JOURNAL OF ANIMAL SCIENCE
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J ANIM SCI 2010, 88:2717-2728.
doi: 10.2527/jas.2009-2744 originally published online May 7, 2010

Prepartum dietary energy source fed to beef cows: I. Effects on pre- and postpartum cow performance[1]

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ABSTRACT: Mature Angus-cross beef cows (n = 144) were used to determine effects of late gestation dietary energy source on pre- and postpartum cow performance in a complete randomized block design experiment. Cows were adapted to diets starting at 167 ± 9 d of gestation and fed until 1 wk before expected calving date. Cows were fed 1 of 3 dietary energy sources: grass hay (HY), corn (CN), or dried distillers grains (DDGS). Cows allotted to HY were allowed ad libitum access to round-bale grass hay, and average hay disappearance was 12.4 kg/d. Limit-fed corn and DDGS diets contained 5.3 kg of whole-shelled corn or 4.1 kg of DDGS, respectively, plus 2.1 kg of hay, and 1.0 kg of supplement to meet cow nutritional needs during late gestation and to allow for an energy intake similar to HY. Every 21 d, BW, BCS, and ultrasound measurement of backfat between the 12th and 13th ribs were collected. At 210 d in gestation, jugular blood samples were collected from cows at 0, 3, 6, and 9 h postfeeding and were analyzed for glucose, insulin, NEFA, and blood urea N (BUN) concentrations. After parturition, cows were fed a common diet and managed similarly. Milk production was determined by weigh-suckle-weigh procedure on d 31, 100, and 176 postpartum. Cows fed DDGS during late gestation gained more ($P = 0.04$) BW than cows fed HY or CN; however, no difference in BCS change was detected ($P = 0.28$) among treatments. Plasma glucose concentrations were similar among treatments ($P = 0.64$), whereas insulin concentrations at 3 h postfeeding were greater ($P = 0.002$) for cows fed DDGS than those fed HY or CN. Plasma BUN concentrations were greater ($P \leq 0.02$) for cows fed DDGS vs. CN or HY up to 6 h postfeeding. Birth weight was greater ($P < 0.001$) for calves from cows fed CN and DDGS than for those fed HY, but this did not result in any differences in frequency of dystocia ($P = 0.21$). Prepartum energy source did not affect conception rates ($P = 0.79$), milk production ($P \geq 0.51$), or milk composition ($P \geq 0.39$). Maternal dietary energy source in late gestation did not affect pre- or postpartum cow performance, but did change plasma hormones and metabolites during gestation. Heavier birth weights in calves from cows fed CN or DDGS indicate the changes in maternal metabolism affected energy partitioning of nutrients to the fetus and subsequent fetal growth.

Key words: beef cattle, maternal nutrition, prepartum energy source, reproduction

J. Anim. Sci. 2010. 88:2717–2728
doi:10.2527/jas.2009-2744

INTRODUCTION

One of the major determinants of net income in a cow/calf enterprise is feed costs (Story et al., 2000). Therefore, identification of economical feed sources would be advantageous. Corn can be an economical alternative to harvested or stockpiled forages and can be limit-fed in late gestation diets without negative effects on cow performance (Loerch, 1996; Schoonmaker et al., 2003). With increased availability of ethanol coproducts, dried distillers grains (**DDGS**) have become more competitively priced with other protein and energy sources; however, limited information has been published on effects of DDGS in limit-fed prepartum diets.

Maternal energy source could affect nutrient supply of glucose and AA to the gravid uterus, and these are important substrates for fetal growth (Bell et al., 2005). Previously, Loerch (1996) reported heavier birth weights in calves from cows fed primarily a starch vs. fiber-based diet at isocaloric intakes, suggesting maternal energy source affects fetal growth.

Previous research has linked energy density of diet before calving to pospatrum reproductive performance (Dunn and Moss, 1992; DeRouen et al., 1994). Studies have investigated prepartum protein and energy

[1]Salaries and research support provided by state and federal funds appropriated to the Ohio Agric. Res. and Dev. Center, The Ohio State University.

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Received December 11, 2009.

Accepted April 22, 2010.

Table 1. Reasons for cows being removed from the trial

Item	Treatment[1] HY	CN	DDGS
Initial cows	49	49	49
Prepartum mortality[2]	—	1	2
Non-first-service AI[3]	—	2	1
Preterm abortions	—	2	2
Birth defects[4]	2	1	—
Calf mortality[5]	1	2	2
Twins	—	1	—
Postpartum mortality[6]	—	—	1
Total removed	3	9	8

[1]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

[2]Causes of death included bovine leukosis, rectal tumor, and unknown.

[3]Cows were removed if calving did not occur within 300 d of first-service AI date.

[4]Calves were born with birth defects determined not to be associated with treatments.

[5]Calves were dead at birth with no dystocia observed.

[6]Cow died of respiratory disease postpartum.

supplementation with varied responses in reproductive performance (Bellows et al., 2001; Small et al., 2004) and milk production (Perry et al., 1991; Alexander et al., 2002; Banta et al., 2006). However, limited information is available on effects of prepartum dietary energy source fed at isocaloric intakes on postpartum cow performance.

We hypothesized that maternal dietary energy source would result in changes in maternal nutrient supply and fetal growth; however, these changes would not result in differences in postpartum cow performance. Therefore, the objectives of this experiment were to determine the effects of prepartum energy source on cow prepartum performance, prepartum metabolites, postpartum milk production, and postpartum reproductive performance.

MATERIALS AND METHODS

The Agricultural Animal Care and Use Committee of The Ohio State University approved the procedures used in this experiment.

Animals, Experimental Design, Treatments

Mature Angus-cross cows (n = 144; BW = 606.6 ± 4.4 kg; age = 4.9 ± 0.5 yr) were used in a randomized complete block design experiment to determine the effects of late gestation dietary energy source on pre- and postpartum cow performance. The study was conducted at 3 branch locations of the Ohio Agricultural Research and Development Center: The Ohio State University campus (**OSU**; n = 42), Columbus; North Appalachian Experimental Watershed (**NAEW**; n = 48), Coshocton; and Eastern Agricultural Research Station (**EARS**; n = 54), Belle Valley.

In June 2007, cows were synchronized for timed AI to a single sire, and clean-up bulls were exposed to cows for 30 d, 3 wk after timed AI. Pregnancy diagnosis was conducted by transrectal ultrasonography (5-MHz linear array transducer, 500 V, Aloka, Wallingford, CT) approximately 30 d after timed AI and was confirmed again approximately 90 d after timed AI by transrectal ultrasonography or hand palpation. Only cows confirmed by ultrasound for first-service conception by timed AI were used in the trial. The cows were blocked by location (n = 42, OSU; n = 51, NAEW; n = 54, EARS) and within location, were stratified by BW, BCS, and cow age and were assigned to 1 of 3 pens at OSU, 1 of 3 pens at NAEW, and 1 of 9 pens at EARS. Dietary treatments were randomly assigned to pens within a location. Cows were removed from the experiment for reproductive failure, failure to calve before 300 d after first AI service, and death (Table 1).

In November 2007, cows were adapted to diets starting at an average of 167 ± 9 d of gestation. Dietary treatments were 1 of 3 dietary energy sources (Table 2): ad-libitum grass hay (high-fiber concentration; **HY**); limit-fed corn (high-starch concentration; **CN**); or limit-fed corn DDGS (high fiber, protein, and fat concentrations, **DDGS**). In all locations, cows fed CN and DDGS were housed in drylot pens and were provided at least 0.6 m of bunk space per cow. At EARS and OSU, cows fed HY were housed in similar drylot pens as their counterparts, whereas in NAEW cows fed HY were fed in a dormant 21-ha pasture, where available forage was removed by grazing before the initiation of the trial. Corn, DDGS, and supplements were all from the same source, whereas hay was harvested and fed at each location. Hay harvested at each location was similar in nutrient content with ranges for the following: CP = 9.13 to 9.86%; NDF = 60.5 to 69.7%; and ADF = 39.3 to 41.4% on DM basis.

Diets were formulated to meet or exceed cow nutrient requirements during late gestation (11.08 NE_m of Mcal/d; 840 g of CP/d; NRC, 2000), and intake of CN and DDGS diets (Table 2) was limited. Cows fed HY were allowed ad libitum access to hay in round bale feeders, and hay was fed to minimize waste by only providing a new bale after 90% of the bale had disappeared. Hay bales were weighed before feeding, but refusal was not recorded because it was impossible to accurately quantify. The hay provided was primarily orchardgrass. Cows fed HY were provided with ad libitum access to a salt and mineral mix (29.5% trace mineralized salt, 25% dicalcium phosphate, 25% magnesium oxide, 10% limestone, 10% ground shelled corn, 0.5% ethylene diaminedihydroiodide, and 50 mg/kg of selenium). Fifteen bales in each location were randomly selected, cored, and composited for nutrient analysis.

Limit-fed CN and DDGS diets were hand-fed in fence line bunks once daily and provided 5.3 kg of whole shelled corn or 4.1 kg of DDGS (respectively), plus 2.1 kg of square-bale grass hay, and 1.0 kg of supplement per cow on a DM basis (Table 2). Limit-fed corn diets were similar to those used in previous research (Loerch, 1996), and the NE_m for DDGS was estimated to be 110% the NE_m of corn (Stock et al., 2000). A 4-d adjustment period, in which hay was gradually decreased, was used to adapt cows to the limit-fed diets of CN and DDGS. Diet samples were collected every 21 d and composited for nutrient analysis.

Initial BW and BCS were determined at the start of the trial when cows were fed a common diet of grass hay. A 2-wk period was then used to allow equilibration of gut fill on the experimental diets. Body weight measured at the end of this 2-wk period was used as the basis for evaluation of subsequent changes within each dietary treatment. Starting at the end of this 2-wk adaptation period, and every 21 d subsequently during gestation, BW, BCS (1 = emaciated; 9 = obese; Wagner et al., 1988), and ultrasound measurement of backfat (**BF**) between the 12th and 13th ribs were collected. The diet intakes were adjusted if needed every 21 d during the trial to maintain similar BW gain (based on the 2-wk BW after adaptation to diets and changes in gut fill were equilibrated) and BCS for cows fed CN or DDGS compared with cows fed HY. Intake adjustments were also made to compensate for energy needs in cold environmental temperatures. Corn intake was increased 0.9 kg per cow starting 8 wk after diets were introduced because the difference in BW gain relative to HY was greater than 0.5 kg/d and energy requirements increase during late gestation. No adjustments were made to DDGS diets during gestation because BW gain was similar or greater than cows fed HY. The final gestation weights were collected 3 wk before expected calving date. To have similar differences in gut fill, cows fed HY were denied access to hay for 14 h before weight collection and new hay bales were not fed for 3 d before weigh day. Cows were removed from diets 1 wk before expected calving date, fed a common diet of grass hay until parturition, and then managed on pasture as 1 group within location until weaning. The calving period was 15 d in length.

All feed samples were ground using a Wiley mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA) and analyzed for DM (24 h at 100°C), NDF (using sodium sulfite and heat-stable α-amylase; Ankom[200] Fiber Analyzer, Ankom Technology, Fairport, NY), CP (macro Kjeldahl N × 6.25), fat (using ether extract method; Ankom Technology), and select macro minerals (Ca, P, and S; AOAC, 1997).

Table 2. Late gestation diets and nutrient composition

Item	Treatment[1]		
	HY[2]	CN	DDGS
Ingredient	% DM basis		
Grass hay	100.00	27.50	30.50
Whole shelled corn	—	60.00	—
DDGS	—	—	66.53
Ground corn	—	3.34	—
Soybean meal	—	5.83	—
Limestone	—	0.97	1.53
Dicalcium phosphate	—	0.54	—
Urea	—	0.52	—
Trace mineral salt[3]	—	0.40	0.44
Animal and vegetable fat	—	0.34	0.38
Potassium chloride	—	0.26	0.29
Magnesium oxide	—	0.16	0.18
Mg and K sulfate[4]	—	0.07	0.08
Selenium, 201 mg/g	—	0.04	0.04
Vitamin A, 30,000 IU/g	—	0.01	0.01
Vitamin D, 3,000 IU/g	—	0.01	0.01
Monensin[5]	—	0.01	0.01
Analyzed nutrient content			
CP, %	8.2	11.4	20.5
NDF, %	68.1	24.2	40.1
ADF, %	41.1	13.0	24.4
Ether extract, %	2.0	3.9	8.6
Ca, %	0.2	0.7	0.7
P, %	0.5	0.3	0.5
S, %	0.2	0.2	0.3

[1]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

[2]Cows were provided ad libitum access to a trace-mineral salt mix (29.5% trace mineralized salt, 25% dicalcium phosphate, 25% magnesium oxide, 10% limestone, 10% ground corn, 0.5% ethylene diamin-edihydroiodide, and 50 mg/kg of selenium).

[3]Contained 98% NaCl, 0.35% Zn, 0.28% Mn, 0.175% Fe, 0.035% Cu, 0.007% I, and 0.007% Co.

[4]Magnesium sulfate and potassium sulfate. Contained 22% S, 18% K, 11% Mg.

[5]Provided 28 mg of monensin/kg of dietary DM (Elanco, Greenfield, IN).

Postpartum Measurements

Milk production was measured at approximately 31, 100, and 170 d postpartum using a modification of the weigh-suckle-weigh technique described by Boggs et al. (1980). Calves were separated from their dams for 3 h before the milk intake measurement. After the 3-h separation, calves were allowed to nurse their dams dry, and then were separated again for 6 h (at 31 d postpartum) or 12 h (for 100 and 170 d postpartum). A shorter weigh-suckle-weigh was used at 31 d postpartum, based on concern that calves could not consume the amount of milk produced in 12 h at this age. After 6- or 12-h separation, the calves were weighed. Then, the calves were allowed to suckle their dams and were reweighed immediately once suckling had ceased. Milk production was assumed to be the difference between the 2 weights, and milk production per day was calculated by multiplying intake by 4 for 6-h separation at 31 d postpartum and by 2 for 12-h separation at 100 and 170 d postpartum. Before the weigh-suckle-weigh procedure, calves were assigned randomly to 1 of 3 groups within location and the weigh-suckle-weigh procedure was initiated at consecutive 30-min intervals to more closely monitor the calves during suckling. During the initial 3-h separation, a milk sample (approximately 50 mL) was collected by hand from each cow and treated with bronopol and natamycin as preservatives and held at 4°C until analyzed for composition (fat, CP, lactose, and milk urea N) by a commercial laboratory as described by Beckman and Weiss (2005).

In 2 locations (OSU and EARS), postpartum reproductive performance was measured. Postpartum anestrus at 50 d postpartum was assessed by determination of percentage of cows cycling at 48 and 57 d postpartum by plasma progesterone concentration. Cows were synchronized for timed AI at an average of 80 d postpartum by inserting a controlled internal drug release (**CIDR**; vaginal insert containing 1.38 g of progesterone) for 7 d with $PGF_{2\alpha}$ and GnRH administration after CIDR removal. A $PGF_{2\alpha}$ injection was given 7 d after CIDER removal, then a second GnRH injection was administered at 48 to 66 h after $PGF_{2\alpha}$ concurrent with timed AI. Cows were exposed to intact bulls 25-d after timed AI for approximately 35 d. Pregnancy was diagnosed by transrectal ultrasonography between 30 to 35 d after timed AI to determine first-service AI pregnancy rate. A second pregnancy diagnosis was performed 90 to 100 d after timed AI by transrectal ultrasonography to determine second-service AI conception rates, and overall pregnancy rates for the breeding season.

Blood Collection and Analysis

At 210 d of gestation, a subset of cows (5 cows per pen at NAEW and OSU; 2 cows per pen at EARS) were randomly selected, and then jugular blood samples were collected at 0, 3, 6, and 9 h after feeding CN and DDGS diets. Blood samples from each cow (20 mL) were collected in 2 Vacutainer (Becton, Dickson and Co., Franklin Lakes, NJ) collection tubes with 1 containing EDTA and 1 containing 15 mg of NaF and 12 mg of K oxaloate per tube. Blood samples were placed on ice until they were centrifuged at 3,000 × g for 20 min at 4°C. Plasma collected from tubes containing EDTA were frozen at −80°C for subsequent analysis of blood urea N (**BUN**), NEFA, and insulin. Plasma collected from tubes containing Na fluoride were frozen at −20°C for subsequent glucose analyses. Concentrations of insulin were measured using RIA as described previously (Benson and Reynolds, 2001). The intraassay CV was 12%. Colorimetric assays were used to determine concentrations of plasma glucose (1070 Glucose Trinder, Standbio Laboratory, Boerne, TX), plasma NEFA (Wako Chemicals USA, Richmond, VA) as described by Johnson and Peters (1993), and BUN (BioAssay Systems, Hayward, CA).

At 189, 210, and 231 d of gestation for the same subset of cows, jugular blood samples (10 mL) were collected before feeding for progesterone analysis as an indication of placenta size and function (Sullivan et al., 2009). To determine percentage of cows cycling at 60 d postpartum, jugular blood samples from all cows were taken on the average of 48 and 57 d postpartum at the EARS and OSU locations to detect cows with an active corpus luteum. When either of the 2 blood samples had concentrations of progesterone >1 ng/mL, the cow was considered to be cycling (Perry et al., 1991). Plasma progesterone was measured from blood collected in a Vacutainer (Becton, Dickson and Co., Franklin Lakes, NJ) collection tube containing EDTA. After centrifugation at 3,000 × g for 20 min at 4°C, plasma was recovered and stored at −20°C until subsequent analysis. Progesterone concentrations were determined using a commercially available RIA kit (Coat-a-Count, Diagnostic Products Corporation, Los Angeles, CA) as described previously by Burke et al. (2003).

Statistical Analysis

Twenty cows were removed from the trial due to various reasons (Table 1), and data from these cows were not used for statistical analyses. The GENMOD procedure (SAS Inst. Inc., Cary, NC) was used to analyze binomial data (dystocia, cycling, conception, and pregnancy rates). The PROC MIXED procedure of SAS was used to analyze the remaining variables. The PDIFF statement of SAS was used to separate treatment means when significant ($P < 0.10$). Experimental unit was pen, and location was included as a random variable in all analyses.

Cow measures of prepartum plasma data, postpartum milk production, and postpartum cow performance were analyzed using the PROC MIXED procedure with a repeated measures model. For each analyzed variable, 5 covariance structures were compared: compound symmetric, autoregressive order one, heterogeneous autoregressive order one, spatial power, and unstructured. The covariance structure that yielded the smallest Bayesian information criterion was used for the results presented. For plasma metabolites and hormones, maternal dietary energy source, hours postfeeding, and the 2-way interaction were used in the model. For postpartum variables, gestational dietary energy source, days postpartum, and the 2-way interaction were tested. Simple effects within hours postfeeding and days postpartum were generated by the SLICE function of SAS.

RESULTS AND DISCUSSION

Prepartum Cow Measurements

The prepartum diets were initially formulated to provide similar NE_m intake among treatments according to NRC (2000) for CN and HY diets, whereas the energy value used for DDGS was greater than reported by NRC (2000). Based on previous studies investigating DDGS inclusion levels from 10 to 64% in high-concentrate diets for beef steers, the energy value relative to corn has been reported to range from 83 to 124% with the average at 110% (Stock et al., 2000). Therefore, an energy value for DDGS of 110% of corn was used to

Table 3. Estimated nutrient intake and daily feed cost during gestation

Item	Treatment[1] HY	CN	DDGS
DMI,[2] kg/d	12.4	8.4	7.2
Hay, kg/d	12.4	2.1	2.1
Corn, kg/d	—	5.3	—
DDGS, kg/d	—	—	4.1
Supplement, kg/d	—	1.0	1.0
Calculated NE_m intake,[3] Mcal/d	14.14	16.05	14.34
Estimated diet NE_m,[4] Mcal/kg of DM	1.14	1.82	2.81
Estimated NE_m intake,[5] Mcal/d	14.14	15.28	20.23
CP intake, g/d	1,018	955	1,477
Crude fat intake, g/d	248	325	622
Daily feed costs,[6] $/cow	1.36	1.46	1.04

[1]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

[2]HY DMI was estimated by hay offered to cows and includes wastage.

[3]Calculated from NRC (2000) except for DDGS. Assumed DDGS was 110% energy value of corn (as reviewed by Stock et al., 2000).

[4]Calculated from efficiency of cow BW gain (G:F; Table 4) during late gestation relative to HY diet.

[5]Calculated from estimated diet NE_m, Mcal/kg of DM relative to HY diet.

[6]Calculated with the following prices on an as-fed basis: corn = $0.149/kg ($3.80/bu); hay = $0.110/kg ($100/t); DDGS = $0.143/kg ($130/t); CN supplement = $0.441/kg ($400/t); and DDGS supplement = $0.221/kg ($200/t).

formulate the diets and establish intake at the start of the trial. In Table 3, DMI and daily feed costs during late gestation are reported. Cows fed CN had a greater energy intake during gestation than initially formulated because the amount of corn was increased in the diet starting at 210 d of gestation (in January) and cows fed CN lost BW from December to January, whereas cows fed HY maintained or gained BW. In addition, the increase in amount of corn was to compensate for energy needs in cold environmental temperatures and increasing cow requirements during late gestation. However, the amount of DDGS fed to cows during late gestation was not changed at this time because cows fed DDGS were gaining BW and a reduction in DDGS intake did not seem justified.

Using average commodity prices paid during the trial, diet costs per cow were reduced 24% by feeding DDGS instead of HY as the primary energy source during late gestation (Table 3). In previous studies, limit-feeding corn has been an economic alternative to hay in late-gestation diets (Loerch, 1996; Schoonmaker et al., 2003). However, in those studies, corn was valued at 50% less per kilogram than during the present study. Due to such factors as increasing food costs, fuel costs, and increased ethanol production, corn has accrued in value, thereby requiring identification of economic alternatives.

In accordance with experimental objectives, initial BW, BCS, and BF were not different among treatments at the start of the study (Table 4). The final measurements for BW, BCS, and BF were collected 3 wk before expected calving date. Cows fed DDGS gained approximately 20 kg more ($P < 0.05$) BW than cows fed CN or HY. Efficiency of BW gain during late gestation was different ($P < 0.001$) among treatments, whereas efficiency of BW gain was least to greatest for HY, CN, and DDGS, respectively. There were no differences ($P \geq 0.28$) in BCS among cows fed HY, CN, or DDGS; however, cows fed DDGS also gained more ($P \leq 0.03$) BF than cows fed HY during late gestation.

The differences in efficiency of BW gain during late gestation indicate diets may have different energy values than initially formulated at the start of the trial. The amount of DDGS could have been fed at a lesser amount to achieve similar late gestation performance as cows fed HY or CN. Greater inclusion of DDGS (30% or greater) is typically associated with reduced DMI (Leupp et al., 2009; Vander Pol et al., 2009), which has been attributed to increasing fat and sulfur content of the diet. In the present study, intakes were intentionally limited to meet cow requirements and cows readily consumed their ration. Therefore, fat and sulfur intakes did not affect DMI, nor did it appear to affect cow performance. Few studies have been conducted investigating inclusion of 50% or greater of DDGS in beef cattle diets. Lactating beef cows fed DDGS at 55% inclusion had a smaller reduction in BW and BCS but had decreased milk production than cows fed dried corn gluten feed (Shike et al., 2009) and suggests energy partitioning may have been altered by feeding DDGS. Studies in feedlot cattle have reported a similar result where greater inclusion of DDGS in replacement of corn has been associated with more subcutaneous fat, less muscle, and reduced intramuscular fat (Reinhardt et al., 2007). The current study would suggest energy content of DDGS was greater than 110% of corn and DDGS partitioned more energy to subcutaneous fat deposition. However, the changes in BF were not detectable in visual BCS and, therefore, may not have practical significance. Additionally, differences in performance for CN and DDGS relative to calculated NRC (2000) values could be the result of their effects on for-

Table 4. Effects of prepartum energy source on gestation cow performance

	Treatment[1]				
Item	HY	CN	DDGS	SEM	*P*-value
Cows (pens)	49 (5)	44 (5)	44 (5)		
BW, kg					
Initial	608.5	605.7	605.6	4.42	0.77
Final	657.4[b]	654.2[b]	676.2[a]	5.77	0.04
Change	51.1[b]	47.1[b]	71.1[a]	6.89	0.05
ADG, kg/d	0.52[b]	0.48[b]	0.72[a]	0.070	0.05
G:F[2]	0.0401[a]	0.0643[b]	0.0990[c]	0.0100	<0.001
BCS[3]					
Initial	5.4	5.4	5.3	0.08	0.69
Final	5.1	5.4	5.6	0.34	0.33
Change	−0.30	0.06	0.27	0.310	0.28
Backfat,[4] cm					
Initial	0.46	0.54	0.50	0.071	0.57
Final	0.46	0.60	0.60	0.064	0.16
Change	0.003[b]	0.061[ab]	0.107[a]	0.0238	0.03
Gestation length, d	279.4	281.1	280.4	0.90	0.27
Calf birth wt, kg	38.8[b]	43.1[a]	41.3[a]	1.64	<0.001
Dystocia,[5] %	0.0	4.5	2.2	—	0.21

[a–c]Within a row, means without a common superscript differ at $P < 0.05$.
[1]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]G:F is calculated as ADG/DMI during late gestation.
[3]Scale of 1 (emaciated) to 9 (extremely obese); Wagner et al. (1988).
[4]Measured between the 12th and 13th rib by ultrasound.
[5]Analyzed in GENMOD (SAS Inst. Inc., Cary, NC), and SEM not estimated.

age digestibility. Previous research has reported diets containing greater concentrations of starch can have a negative associative effect on fiber digestibility, whereas highly digestible fiber sources such as DDGS can have positive associative effects on fiber digestibility (Firkins et al., 1984; Loy et al., 2007; Leupp et al., 2009).

The source of energy fed during late gestation did not affect (P = 0.30) plasma glucose concentrations pre- or postfeeding, whereas plasma insulin concentrations were greater (P = 0.001) 3 h postfeeding in cows fed DDGS vs. cows fed CN or HY (Figure 1). Our hypothesis was that feeding a diet with increased starch (CN) vs. fiber (HY or DDGS) would increase maternal glucose supply to the fetus due to greater propionate production during ruminal fermentation. Propionate stimulates release of insulin when it enters the portal vein and when it is converted to glucose by the liver, which would also stimulate insulin secretion (Harmon, 1992). However, the plasma insulin and glucose results from the present study did not follow this hypothesis. In gestating (Susin et al., 1995a) and lactating ewes (Susin et al., 1995b) limit-fed high-grain diets, glucose and insulin concentrations were greater when compared with high-forage diets at similar caloric intakes. Other studies in dairy cattle have reported an increase in plasma glucose and insulin concentrations when comparing high-grain vs. forage diets (Palmquist and Conrad, 1971; Dhiman et al., 1991). More recent studies in dairy cattle investigating prepartum diets with differing energy sources but similar ME intake have observed no difference in plasma glucose concentrations (Moorby et al., 2000; Smith et al., 2008); however, the differences in forage-to-concentrate ratios were smaller than for the present study.

Insulin secretion is also upregulated by elevated concentrations of AA (Harmon, 1992). Dried distillers grains has a greater CP content with a greater proportion of undegradable intake protein (**UIP**) than corn or hay (73, 55.3, and 36% UIP, respectively; NRC, 2000). Cows fed DDGS diets in the present study consumed 1477 g of CP/d, whereas cows fed HY and CN consumed at least 400 g less CP per d (Table 3); therefore, more AA would be expected to be absorbed postruminally in cows fed DDGS diets. In agreement with the present study, UIP supplementation in late-gestation was observed to increase plasma insulin concentrations with increasing UIP supplementation (Sletmoen-Olson et al., 2000). In addition, Luepp et al. (2009) reported DDGS, fed at 60% inclusion in growing cattle diets, resulted in greater propionate production when compared with a high corn control diet. Together, greater AA absorption postruminally and ruminal propionate production could have stimulated greater insulin secretion in cows fed DDGS vs. cows fed HY or CN.

Plasma NEFA concentrations tended to be greater (P = 0.09) for cows fed HY or DDGS vs. CN before feeding and tended to be greater (P = 0.08) for those fed HY at 3 h postfeeding compared with cows fed CN or DDGS (Figure 2a). Energy balance in cows is negatively correlated with plasma NEFA concentrations because NEFA can be a measure of mobilization of lipid stores (Lucy et al., 1991). Greater NEFA concentrations in cows fed HY could indicate mobilization of body fat from reserves for additional energy, and this corresponds with

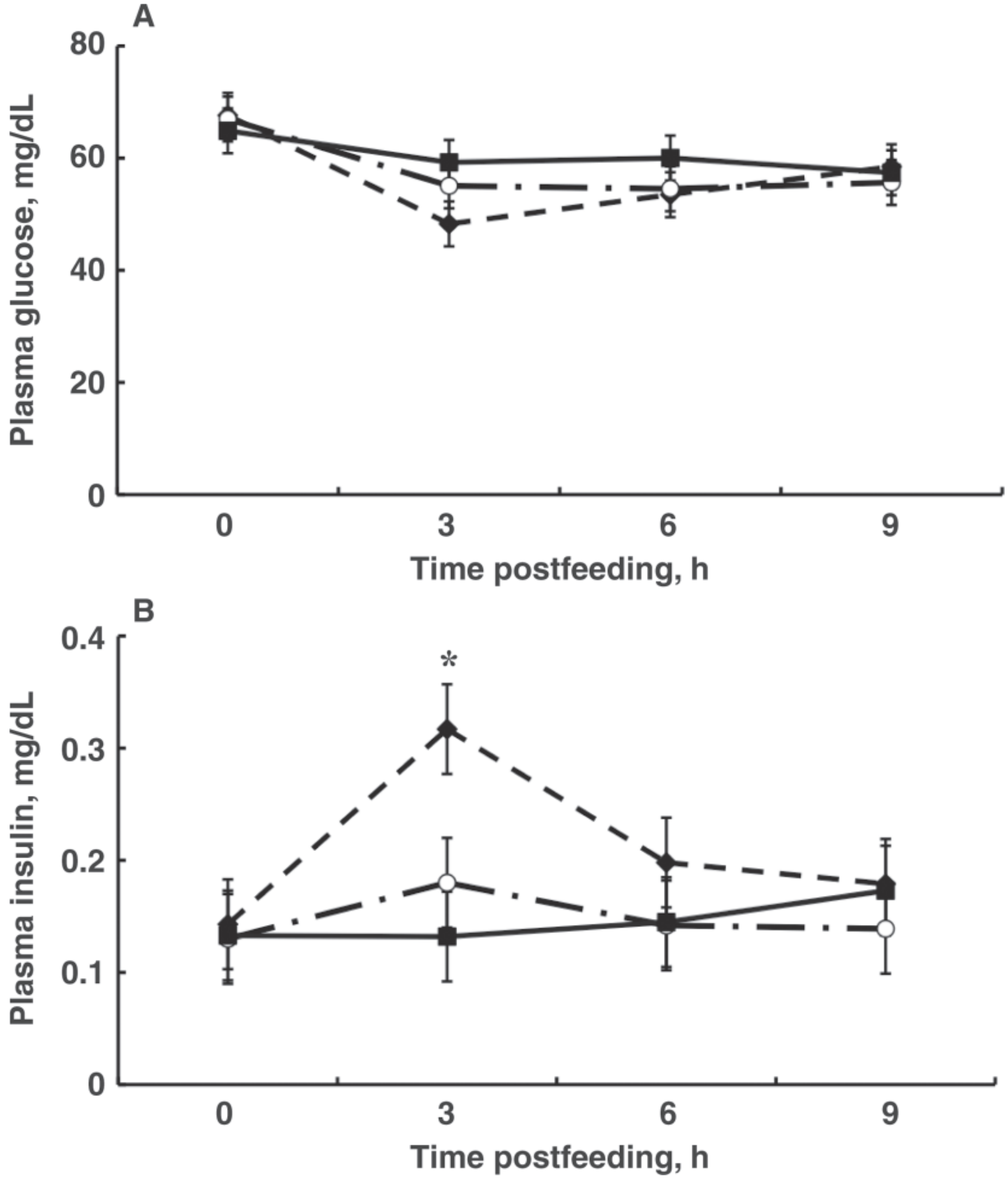

Figure 1. Plasma glucose (A) and insulin (B) concentrations before and after feeding at 210 d of gestation from cows fed ad libitum hay (HY; ■), limit-fed corn (CN; ○), and limit-fed dried distillers grains (DDGS; ◆) in late gestation. Least squares means ± SEM are presented (HY, n = 4; CN, n = 4; DDGS, n = 4). Overall treatment effect was not significant ($P = 0.30$ for glucose and $P = 0.64$ for insulin). *Indicates a significant difference among treatments within time postfeeding ($P < 0.05$).

the reduction in BCS and BF in cows fed HY during this period. In contrast, cows fed DDGS increased BF during late gestation as compared with those fed CN or HY. The cows fed DDGS had greater circulating NEFA concentrations before feeding than those fed CN, which may reflect the greater fat content of the diet. In lactating dairy cows fed dietary fat, NEFA was almost always increased (reviewed by Grummer and Carroll, 1991).

Plasma BUN concentration (Figure 2b) was greater ($P \leq 0.02$) in cows fed DDGS at 0 and 3 h postfeeding as compared with cows fed HY or CN, which is to be expected because CP content of the diet is positively related to plasma concentration of BUN (Preston et al., 1965; Hammond, 1983). Diets attempted to provide isoenergetic intake but not isonitrogeneous content; therefore, the CP intake of the DDGS diet was over 50% greater than HY or CN. In 70% concentrate beef diets similar to the present study, Leupp et al. (2009) reported inclusion of DDGS as a replacement for corn increased postruminal CP digestibility (55.6% for 0% inclusion and 67.3% for 60% inclusion of DDGS). Although CN diets had the least amount of CP fed per day, the amount of UIP was greater than in HY diets. Increasing UIP supplementation in gestating beef cow diets was associated with increases in plasma BUN concentration (Sletmoen-Olson et al., 2000). This could explain the greater plasma BUN concentration in cows fed CN than cows fed HY at 6 h postfeeding. In addition, cows fed HY had free access to hay; therefore, these differences could reflect timing of when HY was consumed compared with when CN and DDGS diets were consumed.

Progesterone is produced primarily by the corpus luteum during early to mid gestation, but by approximately 90 d of gestation the placenta becomes the predominant source of progesterone in the pregnant cow. Progesterone has been associated with placental weight and birth weight in beef heifers (Sullivan et al., 2009). Cows fed DDGS had greater (P = 0.02) circulating concentrations of progesterone at 210 d of gestation compared with cows fed CN or HY (Figure 3). Diets with greater protein content (0.4 vs. 1.4 kg of CP) fed to beef heifers in mid-gestation resulted in heavier birth weights, greater progesterone concentration before parturition, and greater placenta and cotyledonary weights (Sullivan et al., 2009). Additionally, high-protein diets have been associated with increased metabolic clearance of progesterone by the liver (Parr et al., 1993). Therefore, greater circulating progesterone concentrations in cow fed DDGS could be indicative of greater placenta weight or function, which could affect fetal growth.

Parturition

Calf birth weight was greater (P < 0.001) in calves from cows fed CN and DDGS than calves from cows fed HY (Table 4). Differences in birth weights among

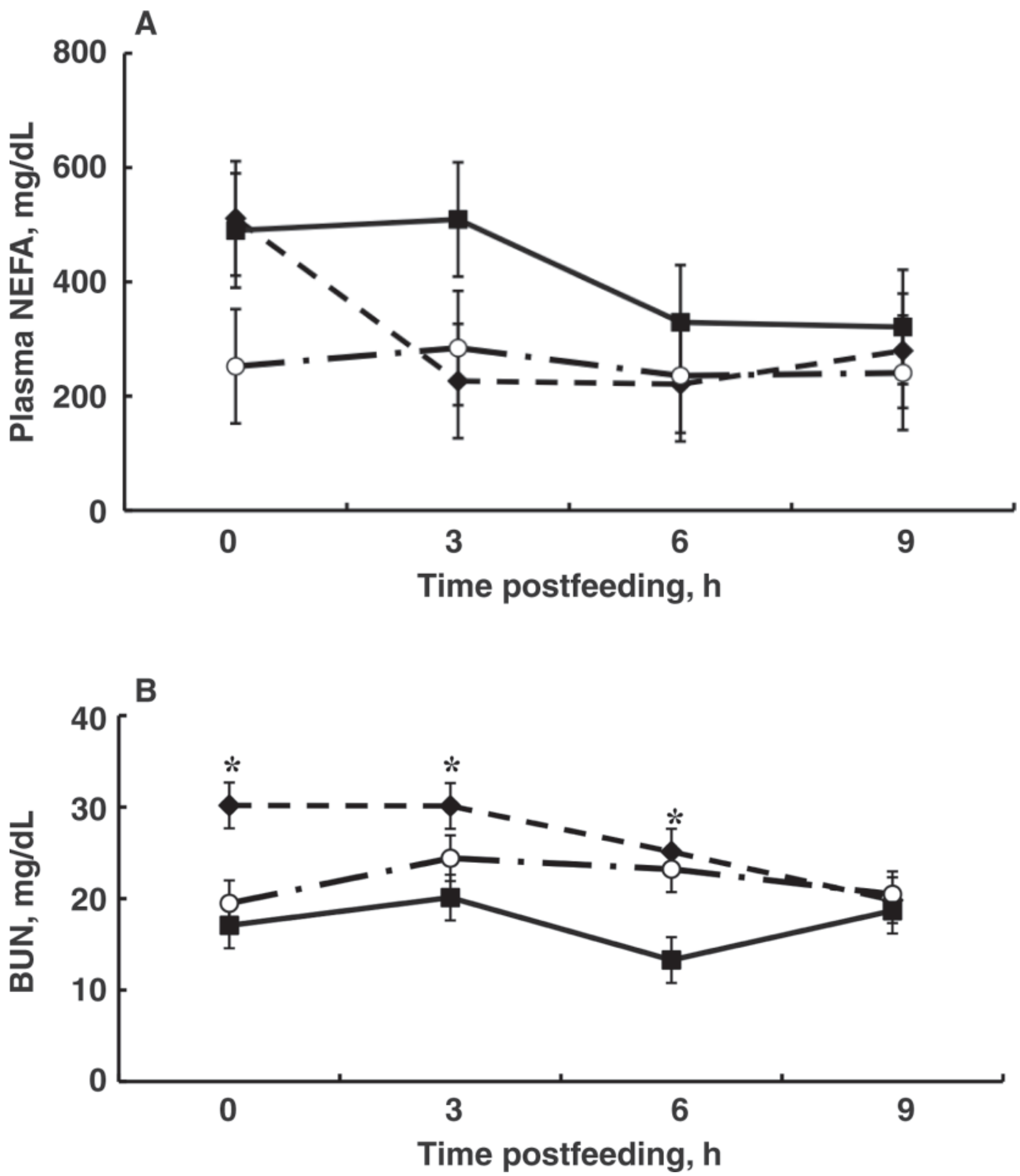

Figure 2. Plasma NEFA (A) and blood urea N (BUN; B) concentrations before and after feeding at 210 d of gestation from cows fed ad libitum hay (HY; ■), limit-fed corn (CN; ○), and limit-fed dried distillers grains (DDGS; ◆) in late gestation. Least squares means ± SEM are presented (HY, n = 4; CN, n = 4; DDGS, n = 4). Overall treatment effect was not significant (P = 0.49). *Indicates a significant difference among treatments within time postfeeding (P < 0.05).

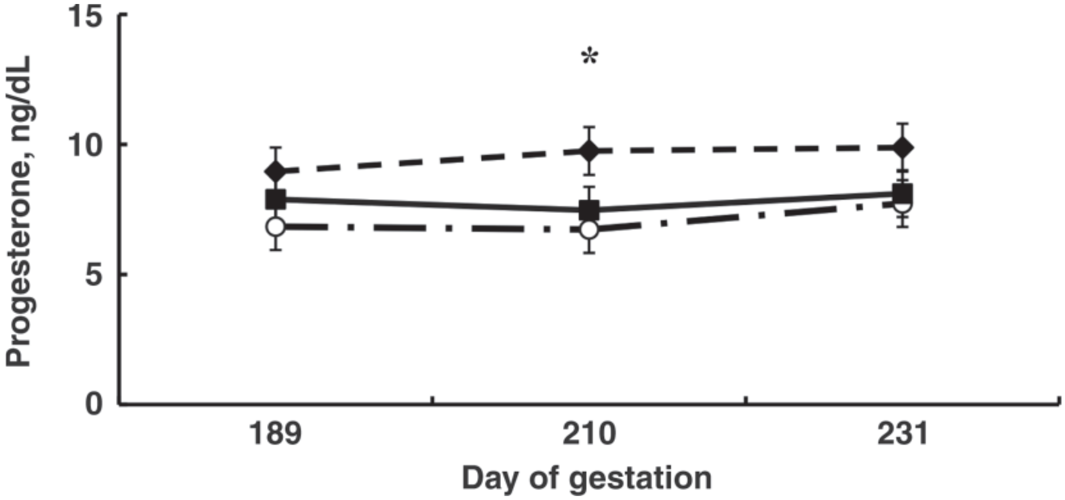

Figure 3. Plasma progesterone concentrations during late gestation from cows fed ad libitum hay (HY; ■), limit-fed corn (CN; ○), and limit-fed dried distillers grains (DDGS; ◆) in late gestation. Least squares means ± SEM are presented (HY, n = 4; CN, n = 4; DDGS, n = 4). Overall treatment effect was not significant ($P = 0.12$). *Indicates a significant difference among treatments within day of gestation ($P < 0.05$).

treatments were not associated with differences in gestation length ($P = 0.27$) or frequency of dystocia ($P = 0.21$) among treatments. Linear estimates have been conducted on the association of calf birth weight and dystocia with estimates for a 1.63 to 2.30% increase in dystocia for each 1 kg increase in birth weight (Hickson et al., 2006). Previous studies investigating limit-feeding corn in late-gestation diets have also reported heavier birth weights, but no increase in calving difficulty (Loerch, 1996; Schoonmaker et al., 2003). Increases in birth weight due to maternal dietary energy source do not appear to be associated with increased frequency of dystocia in mature cows.

In agreement with previous studies, calves from cows fed CN had heavier birth weights than calves from cows fed HY (Loerch, 1996; Schoonmaker et al., 2003). Glucose supply to the fetus is determined by maternal glucose concentration and placental blood flow, which can alter fetal growth (Baumann et al., 2002). High-starch diets can lead to increased propionate production and circulating glucose. In spite of this, in the present study maternal circulating glucose and insulin concentrations were not different between cows fed a starch vs. a fiber-based diet.

The heavier birth weights could be the effect of greater circulating maternal AA supply available to the placenta and fetus, suggested by greater BUN concentration and CP intake in cows fed DDGS than HY. Intake of CP was greater for cows fed HY than cows fed CN; however, these diets were similar in availability of MP (1,163 vs. 1,178 g of MP/d, respectively; NRC, 2000). In contrast, cows fed DDGS had both greater CP intake and supply of MP (1,350 g MP/d) than cows fed CN or DDGS. Therefore, excess protein would not be a plausible explanation for the differences in birth weight between calves from cows fed CN and HY, but could explain the differences between calves from cows fed DGGS and those from cows fed HY.

Previous studies have demonstrated CP intake can affect fetal growth in sheep (Ocak et al., 2005) and cattle (Sullivan et al., 2009). Amino acids are major substrates for fetal growth and development (Bell et al., 2005). In addition, abundance of arginine and associated AA increases amount of NO synthase and, thus, increases NO production, which is a vasorelaxing factor and plays a key role in regulating blood flow (Bird et al., 2000). In contrast, supplemental protein during late gestation in beef cows grazing native range did not affect birth weight (Stalker et al., 2006; Larson et al., 2009), but differences in CP intake were smaller than the present study. Limited data have been reported on effects of feeding excess protein in gestating beef cattle diets at concentrations similar to the present study because the practice is generally expensive and uncommon. Increasing availability of DDGS and use of DDGS as an energy source may warrant more research of excess protein effects in gestation diets of beef cattle. In the present study, excess CP intake with the DDGS diet could have affected maternal energy metabolism, protein metabolism, or both, and any resultant effects on the fetus are not known.

Energy status of the dam is critical to fetal growth by influencing nutrient uptake by the gravid uterus, which is greatest during the last third of gestation (Ferrell et al., 1976). Late-gestation maternal energy restriction, which results in reduced BW and BCS, is associated with decreased birth weight (Corah et al., 1975; Freetly et al., 2000), but when cows are fed to maintain BW and BCS with adequate energy in late gestation, birth weight was not affected independent of previous plane of nutrition during mid gestation (Morrison et al., 1999; Freetly et al., 2000). In contrast, cows in the current study fed CN or HY maintained similar BW and BCS in late gestation, but calf birth weight was altered, indicating maternal dietary energy source may explain the

Table 5. Effects of prepartum energy source on postpartum cow performance, milk production, and milk characteristics

	Treatment[1]				
Item	HY	CN	DDGS	SEM	*P*-value
Cows (pens)	46 (5)	40 (5)	41 (5)		
Early lactation[2]					
BW, kg	552.4	573.9	582.1	33.33	0.07
BCS[3]	4.8[b]	5.1[ab]	5.4[a]	0.41	0.048
Backfat,[4] cm	0.83[b]	1.00[a]	1.18[a]	0.178	<0.001
Milk production,[5] kg/d	10.6	11.4	11.6	1.23	0.85
Fat, g/d	225	200	228	50.1	0.97
CP, g/d	315	350	343	42.7	0.81
Lactose, g/d	576	531	578	68.0	0.84
Mid lactation[2]					
BW, kg	597.6	610.2	621.0	33.33	0.48
BCS	5.6	5.7	5.9	0.41	0.40
Backfat, cm	0.84	0.98	1.04	0.178	0.08
Milk production,[6] kg/d	10.0	10.8	11.2	1.75	0.74
Fat, g/d	290	332	378	44.3	0.42
CP, g/d	292	316	330	37.6	0.75
Lactose, g/d	514	488	536	60.5	0.84
Late lactation[2]					
BW, kg	597.3	610.2	611.1	33.33	0.61
BCS	5.3	5.6	5.8	0.41	0.09
Backfat, cm	0.90	0.95	1.03	0.178	0.33
Milk production,[6] kg/d	7.1	8.9	8.7	1.75	0.51
Fat, g/d	210	256	194	44.3	0.49
CP, g/d	228	288	270	37.6	0.49
Lactose, g/d	444	334	420	60.5	0.39

[a,b]Within a row, means without a common superscript differ at $P < 0.05$.
[1]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]Early, mid, and late lactation = 31, 100, and 170 d postpartum, respectively.
[3]Scale of 1 (emaciated) to 9 (extremely obese); Wagner et al. (1988).
[4]Measured between 12th and 13th rib by ultrasound.
[5]Milk production measured for 6-h × 4.
[6]Milk production measured for 12-h × 2.

difference in birth weight, rather than energy status of the dam.

Limit-feeding high-concentrate diets has been shown to decrease maintenance requirements in growing lambs by reducing visceral organ mass (Fluharty and McClure, 1997; Fluharty et al., 1999). Additionally, research by McLeod and Baldwin (2000) suggests gut energy expenditure is more related to changes in mass relative to ME intake than in changes of viscera metabolism. Therefore, limit-feeding corn to gestating cows may allow more energy to be partitioned to the fetus instead of maintaining maternal tissues. This reduction in maintenance requirements could partially explain greater fetal growth in calves from dams fed CN or DDGS. More research is warranted to determine metabolic changes in the dam due to dietary energy source that affect nutrient supply to the fetus, especially when feeding high-starch diets.

Postpartum Cow Measurements

No prepartum dam energy source × day postpartum interactions were detected ($P \geq 0.15$) for any postpartum variables, and means for treatments are presented in Table 5. Prepartum energy source did not affect postpartum estimated milk production ($P \geq 0.41$) or nutrient content. Previous studies have reported energy restriction (70%) in late gestation resulted in reduced milk production (Corah et al., 1975). In addition, ewes fed diets with increased protein prepartum had decreased colostrum quality and milk production (Ocak et al., 2005), whereas supplemental protein had no effect on milk production and composition in beef cattle (Alexander et al., 2002; Banta et al., 2006). The present study would indicate that when cows are fed adequately in late gestation, energy source does not alter subsequent milk production.

No effects were detected ($P \geq 0.66$) in postpartum cow reproduction performance due to cow prepartum energy source (Table 6). The impacts of prepartum nutrition on postpartum reproduction performance in beef cattle have not been well elucidated, especially in regard to energy source. Conflicting results have been reported regarding effects of prepartum fat and protein supplementation on postpartum reproduction in beef cows. Bellows et al. (2001) reported increased pregnancy rates with prepartum fat supplementation, whereas other studies have reported no difference in duration

Table 6. Effects of prepartum energy source on reproductive performance

Item[1]	Treatment[2] HY	CN	DDGS	*P*-value
Cows (pens)	29 (4)	24 (4)	26 (4)	
Cycling at 50 d postpartum, %	21	33	35	0.66
1st-service AI pregnancy rate, %	55	50	58	0.85
2nd-service AI conception rate, %	76	75	81	0.86
Overall pregnancy rate, %	91	92	88	0.77

[1]Analyzed with GENMOD (SAS Inst. Inc., Cary, NC) and SEM not estimated.
[2]HY = hay; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

of postpartum anestrus or first-service AI conception rates with prepartum fat supplementation (Alexander et al., 2002; Small et al., 2004). Supplementing protein to cows on native range in late gestation did not affect postpartum pregnancy rates (Stalker et al., 2006; Larson et al., 2009), whereas supplemental UIP during late gestation improved overall pregnancy rates in beef heifers (Engel et al., 2008).

Morrison et al. (1999) reported prepartum changes in body energy reserves did not influence reproductive performance as long as cows calved with moderate BCS. Cows in the present study were in adequate body condition before breeding (BCS = 5.3 ± 0.4), which was similar to their body condition 3 wk before parturition. This indicates the cows were in an adequate plane of nutrition; therefore, reproductive performance was not influenced by prepartum energy source.

In conclusion, prepartum dietary energy source, when fed at or above daily requirements, was not associated with detrimental effects on pre- or postpartum cow performance. However, DDGS as a prepartum dietary energy source can reduce daily feed costs during gestation. Differences in partitioning of energy and changes in plasma metabolites could indicate differences in maternal metabolism in late gestation due to maternal dietary energy source. These changes could subsequently affect fetal growth, as evidenced by heavier birth weights in progeny from cows fed DDGS or CN during late gestation vs. those fed HY. More research is warranted to determine effects of various energy sources fed to cows during late gestation on the maternal nutrient supply to the fetus.

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