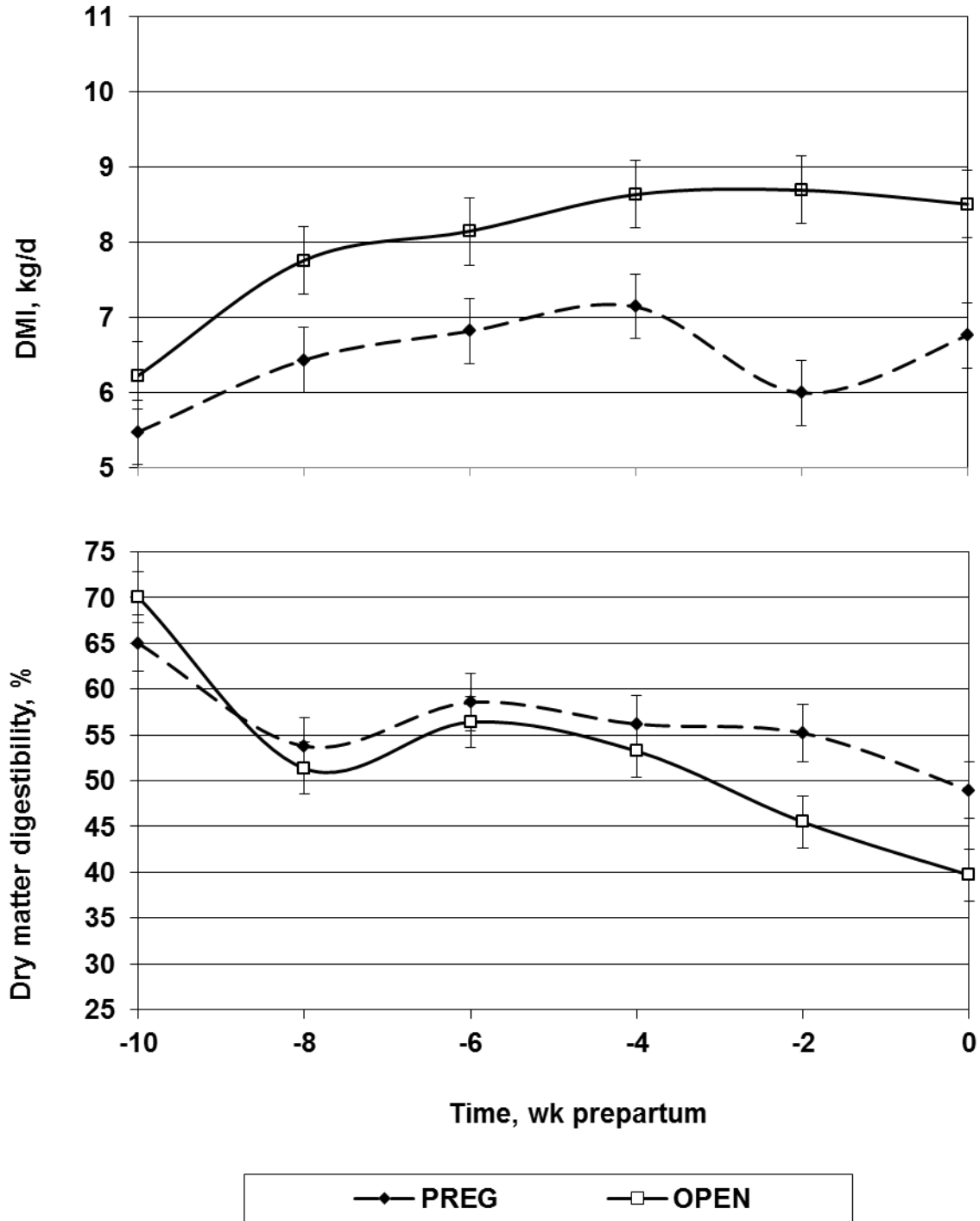


Figure 2-2: Dry matter intake and digestibility by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk postpartum.

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 $P < 0.01$.

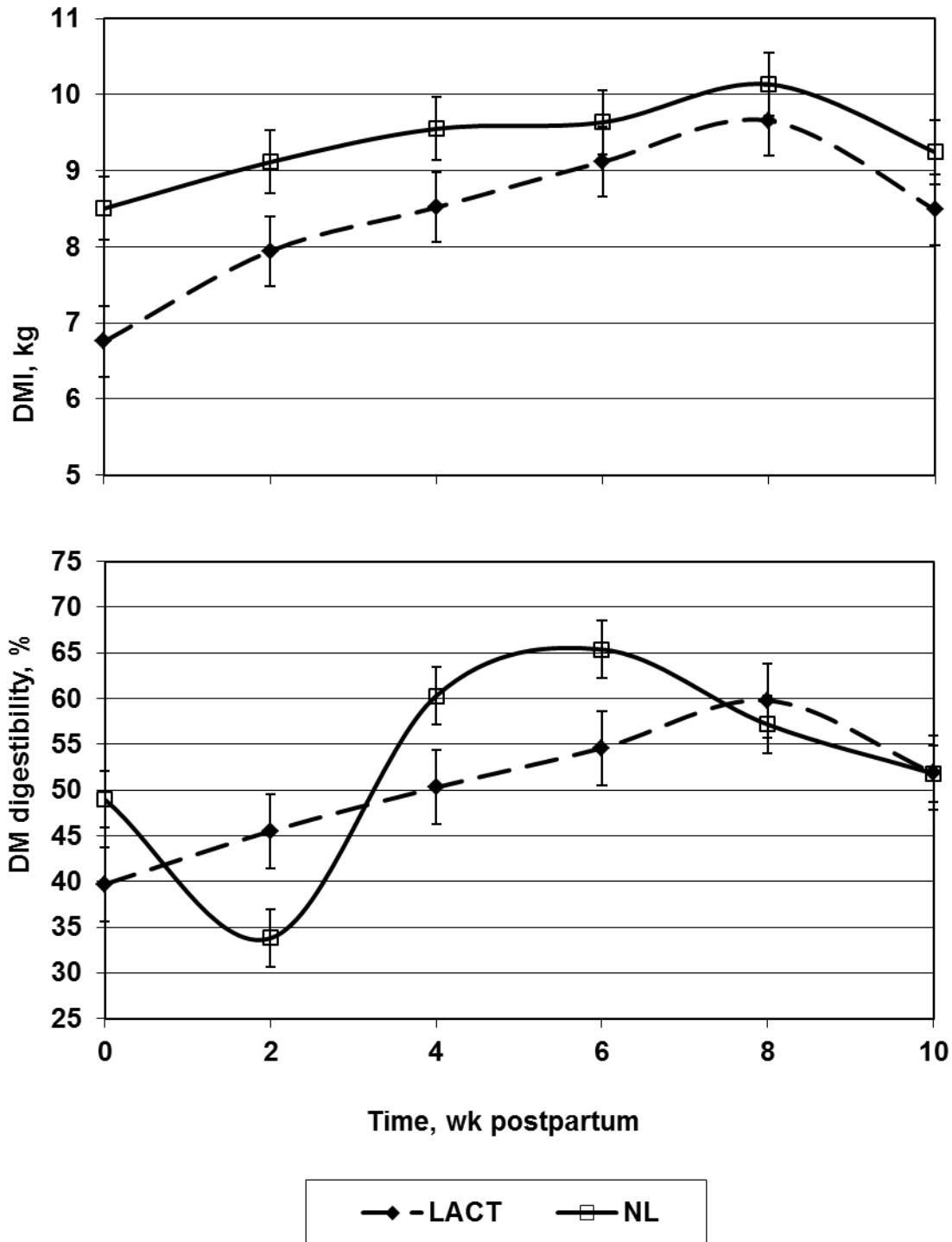


Figure 2-3 Total ruminal fill, ruminal liquid fill, and ruminal solid fill by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

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.

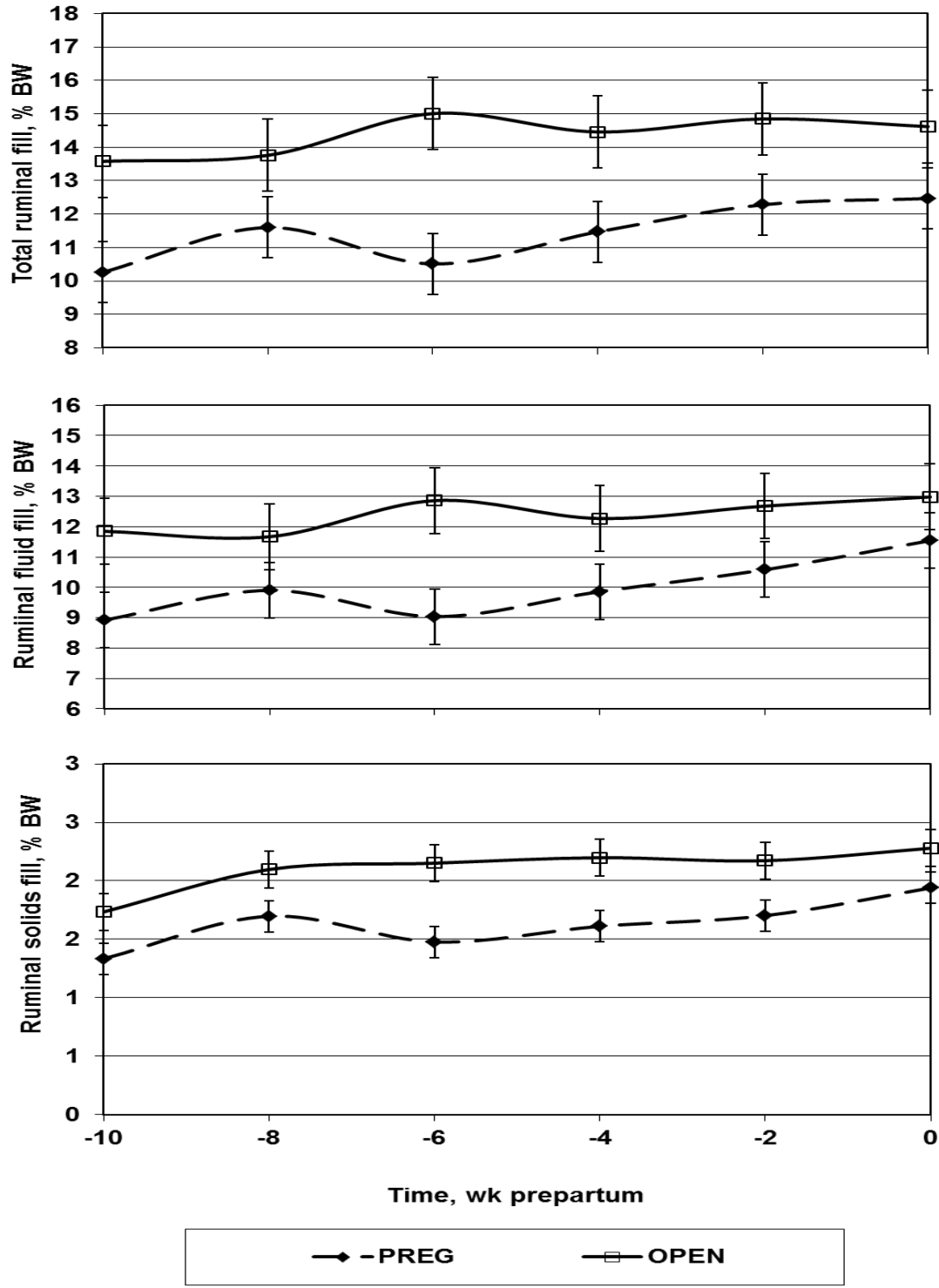


Figure 2-4 Total ruminal fill, ruminal liquid fill, and ruminal solid fill by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk

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 $P = 0.11$.

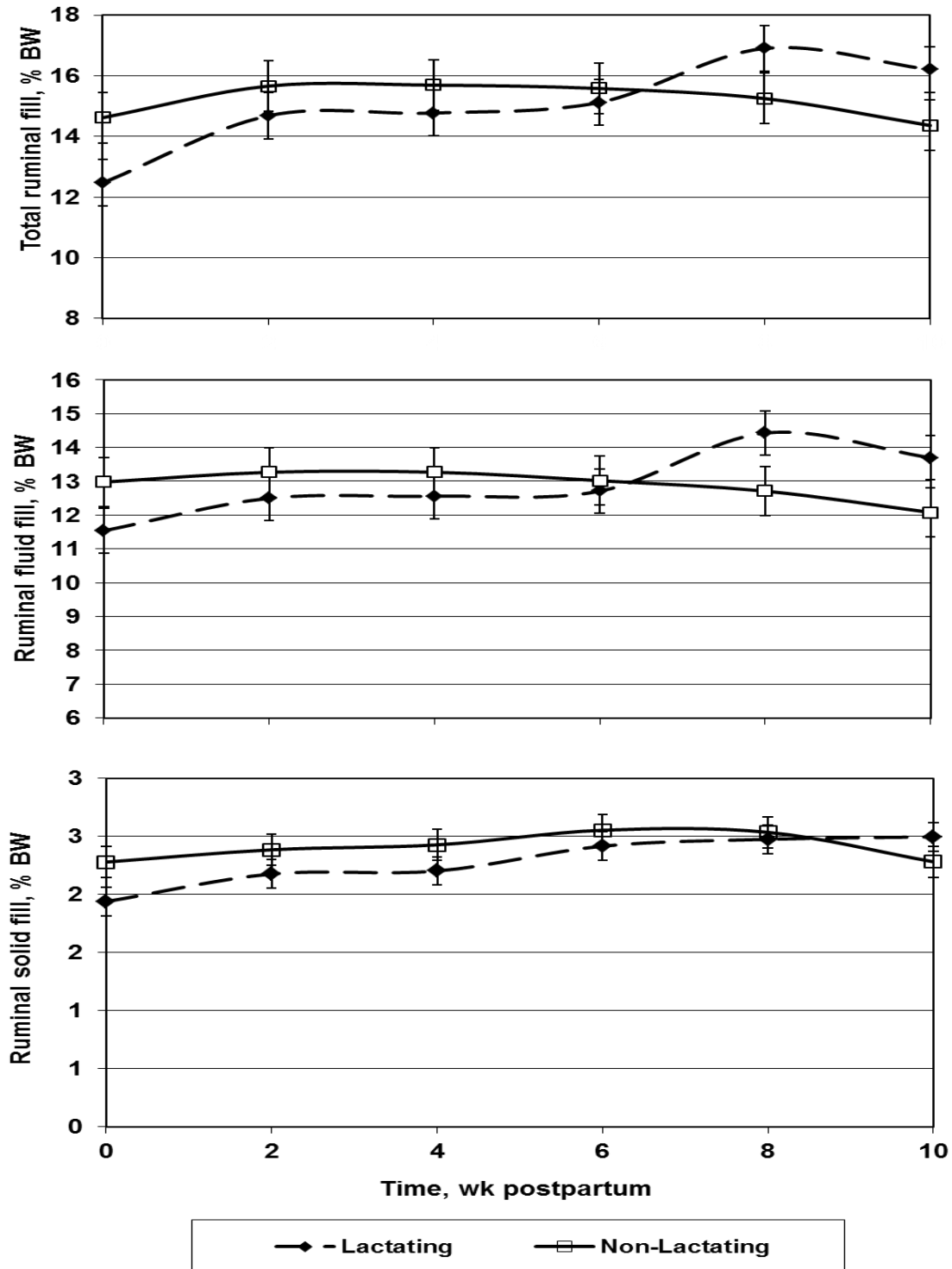


Figure 2-5 Ruminant NH₃ and total ruminant VFA concentration by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

PREG denotes pregnant primiparous beef heifers. OPEN denotes non-pregnant, non-lactating beef heifers. Ruminant NH₃: treatment $P = 0.96$; period $P = <0.01$; treatment x period $P = 0.04$. Total ruminant VFA treatment $P = 0.29$; period $P = <0.01$; treatment x period $P < 0.01$.

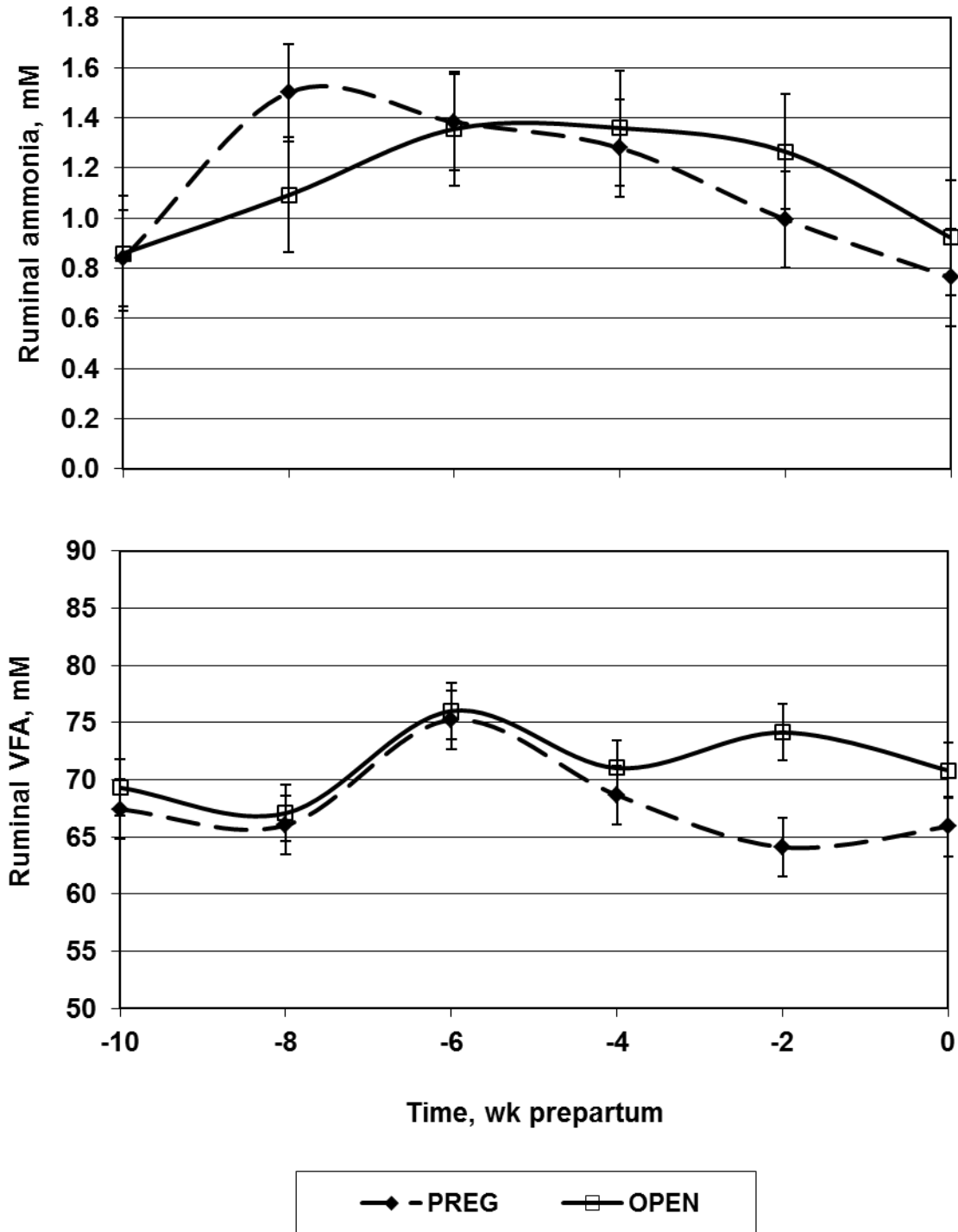


Figure 2-6 Ruminal NH₃ and total ruminal VFA concentration by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk

LACT denotes lactating primiparous beef heifers. NL denotes non-pregnant, non-lactating beef heifers. Ruminal NH₃: 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 $P < 0.01$.

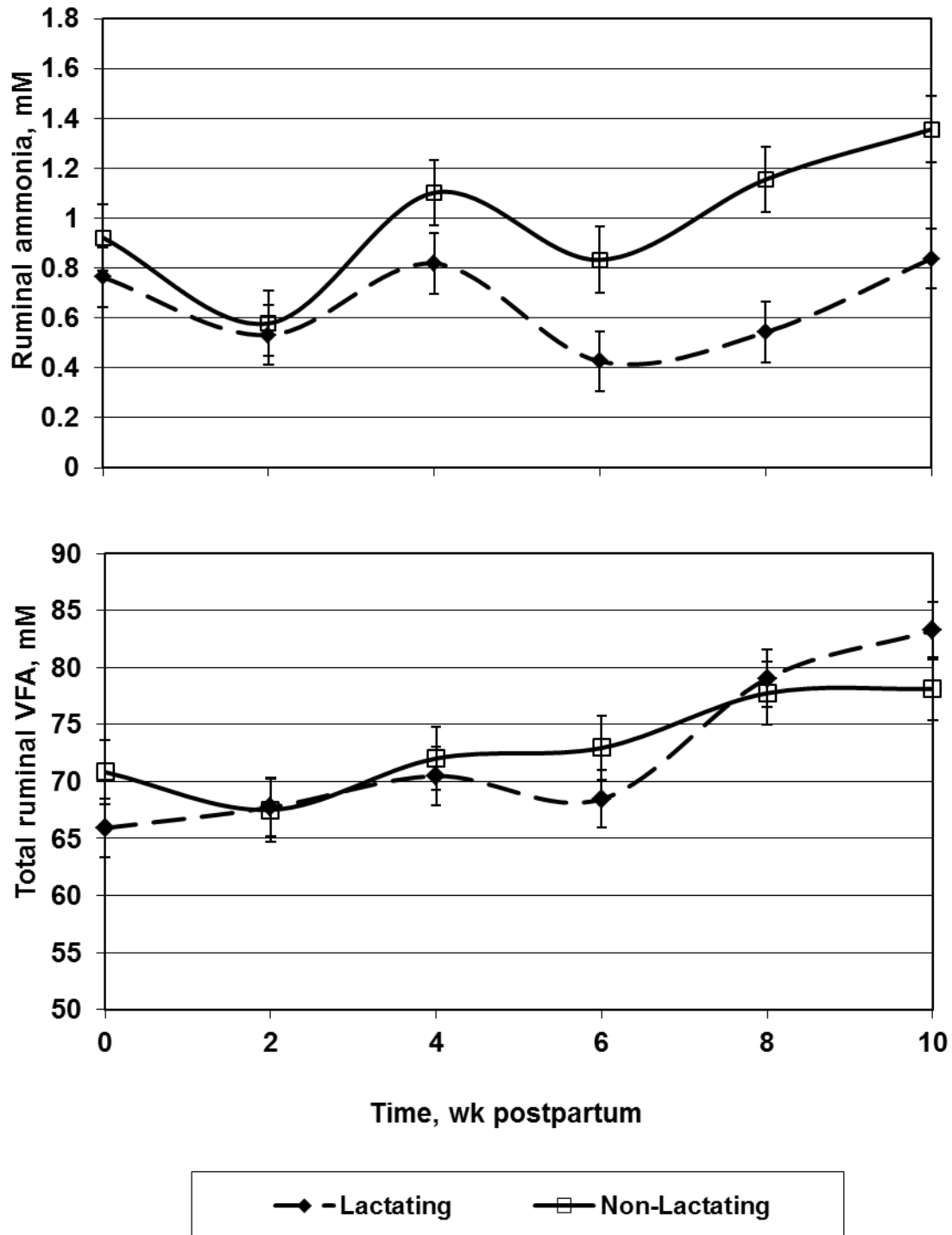


Figure 2-7 Ruminal particulate passage and fluid passage rates by primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

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 $P = 0.35$.

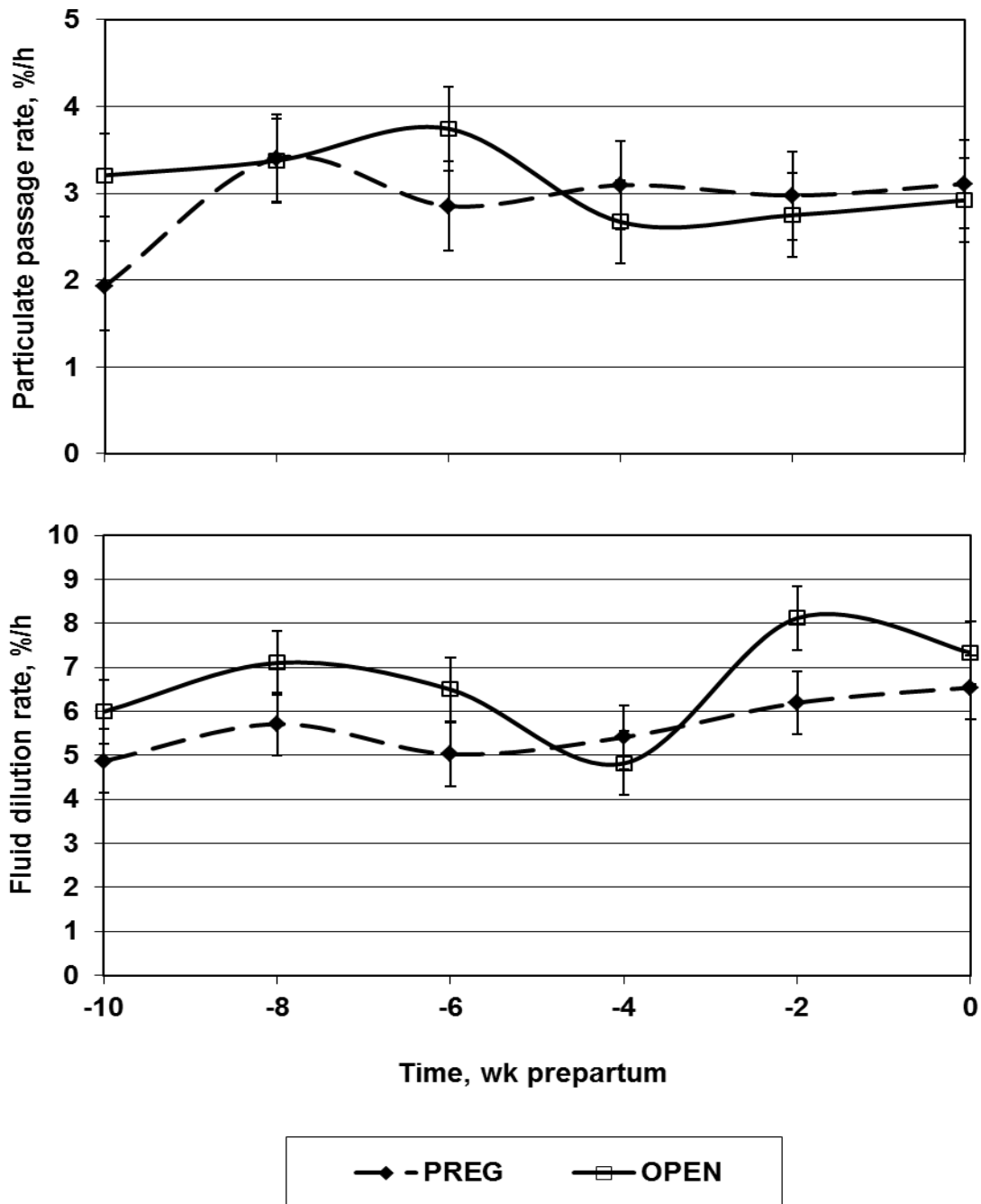


Figure 2-8 Ruminal particulate passage and fluid passage rates by primiparous beef heifers fed low-quality, warm-season grass hay from parturition through 10 wk.

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 $P = 0.66$.

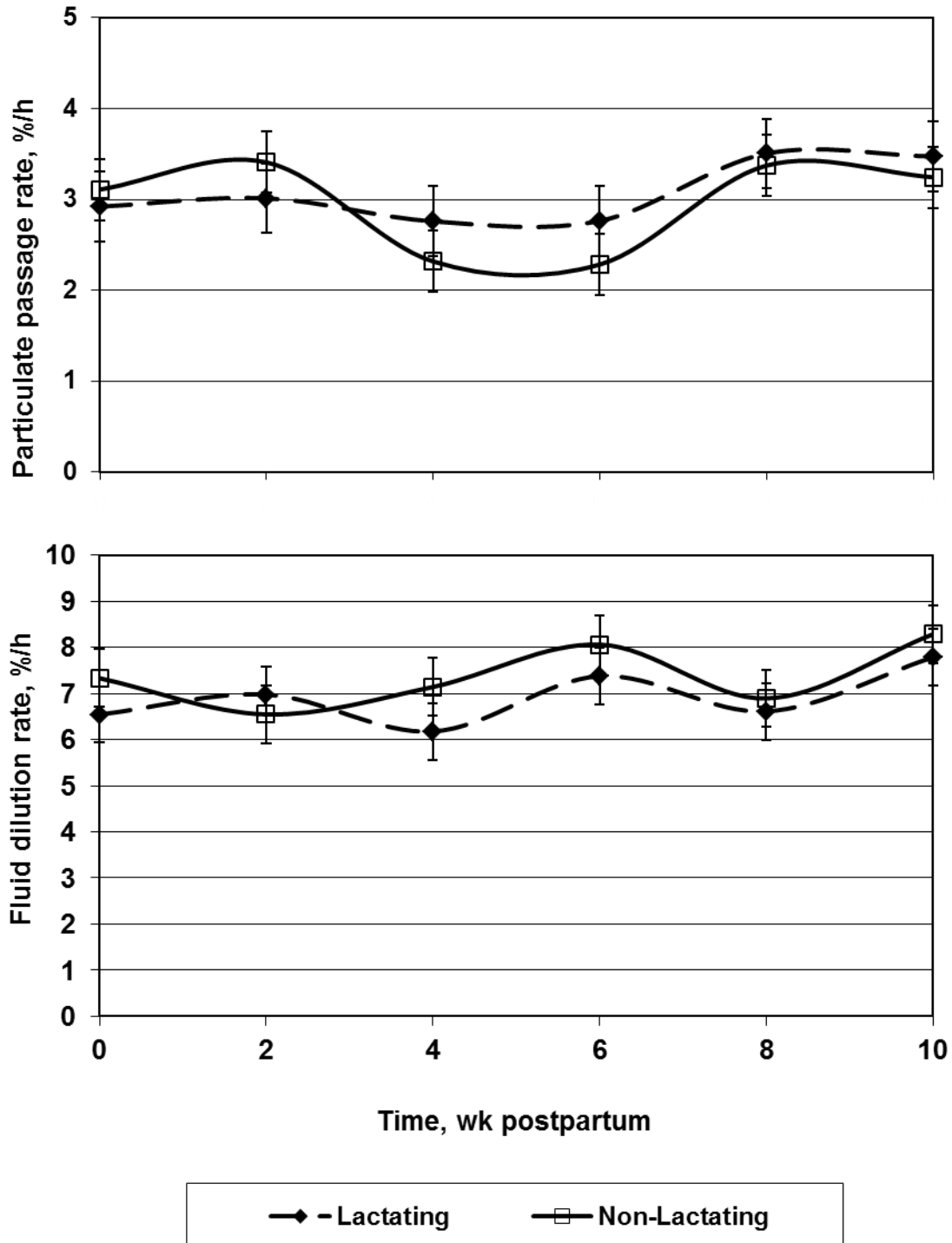


Table 2-1 Body weight and BCS of primiparous beef heifers fed low-quality, warm-season grass hay from 10 wk prepartum to parturition.

		Week prepartum						SE - Period	<i>P</i> - Period	<i>P</i> - interaction
		10	8	6	4	2	0			
Body Weight, kg	PREG	540.9	539.6	548.8	550.6	543.1	503.7	15.3	0.99	0.96
	OPEN	503.4	504.9	506.4	505.3	514.4	518.0			
	SE – trt	18.1								
	<i>P</i> – trt	0.16								
Body Condition	PREG	6.08	5.83	5.67	5.25	5.02	5.05	0.14	<0.01	0.21
	OPEN	6.17	6.00	5.28	5.28	5.42	5.42			
	SE – trt	0.11								
	<i>P</i> – trt	0.71								

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.

		Week postpartum						SE - Period	<i>P</i> - Period	<i>P</i> - interaction
		0	2	4	6	8	10			
Body Weight, kg	LACT	503.7	501.5	487.5	489.0	492.8	490.0	12.1	<0.01	<0.01
	NL	518.0	521.5	539.2	563.7	576.9	565.5			
	SE – trt	16.0								
	<i>P</i> – trt	0.03								
Body Condition	LACT	5.05	5.08	4.67	4.60	4.78	5.09	0.15	<0.01	0.01
	NL	5.42	5.42	5.54	5.62	6.28	6.40			
	SE – trt	0.15								
	<i>P</i> – trt	<0.01								

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.

		Week prepartum						SE - Period	P - Period	P - interaction
		10	8	6	4	2	0			
Acetate	PREG	71.96	71.52	71.28	70.56	72.25	69.86	0.28	<0.01	<0.01
	OPEN	71.13	69.67	69.51	69.14	71.69	68.72			
	SE- trt	0.38								
	P - trt	0.03								
Propionate	PREG	17.39	16.70	17.38	17.52	16.80	17.42	0.25	<0.01	<0.01
	OPEN	17.28	17.31	17.30	17.32	16.15	16.91			
	SE- trt	0.35								
	P - trt	0.85								
Butyrate	PREG	8.97	9.32	9.15	9.39	8.91	10.54	0.13	<0.01	<0.01
	OPEN	9.53	10.10	10.55	10.44	9.68	11.42			
	SE- trt	0.18								
	P - trt	<0.01								
Minor VFA*	PREG	1.67	2.46	2.19	2.53	2.03	2.17	0.06	<0.01	0.51
	OPEN	2.06	2.92	2.64	3.10	2.48	2.68			
	SE- trt	0.07								
	P - trt	<0.01								

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.

		Week postpartum						SE - Period	<i>P</i> - Period	<i>P</i> - interaction
		0	2	4	6	8	10			
Acetate	LACT	69.86	67.47	69.46	67.34	70.67	70.32	0.27	<0.01	0.09
	NL	68.72	66.30	69.17	67.23	69.93	69.56			
	SE- trt	0.33								
	<i>P</i> - trt	0.21								
Propionate	LACT	17.42	18.05	16.93	18.17	17.15	16.82	0.17	<0.01	0.31
	NL	16.91	17.66	16.68	17.93	16.69	16.88			
	SE- trt	0.22								
	<i>P</i> - trt	0.43								
Butyrate	LACT	10.54	12.18	11.19	12.04	10.08	10.74	0.13	<0.01	<0.01
	NL	11.42	13.16	11.27	11.61	10.78	10.87			
	SE- trt	0.13								
	<i>P</i> - trt	0.12								
Minor VFA*	LACT	2.17	2.31	2.42	2.45	2.10	2.12	0.06	<0.01	<0.01
	NL	2.68	2.88	2.88	3.22	2.59	2.69			
	SE- trt	0.03								
	<i>P</i> - trt	<0.01								

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 \times time; $P = 0.03$; age \times pregnancy status \times 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 \times 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 \times 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 x 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: $5.5 \pm 0.28\%$ CP, $66.8 \pm 2.2\%$ NDF, and $40.4 \pm 0.88\%$ ADF) for ad libitum intake and 450 g soybean meal daily to meet rumen degradable protein requirement (DM basis: $46.4 \pm 5.0\%$ CP, $10.8 \pm 1.5\%$ NDF, $7.1 \pm 0.8\%$ 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 (YbCl_3) as the marker. A solution of 8 g of YbCl_3 per 100 ml H_2O 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 YbCl_3 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 $500 \times g$ 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 HNO_3 + 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

Scientific, Inc., Canton, MI). Samples (10 μ L) were pipetted into the plate wells along with 250 μ L 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 ($P \leq 0.05$) were observed, pair-wise *t*-tests were used to separate means. Outliers were removed when |student residuals| were > 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} (DMI kg ; Figure 3-4), tended to increase for pregnant heifers while pregnant cows did not differ over time (age x pregnancy x time; $P = 0.12$). DMI kg 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). Plasma 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.

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Table 3-1 Mineral block content

Mineral	Content
Salt (NaCl)	96 to 99 %
Manganese	≥2400 ppm
Iron	≥ 2400 ppm
Copper	260 to 380 ppm
Zinc	≥ 320 ppm
Iodine	≥ 70 ppm
Cobalt	≥ 40 ppm

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.

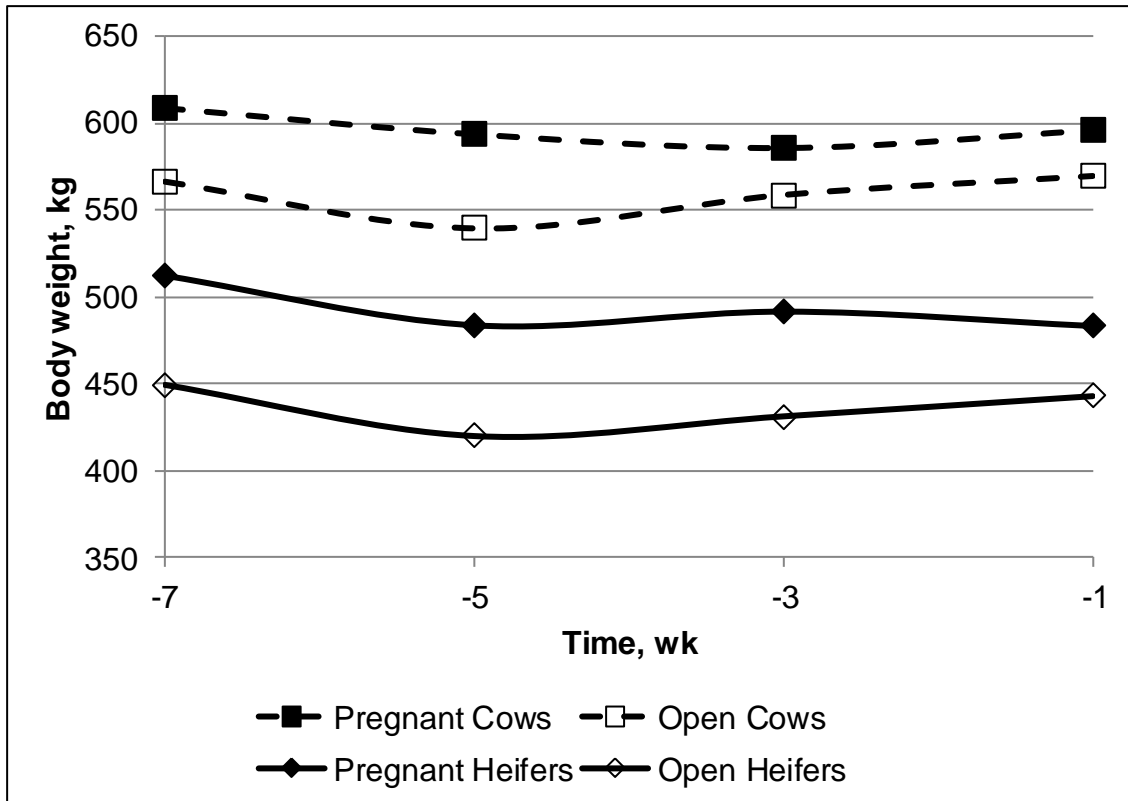


Figure 3-2 Body condition of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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. $SEM = 0.25$.

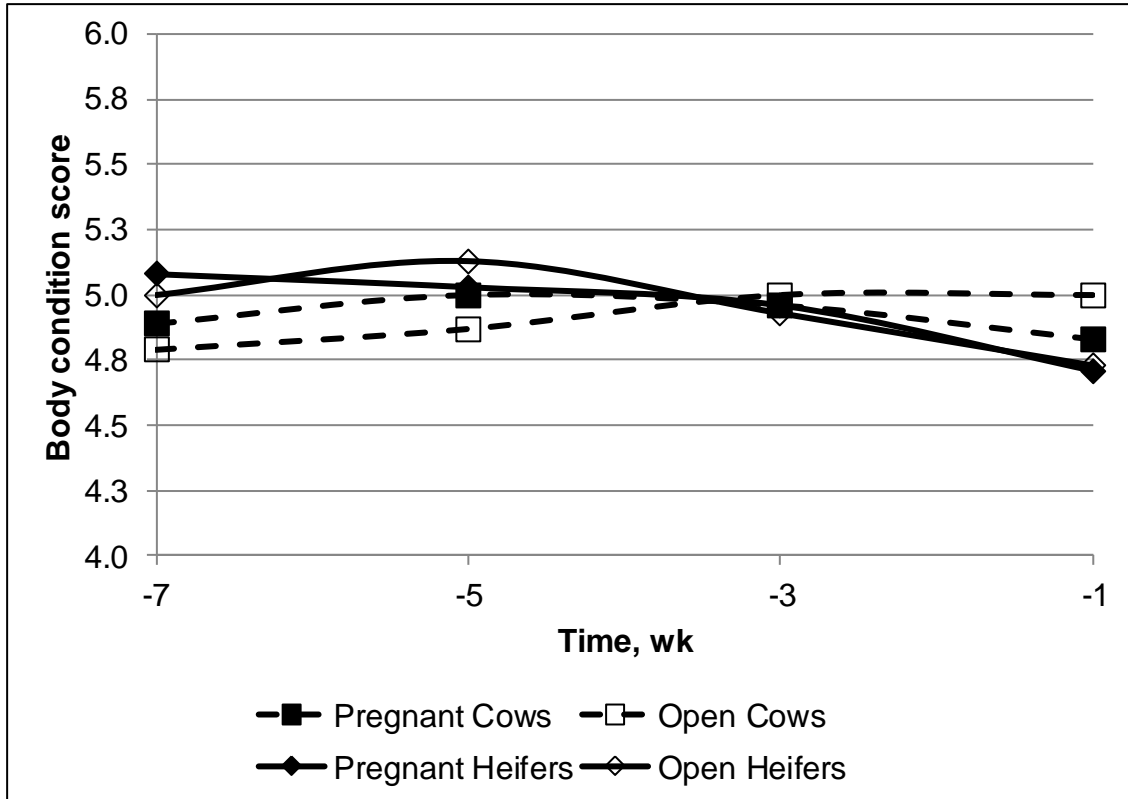


Figure 3-3 Hip height of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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.

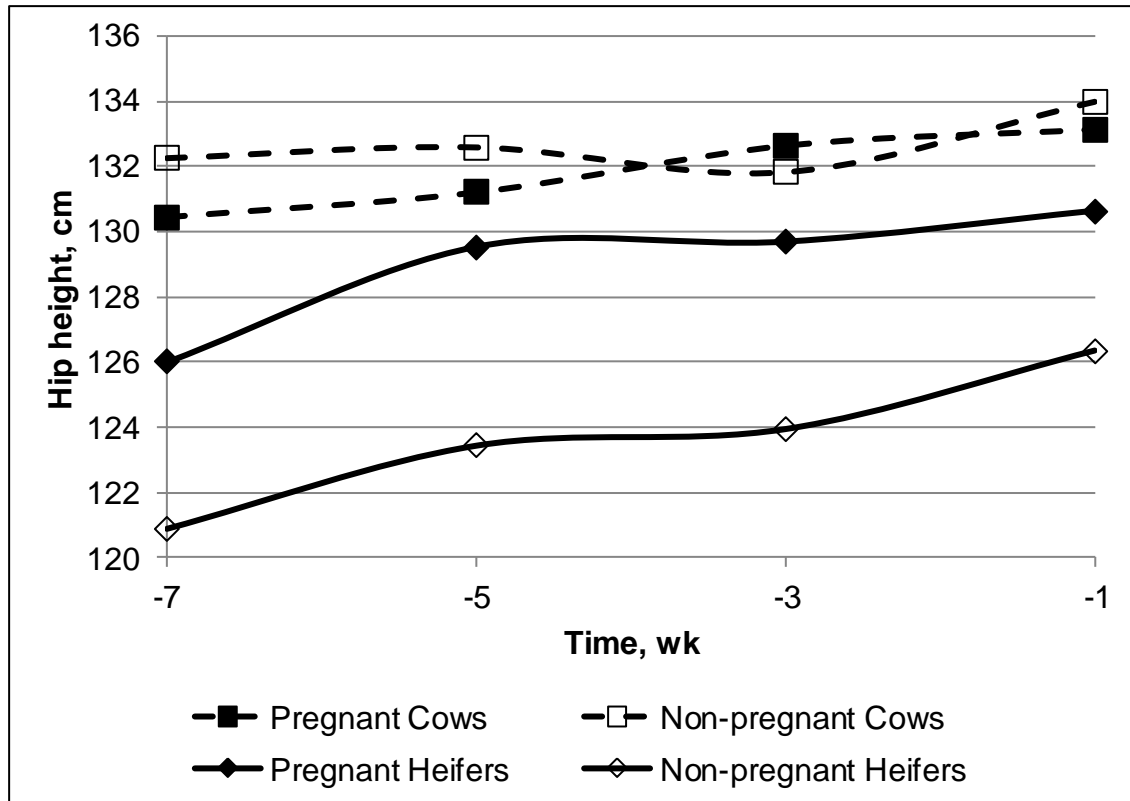


Figure 3-4 Dry matter intake, kg d⁻¹, of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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.

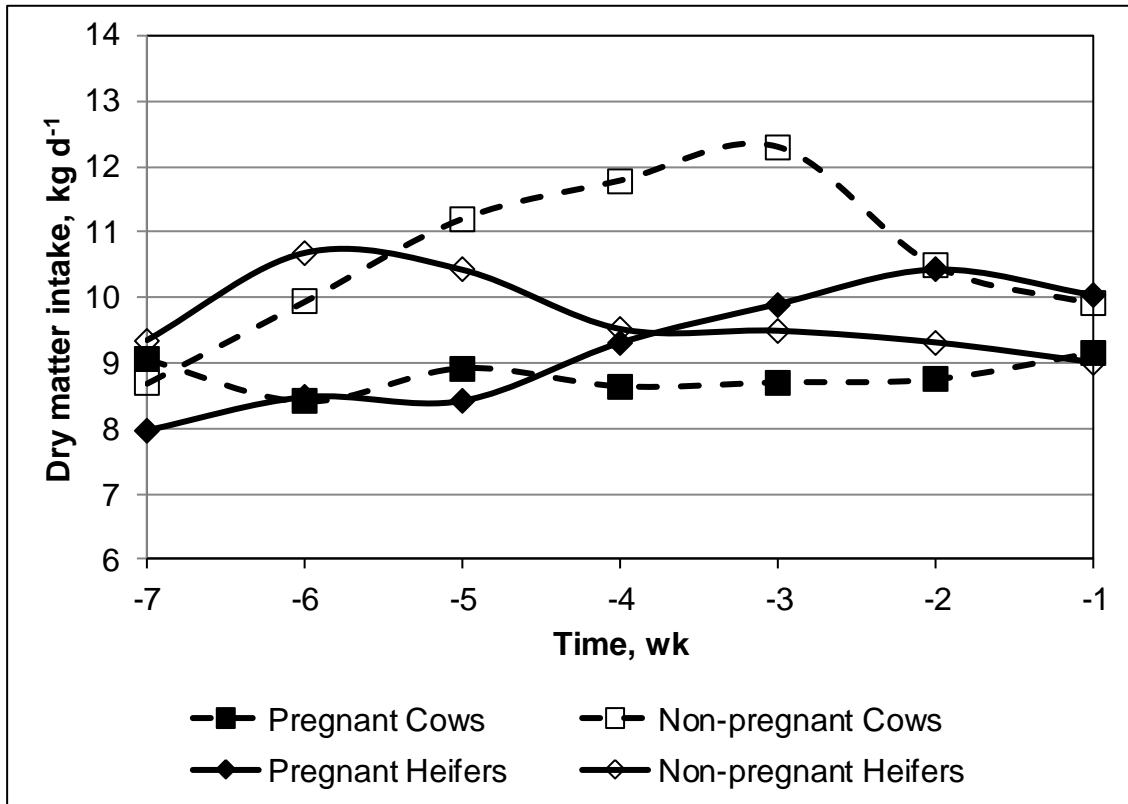


Figure 3-5 Dry matter intake, %BW, by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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.

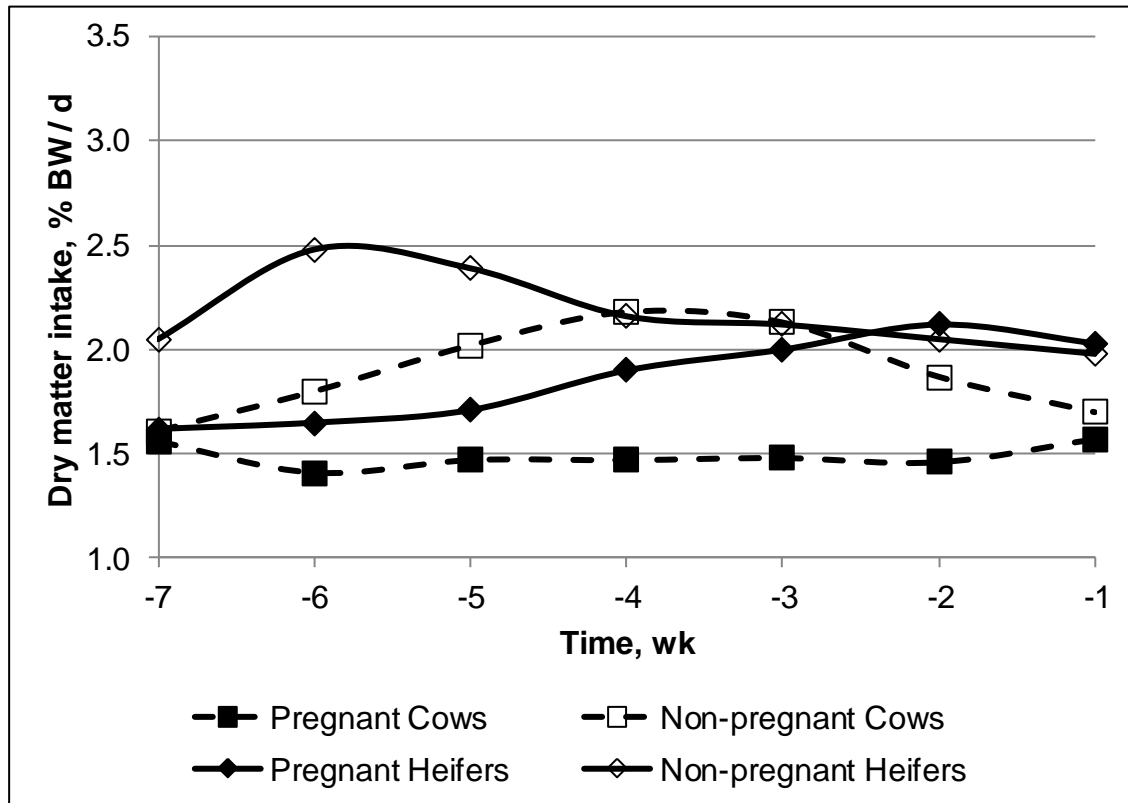


Figure 3-6 Dry matter digestibility by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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. $SEM = 5.87$.

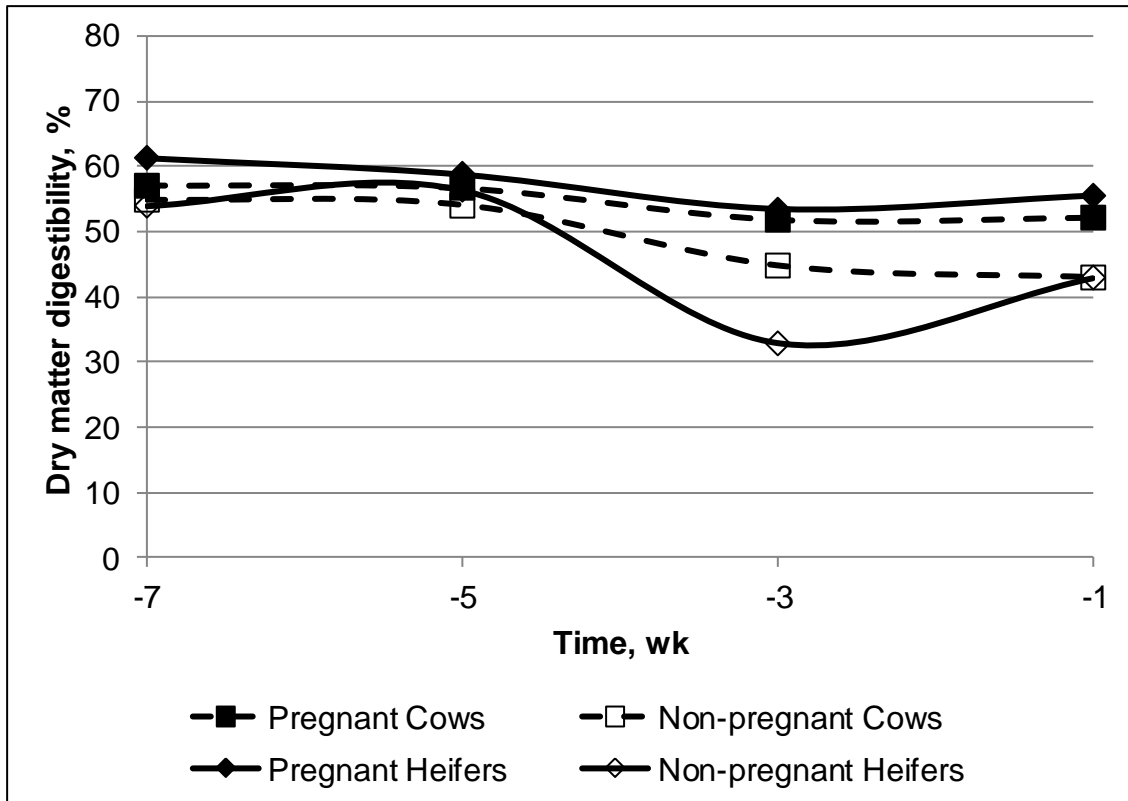


Figure 3-7 Digesta passage rate by pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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. $SEM = 0.47$.

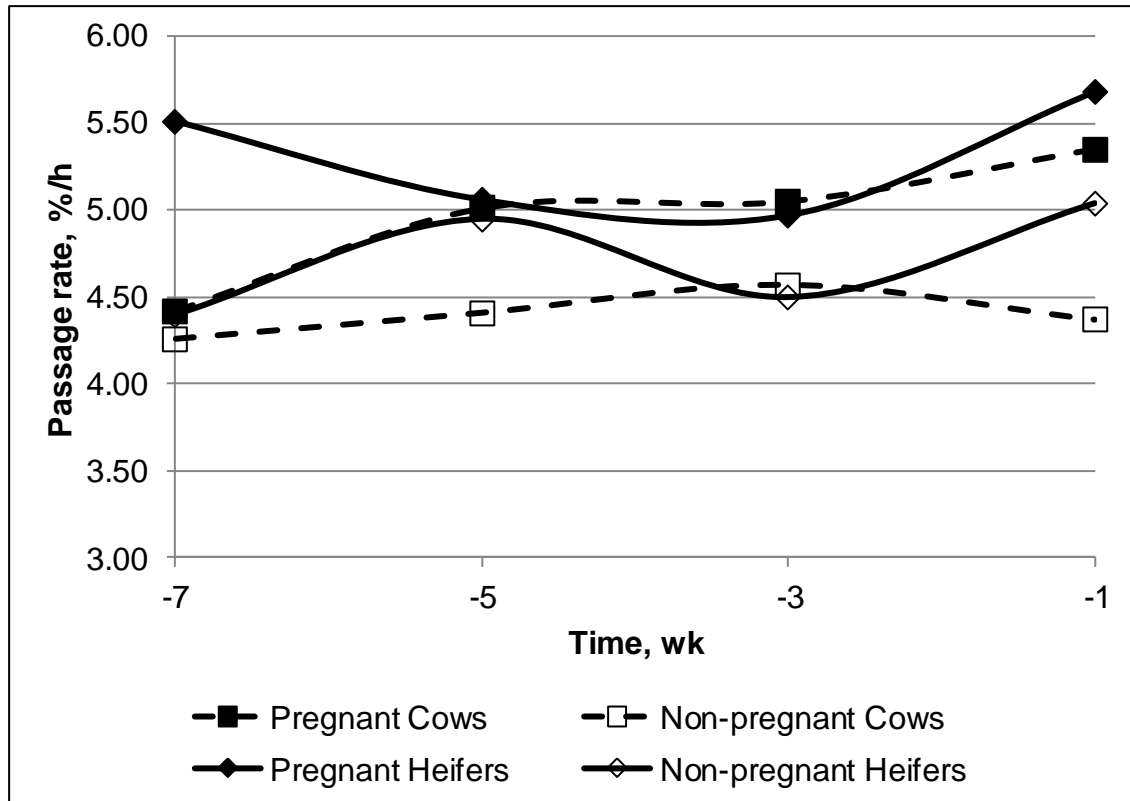


Figure 3-8 Plasma glucose concentration of pregnant and non-pregnant cows and heifers from 7 to 1 wk prepartum.

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.

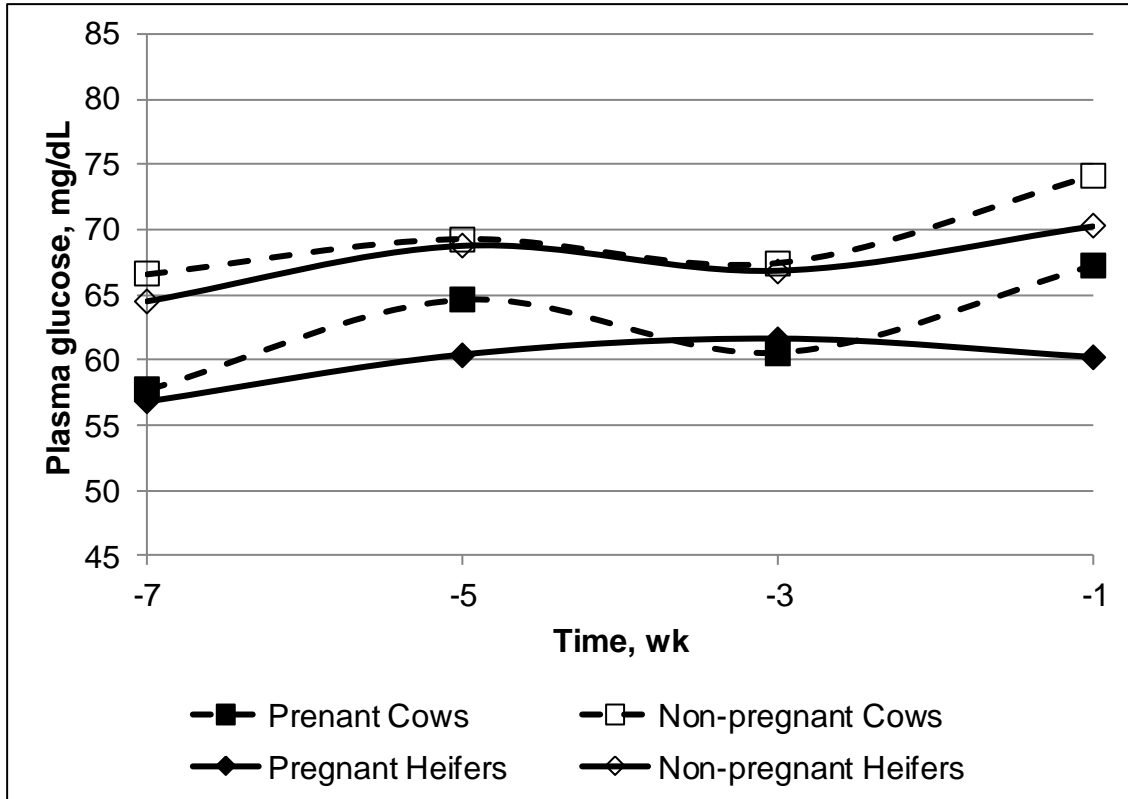


Figure 3-9 Plasma beta-hydroxybutyrate concentration of pregnant and non-pregnant beef cows and heifers from 7 to 1 wk prepartum.

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.

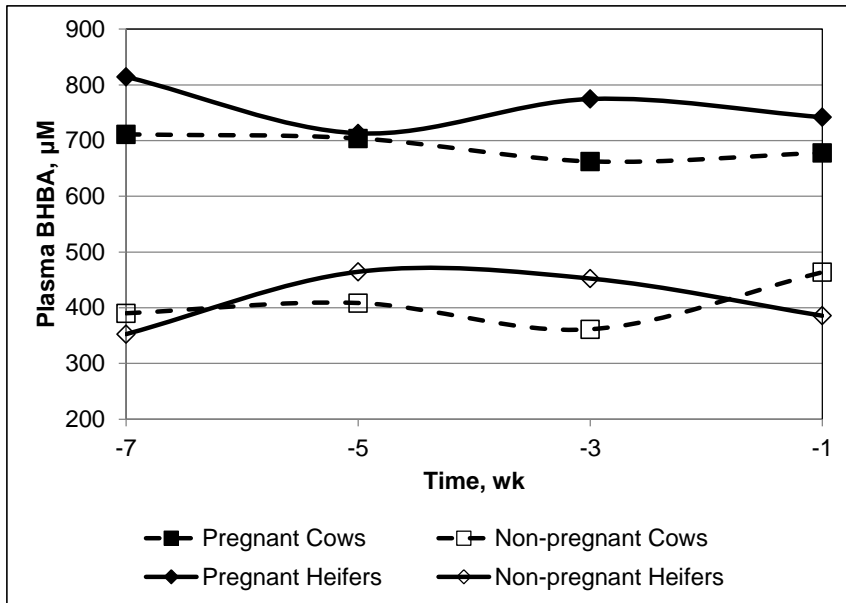


Figure 3-10 Body weight of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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.

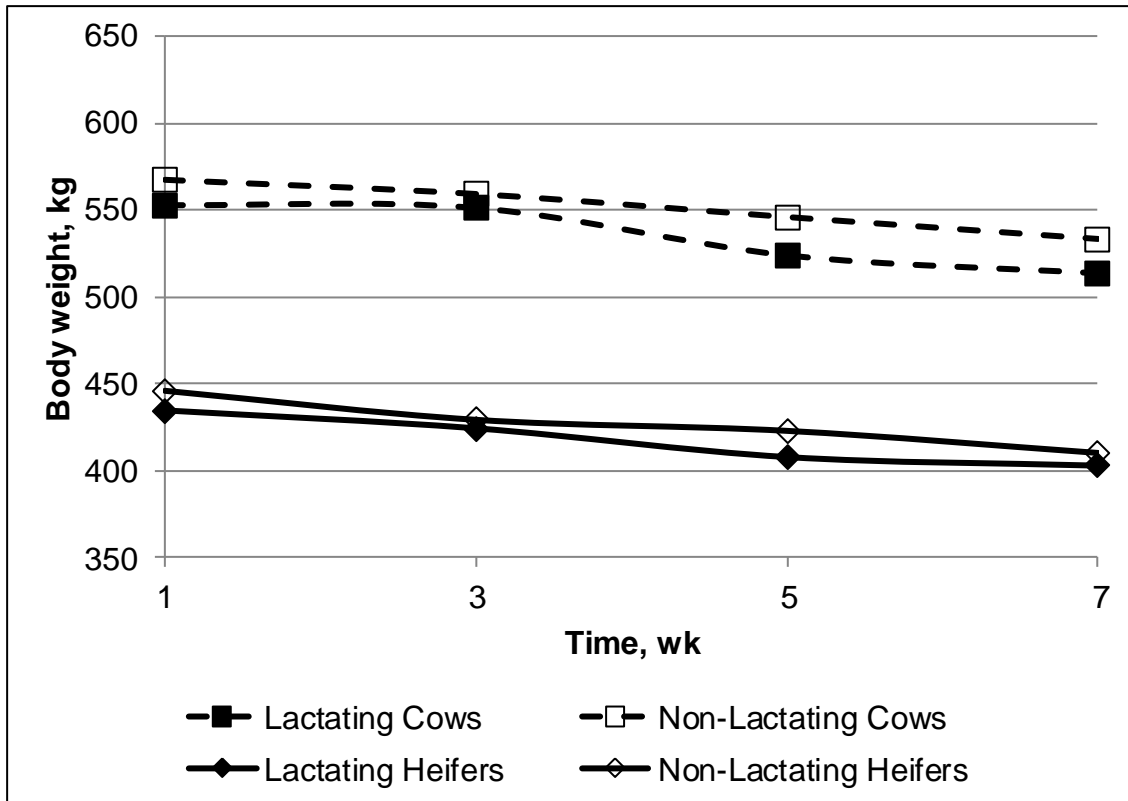


Figure 3-11 Calf body weight from lactating beef cows and heifers from birth to 7 wk postpartum.

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.

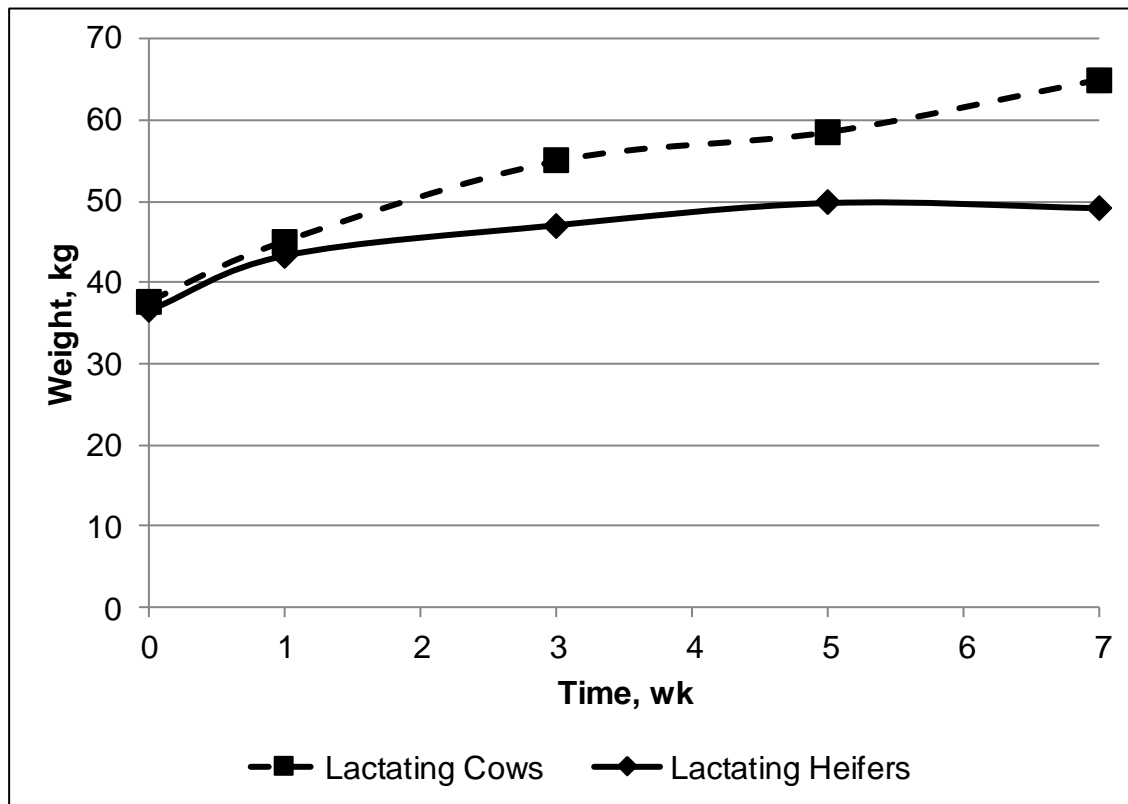


Figure 3-12 Body condition of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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. $SEM = 0.26$.

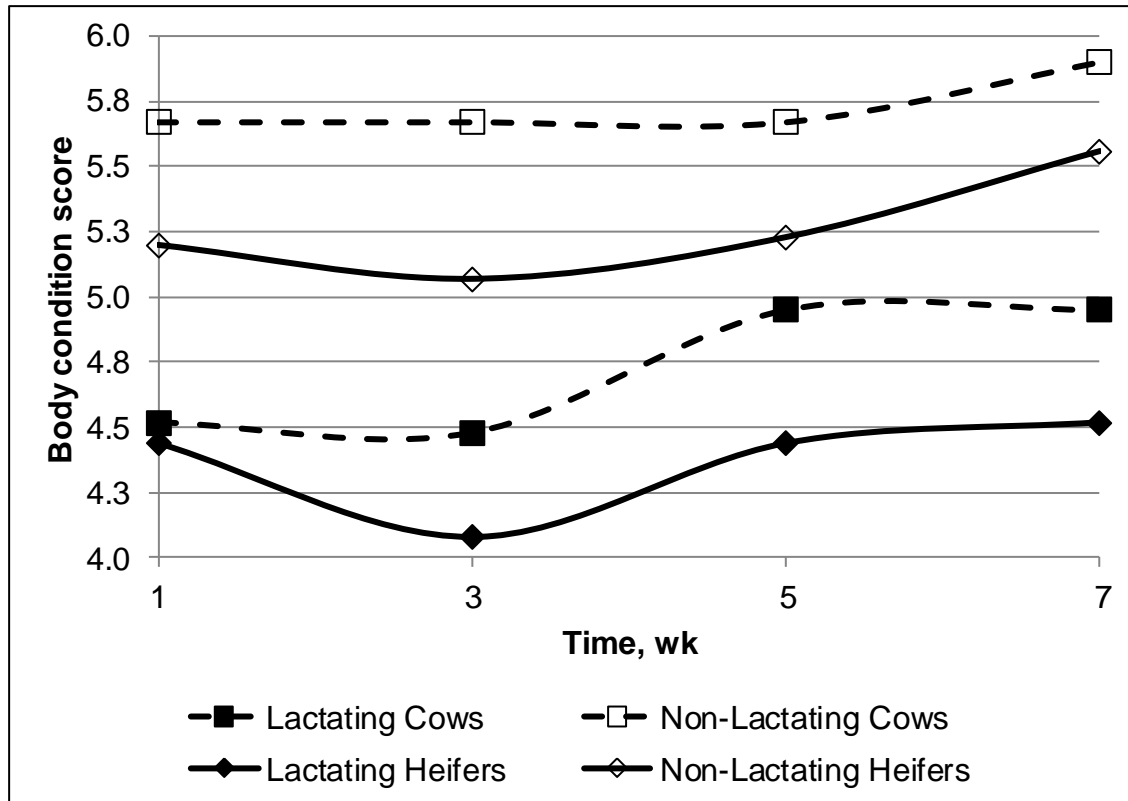


Figure 3-13 Hip height of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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. $SEM = 1.80$.

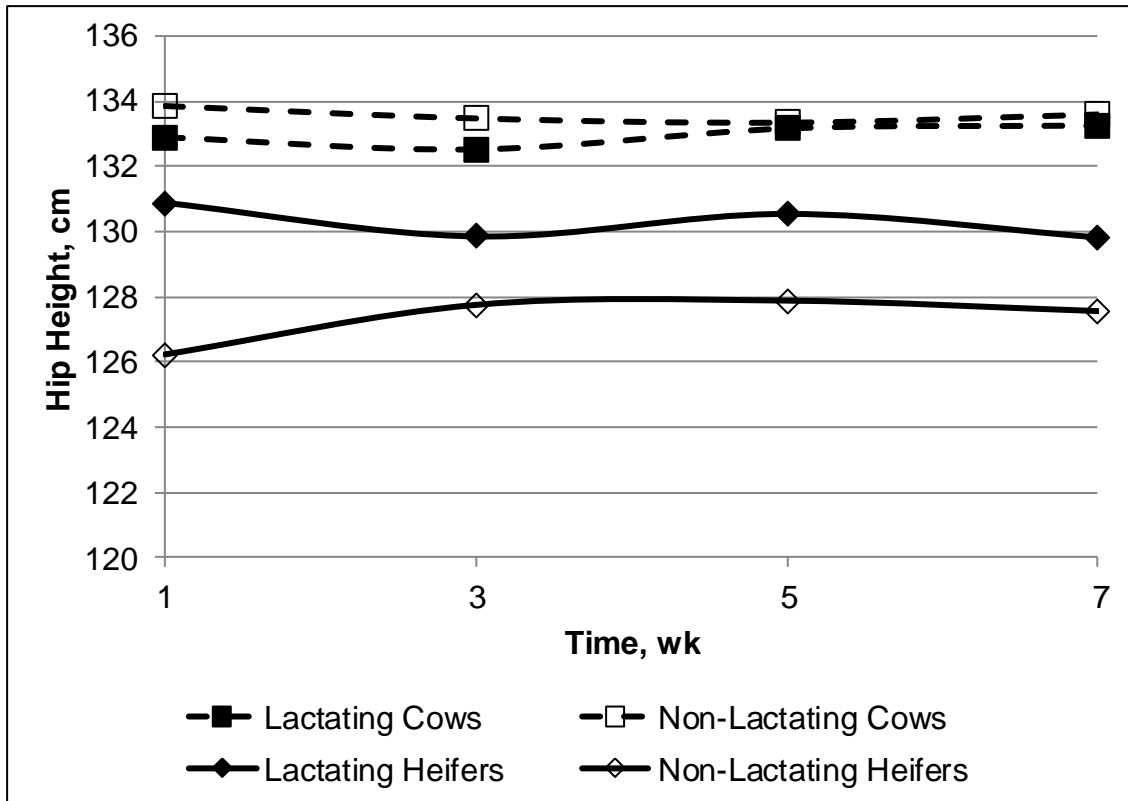


Figure 3-14 Dry matter intake, kg d⁻¹, by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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.

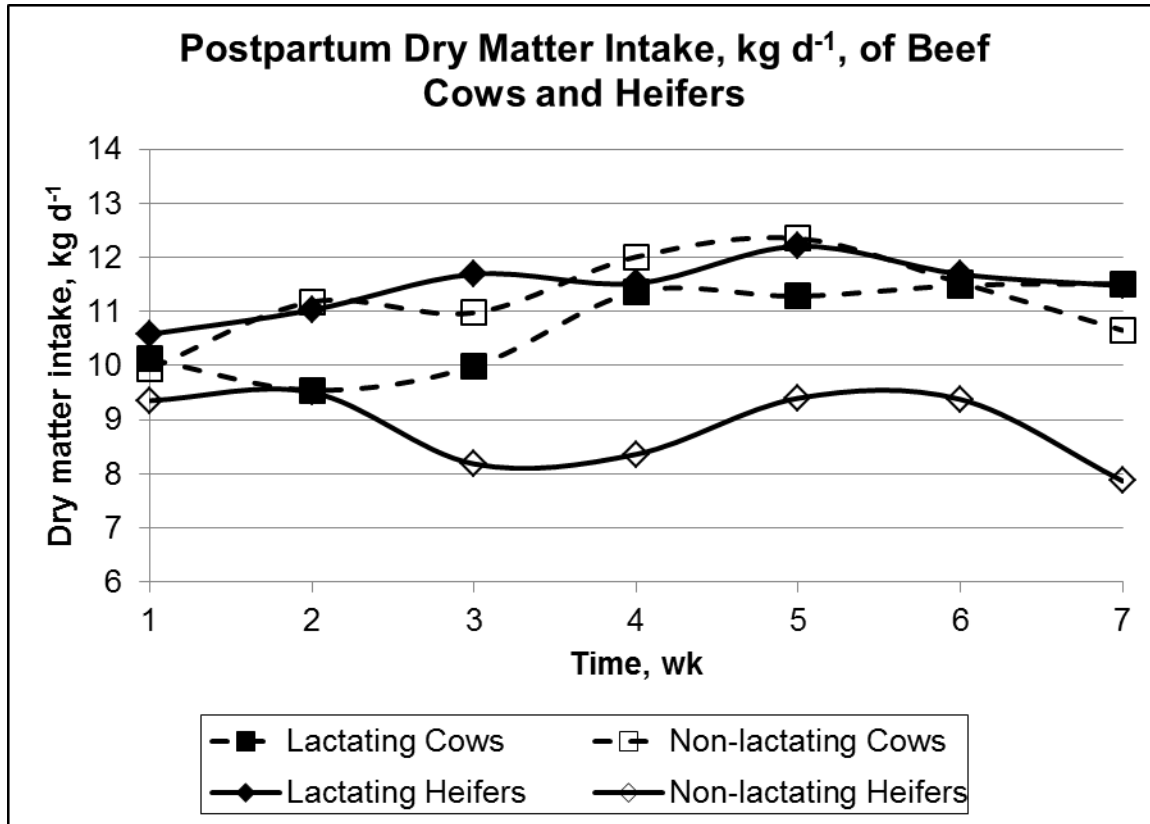


Figure 3-15 Dry matter intake, %BW, by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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.

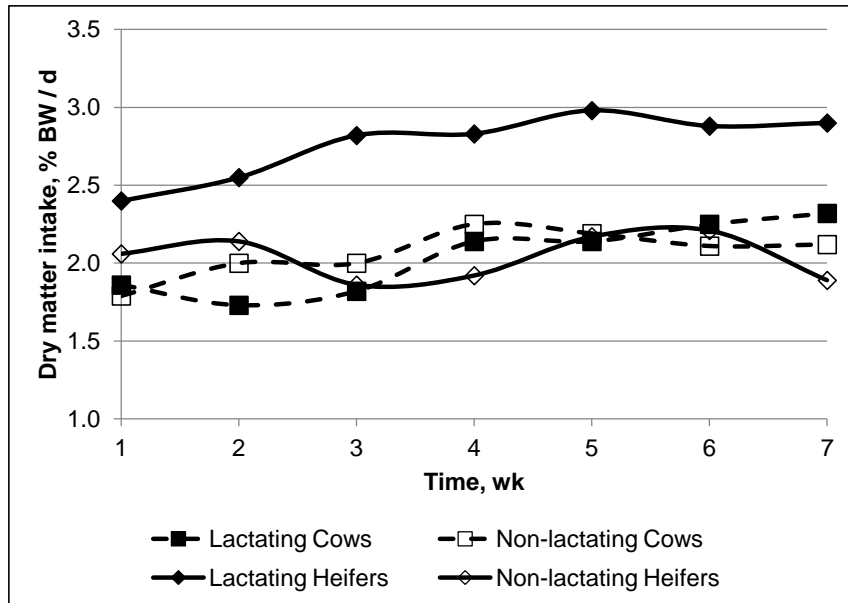


Figure 3-16 Dry matter digestibility by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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.

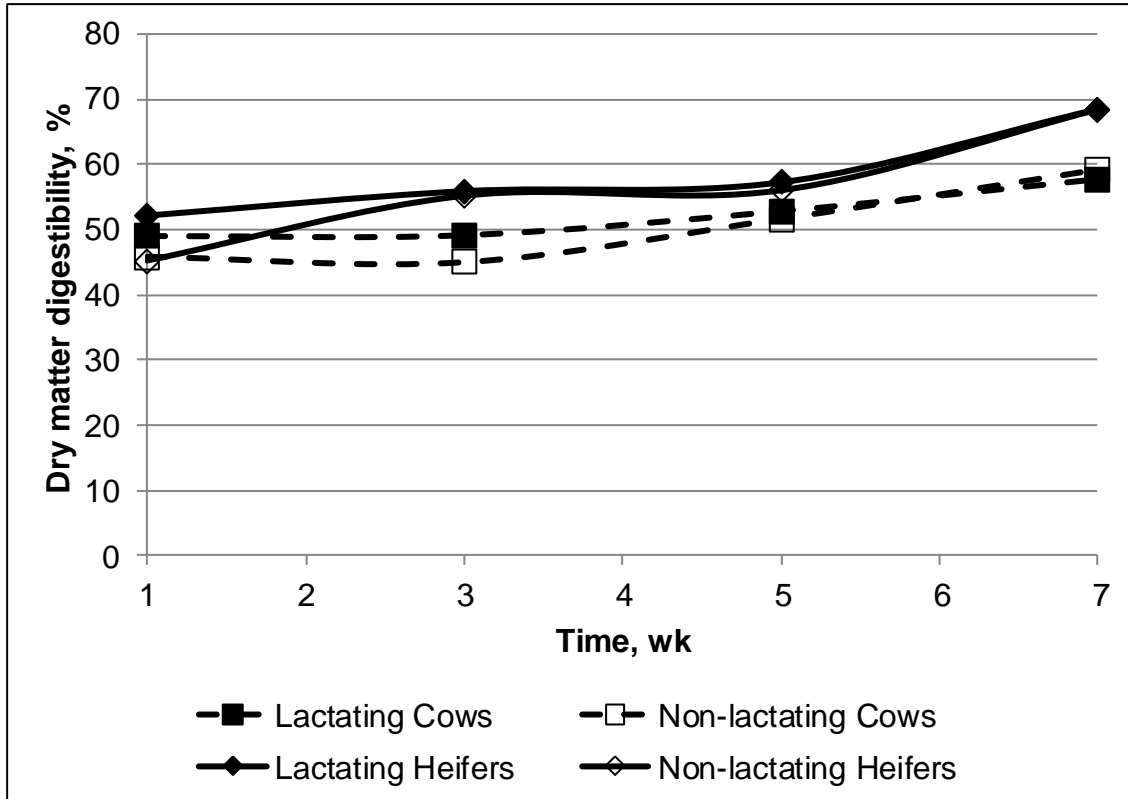


Figure 3-17 Digesta passage rate by lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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. $SEM = 0.34$.

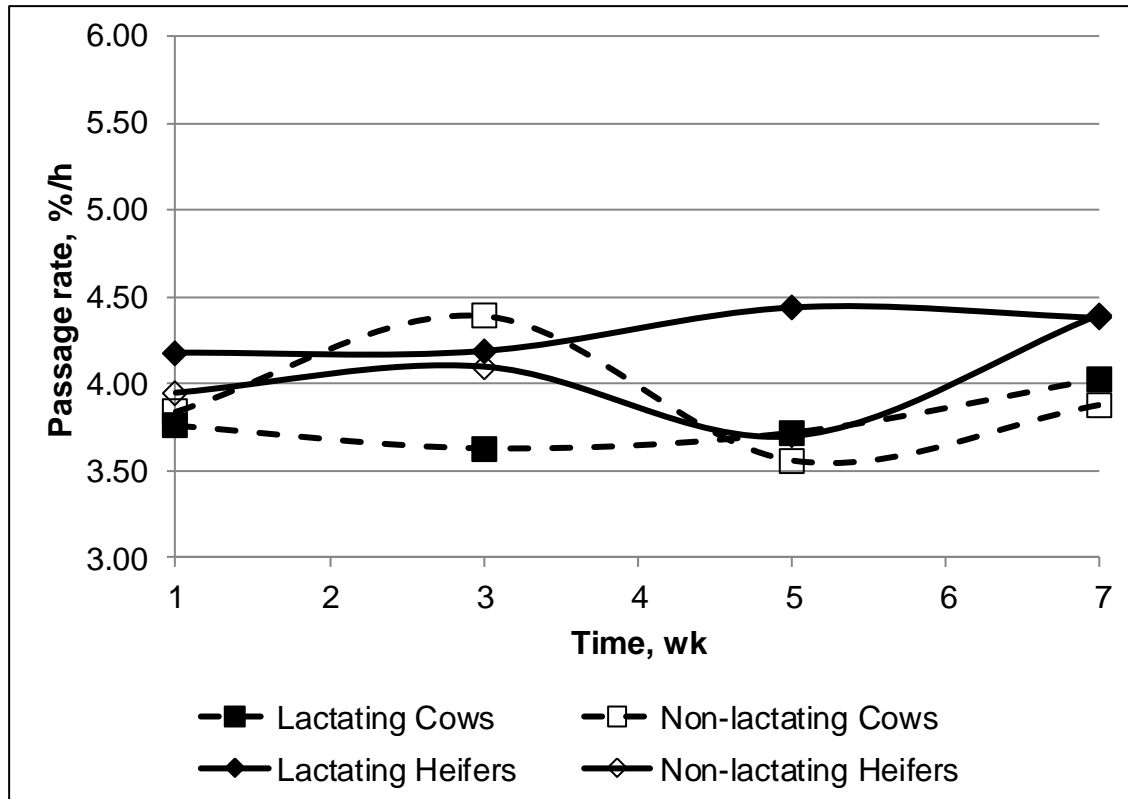


Figure 3-18 Plasma glucose concentration of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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.

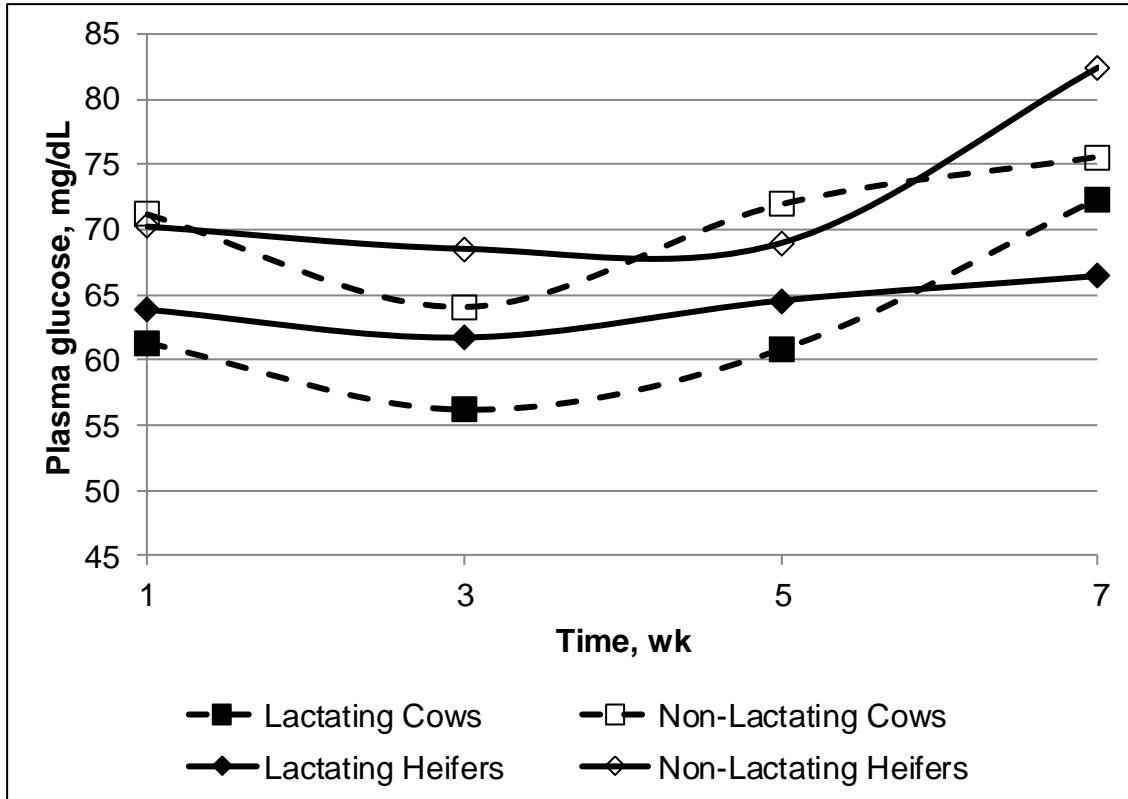


Figure 3-19 Plasma beta-hydroxybutyrate concentration of lactating and non-lactating beef cows and heifers from 1 to 7 wk postpartum.

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. $SEM = 57.1$.

