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Effects of Feeding Supplemental Fat During Gestation to First-Calf Beef Heifers[1]

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Abstract

Study 1, pregnant crossbred, first-calf heifers (n = 149; BW 493.8 ± 6.3) received gestation diets: control (CON), or added safflower seeds (SAFF), raw soybeans (SOY), or sunflower seeds (SUN). Diets were formulated isocaloric-isonitrogenous, contained 2.4, 4.7, 3.8, or 5.1% fat, and were fed for the last 65.3 ± 4.6 d precalving. Supplemental fat feeding was terminated at calving. Diet effects on dam BW or condition scores and calf birth BW, calving difficulty, and dam estrous cyclicity were generally nonsignificant (P>0.10). Fat-supplemented dams had greater pregnancy rates (P<0.05) and fall calf BW (P=0.08): CON, 79%, 182.4 kg; SAFF 94%, 194.9 kg; SOY, 90%, 197.7 kg; SUN, 91%, 196.8 kg. Study 2, pregnant crossbred, first-calf heifers (n = 83; BW 439.8 ± 7.3) received gestation diets: control (CON2) or added sunflower seeds (SUN2). Diets were formulated isocaloric-isonitrogenous, contained 2.2 and 6.5% fat, and were fed for the last 68.2 ± 5.5 d before calving. Supplemental fat feeding was terminated at calving. Blood samples were collected during the feeding period. Diet effects on dam BW, condition scores, estrous cyclicity, and pregnancy percentage were nonsignificant. Calf birth BW from SUN2 dams tended (P=0.06) to be greater. Diet effects on blood components were nonsignificant except for NEFA concentrations tending to be lower in SUN2 dams at the initial (P=0.08) and mid-gestation feeding (P=0.06) sampling. Major differences were found in forage availability between Studies 1 and 2. We conclude that dietary fat or fatty acids may be an important "reproductive fuel," and effects of supplemental gestation fat may be masked when adequate nutrients are available in forages consumed postpartum.

(Key Words: Beef Cattle, Fat Supplementation, Gestation, Reproduction.)

Introduction

Delayed rebreeding and low pregnancy rates are common problems in the lactating, first-calf heifer. These dams have a longer postpartum interval to first estrus, and this prolonged interval is the basis for recommending starting the breeding season for replacement heifers 20 d prior to beginning breeding for mature cows (28). Nutrition has a major effect on postpartum reproduction with many studies designed to study effects of protein and energy (review by Randel, 24). Recent studies have suggested that dietary fat plays an important role in reproductive processes including ovarian follicular changes (19), increasing luteinizing hormone and progesterone concentrations (14), and prostaglandin effects (18, 26). Effects on rebreeding have been variable and may depend on type and time or duration of fat feeding (9, 10, 13). Most research has studied the effects of increasing fat in the postpartum diet, and little information is available regarding effects of feeding supplemental fat during gestation. The following studies were conducted from 1997 through 1999 and were designed to determine effects of feeding supplemental fat during the last trimester of

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TABLE 1. Study 1. Design and number of heifers per gestation diet.

	Gestation diet				
		Supplemental fat			
Item	Control (2.0% fat)	Safflower seeds (4.2% fat)	Soybeans (3.3% fat)	Sunflower seeds (4.5% fat)	Calving group totals
Calving season					
February	19	19	19	19	76
March-April	10	9	9	9	37
June	9	10	10	10	39
Diet totals	38	38	38	38	152

gestation on reproductive performance in first-calf beef heifers.

Materials and Methods

Study 1. Study 1 involved 152 crossbred, first-calf heifers (Table 1). Seventy heifers were purchased animals comprised of a minimum of 50% Angus breeding and 82 were F_2 crossbred heifers, with a minimum of 50% Hereford, Limousin, or Piedmontese breeding. All heifers were bred to purchased Angus bulls to calve in one of three calving seasons: February, March–April, or June (12). Heifers were randomly assigned within dam breed, calving season, and predicted calving date (breeding date plus 280 d) to a study investigating reproduction effects of feeding oil seeds in the gestation diet. Diet groups were: Control (n = 38; CON); Safflower (added safflower seeds, n = 38; SAFF); Soybean (added raw soybeans, n = 38; SOY); Sunflower (added sunflower seeds, n = 38; SUN). Seeds were processed through a roller mill with sufficient pressure to crack hulls in ca. 90% of the seeds, but without oil loss. Diets (Table 2) were formulated to be isocaloric and isonitrogenous and for heifers to gain 0.5 kg daily. However, CP content of the actual diets differed slightly. Heifers had free access to water and a complete mineral mix containing 6% calcium and 6% phosphorus. Diets CON, SAFF, SOY, and SUN contained 2.4, 4.7, 3.8, and 5.1% fat, respectively (analyses of composite sample collected throughout feeding period) and were fed in dry lots starting at ca. d 215 of gestation and continued until calving ($\bar{x}$ 65.3 ± 4.6 d feeding period). Safflower seeds (*Carthamus tinctorius* L., variety Centennial) were a genotype selected for high linoleic-acid content (5, 16, 17). Soybeans and sunflower seeds were purchased commercially. All seeds were cleaned to remove trash and weed seed contaminants before determining chemical analyses and feeding. Percentage oil (DM basis) and oleic and linoleic fatty acid contents of the fat for safflower seeds, soybeans, and sunflower seeds fed were: 35, 10, and 79; 18, 26, and 51; 37, 23, and 65, respectively.

TABLE 2. Study 1. Composition of experimental diets.

		High fat		
Item	Control	Safflower	Soybeans	Sunflower
Ingredients				
Corn silage	74.8[a]	74.2[a]	80.0[a]	73.3[a]
Ground grass hay	12.0	12.0	12.0	12.0
Barley	6.7	2.3	–	4.0
Soybean meal	6.5	6.0	–	5.5
Safflower seeds	–	5.5	–	–
Soybeans	–	–	8.0	–
Sunflower seeds	–	–	–	5.2
Chemical analyses[b]				
Dry matter, % as fed	42.3	43.3	39.0	42.2
Crude protein, %	12.6	13.1	11.0	12.4
Fat, %	2.4	4.7	3.8	5.1
ADF, %	29.4	29.5	30.8	29.6
Estimated TDN[c], %	55.6	55.8	54.5	55.7

[a]Percentage of diet; as fed basis. Heifers had ad libitum access to trace mineral salt.
[b]Analyses of weekly samples collected throughout all feeding periods, DM basis.
[c]Calculated value based on ADF (1).

Heifers were observed for signs of parturition every 2 h, and when parturition was determined to be imminent, were observed continuously until the calf was born. Data obtained at parturition included calving difficulty score (1 = no assistance, 2 = minor assistance with hand traction only, 3 = traction with calf puller, 4 = major traction required with calf puller or caesarean delivery required) and calf vigor score (1 = alive, normal vigor; 2 = slow in standing, but did so without assistance; 3 = very slow, unable to stand without assistance, required placing in warm room to revive; 4 = dead or died shortly after birth). Calf sex and birth BW plus dam BW and condition scores (1 = emaciated to 10 = obese) were obtained within 12-h postpartum. If the dam and calf exhibited normal maternal behavior and vigor, they were moved from the lots to an improved pasture within 24-h postpartum. Supplemental

TABLE 3. Study 2. Design and number of heifers per gestation diet.

	Gestation diet		
Item	Control (2.2% fat)	Sunflower seeds (6.3% fat)	Calving season totals
Calving season			
February	15	15	30
March-April	17	16	33
June	9	11	20
Diet totals	41	45	83

concentrate feeding was terminated at calving, but supplemental alfalfa hay was provided at the rate of ca. 10.5 kg per head daily until sufficient forage was available to maintain BW in the lactating dams. Hay was fed for 40, 21, and 0 d after calving for dams calving in February, March–April, and June, respectively. Estrous cyclicity was based on progesterone (P4) concentrations in two blood samples collected 7 d apart immediately preceding the beginning of the breeding season. Animals with P4 concentrations of 1 ng/mL or greater were considered to have exhibited estrus, to have a functional corpus luteum, and to be cycling.

Heifers were bred by natural service to crossbred bulls in a 37-d breeding season. After breeding for the first 5 d of the breeding season, estrus was synchronized with a single injection of 25-mg prostaglandin F (PGF) given to all heifers (21). Natural service continued for an additional 32 d. Pregnancy was determined by rectal ultrasound scanning of the reproductive tract ca. 75 d after end of the breeding season.

Calf fall BW were obtained in September and October at ca. 190 d of age. Dam and calf BW and dam condition scores were obtained at each weighing.

Study 2. Primiparous crossbred heifers (n = 83; Angus sires bred to crossbred dams with varying percentages of Hereford, Simmental, or Charolais breeding) bred to crossbred composite bulls (22) to calve in three calving seasons (February, March–April, or June) were assigned within calving season and predicted calving date (based on ultrasound estimate) to one of two gestation diets: Control (n = 41; CON2) or Sunflower (added sunflower seeds, n = 42; SUN2). Seeds were processed as described in Study 1, and diets contained 2.2% (CON2) and 6.3% (SUN2) fat (Table 3). Sunflower seed oil percentage and fatty acid composition were the same as in Study 1. Diets (Table 4) were formulated to be isocaloric-isonitrogenous, for heifers to gain 0.5 kg daily, and were fed in dry lots starting at ca. d 215 of gestation and continued until calving (68.2 ± 5.5 d feeding period) with water and mineral supplied as in Study 1. Supplemental fat feeding was terminated at calving and postpartum supplementation of 11-kg alfalfa hay daily continued for ca. 19 d. Dam and calf BW and condition scores were obtained throughout the study. Calving observations and estrous cyclicity were determined as described in Study 1. Lactating dams were bred by natural service to

TABLE 4. Study 2. Composition of experimental diets.

Item	Control	High fat
Ingredient		
Corn silage	62.4[a]	64.0[a]
Alfalfa hay, ground	33.0	30.0
Barley	3.6	1.0
Soybean meal	1.0	–
Sunflower seeds	–	5.0
Chemical analyses[b]		
Dry matter, % as fed	46.0	46.9
Crude protein, %	13.6	13.8
Fat, %	2.2	6.3
ADF, %	35.2	34.1
Estimated TDN[c], %	57.3	58.4

[a]Percentage of diet; as fed basis. Heifers had ad libitum access to trace mineralized salt.
[b]Analyses of weekly samples collected throughout all feeding periods, DM basis.
[c]Calculated value based on ADF (1).

TABLE 5. Rainfall and range forage quantity/quality estimates for 1998 and 1999.

	Months					
Item	April	May	June	July	August	
Precipitation, mm						Total
1998	15	21	66	59	49	210
1999	64	42	51	15	51	223
115-yr average	30	54	71	39	29	223
Forage available[a], kg/ha						Average
1998	512	571	754	635	538	602
1999	584	810	1,459	1,226	1,069	1,030
Dietary crude protein[b], %						
1998	13.9	10.0	8.8	7.2	5.7	9.1
1999	10.9	16.1	10.9	6.5	7.2	10.3
Digestible organic matter[b], %						
1998	62.6	61.6	59.4	58.4	57.0	59.8
1999	61.5	61.1	60.8	57.0	56.8	59.4

[a]Based on standing crop.
[b]Fecal NIR estimate.

TABLE 6. Composition of predominant forages in pasture (1999) [a].

Item	Russian wildrye	Crested wheatgrass	Western wheatgrass	Threadleaf sedge
	Forage			
Chemical analyses, %				
Moisture	73.4	75.8	64.3	57.5
Fat, Goldfisch[b]	2.2	3.5	3.2	3.3
Fiber, AD[b]	25.8	21.8	27.5	29.9
Protein, N x 6.25[b]	29.8	34.3	19.3	17.8
Fatty acid profile[c]				
Palmitic, 16:0	18.9	13.2	19.1	18.4
Palmitoleic, 16:1	6.7	8.8	5.9	6.5
Stearic, 18:0	1.3	1.2	1.8	2.4
Oleic, 18:1	3.2	1.5	2.6	2.5
Linoleic, 18:2	13.3	11.8	10.3	16.1
Linolenic, 18:3	50.6	58.4	47.0	37.8
Total fatty acids[c], %				
Saturated	24.2	18.2	32.3	32.6
Unsaturated	75.8	81.8	67.7	67.4

[a]These analyses are from adjunct studies to Studies 1 and 2 and are presented as support for hypotheses presented in the Results and Discussion section.

[b]Reported on DM basis.

[c]Reported on percentage total fat.

crossbred bulls in a 35-d breeding period. Estrus was not synchronized. Pregnancy was determined by ultrasound examination at 67 d after the end of breeding. Calf fall BW were obtained in September and October at ca. 180 d of age.

Blood samples were collected via puncture of a tail vessel at the beginning (prior to any supplemental fat feeding), middle, and end of the precalving diet feeding period. Blood was placed on ice and processed to yield serum or plasma and stored at $-20°C$ until analyzed for IGF (11; intra- and interassay CV 13 and 9%, respectively), glucose (Sigma Kit No. 16; Sigma Chemicals, St. Louis, MO; interassay CV 7.3%), and nonesterified fatty acids (NEFA) (WACO NEFA-C; Wako Chemicals, Dallas, TX; interassay CV 9.9%). Prebreeding progesterone concentrations were determined using coated tubes (Kit TKPGX; DPC, Los Angeles, CA) as described by Bellows et al. (4) with intra- and interassay CV of 8.7 and 9.3%, respectively.

As an adjunct to Study 2, data to estimate forage availability are included in this paper (Table 5). These samples were collected on a concomitant study from pastures similar to those grazed by heifers on Study 2, but Study 2 heifers did not graze in the sampled pastures. These samples were obtained from locations identified in each pasture to represent side-hill, bottomland, and upland vegetation. Fifteen 0.1- m^2 plots were randomly located and hand-clipped to the ground at each of three sites per vegetation type. Forage was dried at 60°C and weighed. Total pasture standing crop was determined by adjusting the forage weight by the hectares of each vegetation type within the pasture. Fecal samples were collected from 10 cows per pasture, composited, and CP and digestible organic matter composition were estimated by near infrared reflectance spectrophotometry (20). Forage samples were collected from forage species predominant in pastures grazed by the experimental heifers during the prebreeding period. Samples were frozen on dry ice and analyzed (Table 6) by a commercial laboratory (MVTL Laboratories, New Ulm, MN) using standard AOAC procedures.

All protocols for Studies 1 and 2 were reviewed and approved by the Location Animal Care and Use Committee.

Statistical Analyses. Preliminary analyses were conducted in Study 1 to determine if breed of dam had significant effects on endpoints measured. All main effects and two-way interactions were nonsignificant so data were pooled over breed of dam for further analyses. Accurate breed of dam was unknown in Study 2 and was ignored as a variable in statistical analyses. Data in all studies were analyzed by SAS-GLM procedures (25) using model variables of calving season, diet, calf sex plus the two- and three-way interactions. The residual mean square was used as the error term to test all main effects and interactions in both studies with tests among means made by protected LSD. Initial BW and condition scores and days on experimental diet were used as covariates where appropriate, birth BW was used as a covariate for analyses of fall calf BW, and fall calf BW were adjusted for day of age. Comparisons of calving difficulty incidence, estrous cyclicity, and pregnancy percentage main effects were tested by Chi-square, and CATMOD procedures were used to evaluate interactions (25). Blood constituents were analyzed within sample times with and without initial hormone or metabolite concentrations as covariates, and no significant covariate effects were detected. Therefore, blood constituent results and least-squares mean values reported are for analyses without covariates.

Results and Discussion

Least squares mean values for main effects and important interaction of calving season and diet are presented in the tables. Significant

TABLE 7. Least squares means for Study 1 dam body weights and condition scores.

Item	no.	Initial BW (kg)	Initial Condition score	Precalving BW (kg)	Precalving Condition score	Prebreeding BW (kg)	Prebreeding Condition score	End breeding BW (kg)	End breeding Condition score
Calving season									
February	76	441.8	5.5	509.1[a]	6.2[a]	437.8[a]	5.2[a]	460.0	5.4[a]
March-April	37	436.1	5.2	500.7[a]	5.9[b]	495.2[b]	6.5[b]	469.4	5.5[b]
June	39	441.6	5.4	531.9[b]	6.4[c]	472.2[c]	5.9[c]	443.9	4.9[a]
SE[d]		6.3	0.1	7.0	0.1	8.0	0.1	7.6	0.2
Diet									
Control	38	423.5	5.3	505.3	6.0	454.8	5.6[a]	448.0	5.2
Safflower	38	443.8	5.4	519.4	6.3	478.2	6.0[b]	467.1	5.4
Soybean	38	441.4	5.4	505.6	6.1	464.8	5.8[a]	454.3	5.1
Sunflower	38	450.6	5.5	525.2	6.2	475.8	6.0[e]	461.8	5.2
SE[d]		7.4	0.1	8.3	0.1	9.4	0.1	8.9	0.2

[a,b,c]Means within columns and main effects without a common superscript differ ($P<0.05$).
[d]Pooled SE.
[e]$P<0.10>0.05$.

interactions are indicated in table footnotes. Calf sex was an identifiable source of variation in the statistical analyses, but it is biologically difficult to rationalize meaning of effects within the objectives of this work since all sex x diet interactions were nonsignificant ($P>0.10$). Results were in agreement with numerous other studies in that calf BW analyses found male calves exceeded females at all weighings. We recognize male calves can place additional lactation stress on dams, but this was not identifiable in this study. Calf sex effects are not discussed further.

Study 1. Initial BW and condition scores did not differ over the three calving seasons (Table 7). However, precalving and prebreeding BW and condition scores were affected ($P<0.01$) by calving season with the season effect on end-breeding condition scores approaching significance ($P=0.06$). This result was expected since season effects on BW, and condition scores have been reported in numerous studies. Diet effects on BW and condition scores were nonsignificant with the exception of prebreeding condition scores ($P=0.08$), with heifers receiving the high-fat diets tending to have the highest condition scores (Table 7).

The interaction of calving season x diet for precalving body condition score ($P<0.01$) resulted from changes in ranking of which diet resulted in the highest precalving condition score for the three calving seasons. However, no consistent pattern was evident.

Heifers calving in February experienced a greater incidence of calving difficulty ($P<0.05$) and had higher difficulty scores ($P<0.01$), but calf BW and vigor score main effects did not differ over season (Table 8). Diet effects on calving difficulty, birth BW, and calf vigor score were nonsignificant (Table 8). The interaction effect of calving season x diet on vigor scores was significant and was caused by changes in diet ranking of vigor scores among the four diets. Vigor was highest in calves from dams on the CON diet in the February-calving group. However, vigor was highest for calves from dams on the CON, SAFF, and SUN diets (the same numerical value) for the March–April calving group and was the highest for calves from SOY-supplemented dams for the June calving group.

Dam reproduction data are also summarized in Table 8. Differences in dam estrous percentages were not significantly affected by calving season. However, pregnancy percentage of dams that calved in June and bred in August tended to be lower ($P=0.09$) than dams calving in February or March–April and bred in April or July, respectively. Differences in fall calf BW were highly significant, with calves born in June being the lightest. This adjusted calf-BW difference was a result of an unidentified effect of season on calf BW gain and agrees with the findings of Grings et al. (12), who reported calf BW at 190 d of age decreased ($P<0.05$) as calving season became later. Diet effect on estrous percentage at the beginning of the breeding season was nonsignificant although the trend was for more dams from the high-fat diets to be cycling than for dams on the low-fat diet. The effect of diet on pregnancy percentage was significant with dams that received the control diet having a lower percentage pregnant than fat-supplemented dams, regardless of fat source. The average pregnancy advantage for the fat-supplemented dams exceeded that of the control-diet dams by 15.2 percentage points.

Fall BW of calves from the fat-supplemented dams tended to exceed ($P=0.08$) that of the control-diet

TABLE 8. Least squares means for Study 1 calving and reproduction data.

Item	no.	Calving difficulty Score	Calving difficulty Incidence (%)	Calf birth BW (kg)	Calf vigor score	Dam estrus at begin breeding (%)	Dam pregnancy (%)	Calf fall BW (kg)
Calving season								
February	76	2.0[a]	50.5[a]	38.2	1.2	76.4	90.4[a,d]	197.7[a]
March-April	37	1.4[b]	24.4[b]	38.5	1.0	66.7	93.3[a]	221.0[a]
June	39	1.5[b]	20.6[b]	38.1	1.2	84.6	80.6[d]	160.0[b]
SE[c]		0.2	–	0.7	0.1	–	–	3.9
Diet								
Control	38	1.6	28.1	37.0	1.3	68.4	78.8[a]	182.4[a]
Safflower	38	1.7	35.7	37.7	1.1	85.3	96.9[b]	193.6[b]
Soybean	38	1.6	25.7	39.3	1.1	75.7	93.3[b]	197.7[b]
Sunflower	38	1.7	37.8	39.0	1.1	76.3	91.7[b]	196.8[b]
SE[c]		0.2	–	0.9	0.1	–	–	4.5

[a,b]Means within columns and main effects without a common superscript differ ($P<0.05$).
[c]Pooled SE.
[d]$P<0.10>0.05$.

dams, again, regardless of fat source. The overall fall BW advantage of calves from fat supplementation of the gestation diet averaged 13.6 kg. Interactions were nonsignificant for endpoints summarized in Table 8. It should be emphasized that differences in pregnancy percentages and calf BW occurred even though the dams had not received the high-fat diets for an average of 53 d elapsing from calving to the beginning of the breeding season. We interpret this observation to indicate a carry-over effect of gestation fat supplementation on postpartum reproductive performance.

Study 2. Season effects on dam BW (Table 9) approached significance ($P=0.06$) at the prebreeding weighing and were significant for end-breeding BW. Season effects on dam condition scores approached significance ($P=0.08$) for precalving scores and were significant for both pre- and end-breeding scores. Lowest scores were observed for dams calving in June (Table 9). Diet effects on dam BW and condition scores were nonsignificant. Dams calving in February experienced a greater incidence of dystocia ($P<0.05$), and dystocia scores and calf birth BW were higher ($P<0.05$) than dams calving in either of the other two calving seasons (Table 10). Calf vigor scores were nonsignificantly affected by season of calving (Table 10). Season effects on dam estrous or

TABLE 9. Least squares means for Study 2 dam body weights and condition scores.

Item	No.	Initial BW (kg)	Initial Condition score	Precalving BW (kg)	Precalving Condition score	Prebreeding BW (kg)	Prebreeding Condition score	End breeding BW (kg)	End breeding Condition score
Calving season									
February	30	431.8	4.9	501.8	5.4[a]	431.7[a]	5.1[a]	467.4[a]	5.1[a]
March-April	33	430.9	5.1	502.1	5.4[a]	476.2[b]	5.2[a]	447.4[b]	4.6[b]
June	20	439.2	5.1	486.4	5.2[b]	435.3[a]	4.3[b]	434.5[b]	4.4[b]
SE[c]		6.3	0.1	7.3	0.1	8.3	0.1	3.0	0.1
Diet									
Control	41	431.6	5.1	496.6	5.4	447.6	5.0	451.6	4.8
Sunflower	42	434.0	5.0	499.8	5.3	452.9	4.9	450.7	4.6
SE[c]		5.0	0.1	5.6	0.1	8.2	0.1	8.1	0.1

[a,b]Means within columns and main effects without a common superscript differ ($P<0.05$).
[c]Pooled SE.
[d]$P<0.10>0.05$.

TABLE 10. Least squares means for Study 2 reproduction and calf-weight data.

Item	no.	Calving difficulty Score	Calving difficulty Incidence (%)	Calf birth BW (kg)	Calf vigor score	Dam estrus at begin breeding (%)	Dam pregnancy (%)	Calf fall BW (kg)
Calving season								
February	30	1.6[a]	30.0[a]	36.4[a]	1.13	67.8	89.3	229.5[a]
March-April	33	1.2[b]	15.2[b]	34.4[b]	1.00	60.6	81.8	225.5[a]
June	20	1.0[b]	0	32.9[c]	1.00	50.0	85.0	171.3[b]
SE[d]		0.01	–	0.5	0.1	–	–	3.9
Diet								
Control	41	1.2	12.2	33.8	1.02	65.8	90.2	212.2
Sunflower	42	1.4	21.4	35.7[e]	1.07	55.0	80.0	215.2
SE[d]		0.2	–	0.7	0.1	–	–	4.0

[a,b,c]Means within columns and main effects without a common superscript differ ($P<0.05$).
[d]Pooled SE.
[e]$P=0.06$.

pregnancy percentage were nonsignificant, but the effect on age adjusted-calf fall BW was highly significant, with the lightest calves being those from June-calving dams. This result is in agreement with results in Study 1. Diet had a nonsignificant effect on calving difficulty incidence or score, or calf vigor. Calf birth BW tended ($P=0.06$) to be greater from dams receiving the high-fat diet. Diet effects on dam estrous percentage at the beginning of the breeding season and fall pregnancy percentage were nonsignificant.

Results of analyses of blood samples for hormones and metabolites are summarized in Table 11. Season of calving effects on insulin-like growth factor (IGF) concentrations were important for all sample periods. There appeared to be a general, but inconsistent trend, for IGF concentrations to be highest in dams calving in June. Season effects on glucose concentrations were all highly significant for all sample periods, with the exception of the initial sampling. The general trend was for glucose concentrations to be highest in February-calving dams. Seasonal effects on NEFA concentrations were highly significant with the exception of concentrations at the prebreeding sampling. In general, concentrations were highest in June-calving dams at the initial and midperiod, but were highest in dams calving in March–April at the precalving and prebreeding samplings. Diet effects on IGF and glucose concentrations were nonsignificant at all sampling times. Diet differences in NEFA concentrations approached significance at the initial ($P=0.08$) and midperiod ($P=0.06$) samplings with concentrations being highest in dams receiving the control diet.

Results of Studies 1 and 2 differ in their effects of feeding supplemental fat on reproduction. Fat supplementation significantly increased pregnancy percentage in Study 1, but tended to decrease ($P\cong0.13$) pregnancy in Study 2. Analyses of the diets revealed similar compositions, and we conclude that differences in diet composition and fat content can reasonably be ruled out as causative factors. Genetic differences between heifers in the two studies cannot be ignored, but are probably not a major factor. We hypothesize that year differences in forage availability and composition played a key role in the response difference between the two studies and pursued this hypothesis further.

Forage production at the Miles City location is highly dependent on rainfall, with precipitation during April and May being the most critical (15). Rainfall and forage production in 1998 and 1999 are briefly summarized in Table 5 and indicate major yearly differences between the two studies. Heifers grazing native or improved pastures postpartum in 1998 had limited forage available, whereas those grazing pastures in 1999 had abundant forage that can be calculated from values in Table 5 and show 71% more forage available in 1999. Additionally, near infrared reflectance spectrophotometry fecal analyses indicated that forage nutrient quality in 1999 was superior to that in 1998. Intakes are not available, but it is logical to assume forage intake and quality were greater in 1999.

Forage samples were collected from two introduced (Russian wildrye and crested wheatgrass) and two native (western wheatgrass and threadleaf sedge) forage species predominant in the pasture on May 7, 1999. Protein content of these forages was high, ranging from 29.8 to 34.3% for introduced forages and 17.8 to 19.3% for native species (Table 6). Fat content was moderate and was in the range of some of the high-fat diets fed at this location (3). The fatty acid content for saturated fatty acids ranged from 18.2% for crested wheatgrass to 32.6% for threadleaf sedge,

TABLE 11. Least squares means for Study 2 dam blood hormone and metabolite analyses.

Item	no.	Initial data IGF (ng/mL)	Initial data Glucose (mg/dL)	Initial data NEFA (mEq/mL)	Mid period data IGF (ng/mL)	Mid period data Glucose (mg/dL)	Mid period data NEFA (mEq/mL)	Precalving data IGF (ng/mL)	Precalving data Glucose (mg/dL)	Precalving data NEFA (mEq/mL)	Prebreeding data IGF (ng/mL)	Prebreeding data Glucose (mg/dL)	Prebreeding data NEFA (mEq/mL)
Calving season													
February	30	87.8[a]	67.9	437	90.7[a]	73.0[a]	358	83.8	74.1[a]	381	–[d]	73.4[a]	512
March-April	33	80.4[b]	65.8	315	96.7[a]	65.8[b]	314	86.9	63.6[b]	540	61.6	65.8[b]	570
June	20	71.3[c]	66.8	761	105.0[b]	66.7[bc]	772	91.8	63.4[bc]	359	82.8	73.8[a]	442
SE[e]		3.0	1.1	47	3.6	1.5	43	2.8	2.5	39	4.3	1.3	49
Diet													
Control		78.7	67.4	553	96.2	67.1	530	88.5	66.8	424	74.5	70.3	490
Sunflower		80.9	66.3	456	98.8	69.8	433[f]	86.6	67.3	430	70.0	71.6	526
SE[e]		2.5	1.2	39[f]	2.9	1.2	36	2.3	2.1	32	4.3	1.1	32

[a,b,c]Means within columns and main effects without common superscripts differ ($P<0.05$).
[d]Samples not analyzed.
[e]Pooled SE.
[f]$P<0.10>0.05$.

and the unsaturated fatty acid content ranged from 67.4% for threadleaf sedge to 81.8% for crested wheatgrass. Fatty acid profiles indicated that linolenic (18:3) content was greatest, ranging from 37.8% for threadleaf sedge to 58.4% for crested wheatgrass. This was followed, in descending order, by palmitic (16:0), linoleic (18:2), palmitoleic (16:1), oleic (18:1), and stearic (18:0) acids. We hypothesize that the abundant, high-quality forage available in 1999 resulted in a near-maximal, plateaued nutritional-reproduction response in these dams, and this tended to mask any carryover effect resulting from supplemental fat fed in the gestation diet.

Feeding fish meal resulted in a positive effect on pregnancy rates in dairy cattle (2, 7, 8). Staples et al. (26) and Bonnette et al. (6) suggested that these positive effects result from fatty acids in the fish meal, inhibiting uterine synthesis of $PGF_{2\alpha}$ resulting in extending the life of the CL and its production of progesterone, thus avoiding early embryonic death. This hypothesized mechanism may, at least partially, explain results in Study 1. Additionally, Lammoglia et al. (16, 17) found calf response to cold stress was improved by feeding supplemental fat to the pregnant dam during late gestation, suggesting direct effects of fat feeding on fetal physiology. The embryo produces Interferon tau which blocks release of $PGF_{2\alpha}$ from the uterus, allowing the corpus luteum to continue producing progesterone, leading to establishing pregnancy (27). We suggest that increased dietary fat may have a direct effect on the embryo, causing increased production of Interferon tau, resulting in enhancing establishment of pregnancy. Results of the present studies do not permit determining which of these mechanisms or combination of mechanisms may be responsible for the improved reproductive performance found in our work, but these hypotheses suggest interesting possibilities for future studies.

Many studies have shown major reproduction responses in cattle moving from winter feed to spring-summer forages. This response has been attributed to increased protein, energy, vitamins, and minerals while Preston and Willis (23) attribute this response to unidentified feed factors. Data are accumulating showing supplemental dietary fat has positive effects on ovarian and pituitary activity in cattle with results of Study 1, confirming a positive effect on pregnancy rate and calf fall BW. Dietary fat or fatty acids or both may be a previously unidentified feed factor. We conclude this positive effect was masked by more than adequate amounts of nutrients available in forages consumed in Study 2.

Implications

Dietary fat and, possibly more specifically, unsaturated fatty acids may be important components of the "reproductive fuel" required for optimal reproductive activity. These nutrients should be given consideration in future research. We suggest that this future research include: determining controlling mechanisms, titration of fat-supplement composition and amounts, plus determining appropriate feeding duration and stage of the reproductive cycle to give best results.

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