Winter-feeding systems for gestating sheep I. Effects on pre- and postpartum ewe performance and lamb progeny preweaning performance

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Winter-feeding systems for gestating sheep I. Effects on pre- and postpartum ewe performance and lamb progeny preweaning performance[1]

A. E. Radunz,[2] F. L. Fluharty, H. N. Zerby, and S. C. Loerch[3]

Department of Animal Sciences, The Ohio State University, Wooster 44691

ABSTRACT: Mature pregnant crossbred ewes (n = 90) were used in a randomized complete block design and assigned to 1 of 3 winter-feeding systems differing in primary feed source: haylage (HL), limit-fed corn (CN), or limit-fed dried distillers grains (DDGS). Effects of these winter-feeding strategies on ewe and lamb performance were determined. Diets were formulated to meet or exceed NRC (1985) nutrient requirements during gestation and were fed from about d 60 of gestation until parturition. All ewes were fed a common diet postpartum. Every 2 wk during gestation, BW and BCS were collected and diets were adjusted to maintain similar BW gain for ewes fed CN and DDGS vs. HL. At 80 and 122 d of gestation, jugular blood samples were collected at 0, 3, 6, and 9 h postfeeding to measure plasma glucose, insulin, NEFA, and blood urea nitrogen concentrations. At birth, 6 lambs per treatment were killed to measure body composition. At 28 ± 2 d postpartum, milk yield was measured. Lambs were weaned at 61 ± 4 d of age. During mid gestation (d 60 to 115), BW gain of ewes was similar among treatments; however, at d 115 of gestation ewes fed HL had a smaller ($P = 0.04$) BCS than ewes fed DDGS or CN. Plasma glucose concentrations were greater ($P \leq 0.004$) in ewes fed CN than in those fed HL or DDGS just before feeding on d 80 and 122 of gestation, whereas ewes fed DDGS vs. CN or HL had greater ($P \leq 0.04$) plasma insulin concentrations at 3 h postfeeding. At parturition, ewe BW was greatest for DDGS, least for HL, and intermediate for CN ($P \leq 0.003$). Ewes fed CN and DDGS had greater BCS at parturition than those fed HL, but by weaning, ewes fed DDGS had greater BCS ($P \leq 0.05$) than those fed CN or HL. Birth BW tended ($P = 0.09$) to be heavier for lambs from ewes fed CN and DDGS than from those fed HL prepartum, but there was no difference ($P = 0.19$) due to ewe gestation diet on lamb BW at weaning. At birth, lamb muscle, bone, organ, and fat measures were not affected ($P > 0.13$) by treatment. Ewe milk production and lamb preweaning ADG were also similar ($P > 0.44$) among treatments. Prepartum dam winter feed source did not have detrimental effects on pre- or postpartum ewe performance, but altered prepartum maternal nutrient supply during gestation, which affected birth weight but not preweaning growth or mortality.

Key words: fetal programming, maternal nutrition, prepartum diet, sheep

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INTRODUCTION

Limit-feeding corn-based diets to ewes during gestation (Susin et al., 1995b) did not negatively affect ewe performance, and limit-fed dried distillers grains (**DDGS**) during gestation did not adversely affect cow performance (Radunz et al., 2010). With increased availability of DDGS this feedstuff has become an economical alternative energy source for ruminants; however, few studies have investigated its effects as a primary energy source in sheep gestation diets.

Maternal nutrient intake can affect fetal growth depending on stage of gestation (Fahey et al., 2005; Gardner et al., 2005) and plane of nutrition (Vonnahme et al., 2003; Ford et al., 2007). High-starch diets increase propionate production, and propionate is converted to glucose in the liver and stimulates release of insulin (Harmon, 1992), thereby potentially affecting nutrient supply to the gravid uterus. Previous studies in cattle during late gestation (Loerch, 1996; Radunz et al., 2010) have provided evidence that winter-feeding systems, which differ in primary energy source, can alter

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[2]Current address: University of Wisconsin, Department of Animal Science, 1675 Observatory Drive, Madison, WI 53706.

[3]Corresponding author: loerch.1@osu.edu

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subsequent birth weight of progeny, thereby suggesting maternal dietary energy source may affect fetal growth. To our knowledge, effects on lamb pre- and postnatal growth of these alternative primary feed sources fed to ewes during mid and late gestation have not been investigated.

Therefore, the objectives of this experiment were to determine effects of winter-feeding systems based on corn or DDGS as an alternative to forage during mid to late gestation on ewe prepartum performance, ewe prepartum blood metabolites and hormones, postpartum ewe milk production, and preweaning lamb performance. We hypothesize that these gestation diets will not affect ewe gestation performance but will result in distinctly different blood metabolites and hormone concentrations. Effects on performance, glucose tolerance, and carcass composition of progeny are reported in a companion paper (Radunz et al., 2011).

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 crossbred (Hampshire × Dorset) ewes (n = 90; BW = 83.1 ± 5.3 kg) were used in a randomized complete block design to determine the effects of mid- and late-gestation diets on ewe prepartum performance, ewe postpartum performance, and lamb progeny preweaning performance. The study was conducted at the Sheep Center of the Ohio Research and Development Center, Wooster.

In September 2008, ewes were exposed to rams for 28 d. Ewes were divided into 5 pastures, and each pasture contained 1 ram. Crossbred ewes were grouped by breed composition for breeding and assigned to a purebred Hampshire or Dorset ram, so that progeny would have similar breed percentages. Pregnancy diagnosis and fetal number were determined by ultrasound 41 d after rams were introduced to ewes. Ewes not confirmed pregnant by first ultrasound were diagnosed again 21 d later. At approximately 80 d of gestation, ewes were blocked (n = 3; heavy, medium, and light) by BW (83.1 ± 5.3 kg); within block, ewes were stratified by BCS (2.9 ± 0.25), age (2.4 ± 0.41 yr), fetal number as determined by ultrasound (1.7 ± 0.09 fetuses), and sire (n = 5). Ewes were housed in 18 pens. Ewes in each BW block were assigned to 6 pens with 5 ewes per pen. The 3 dietary treatments were randomly allotted to the 6 pens of ewes within each BW block, resulting in 2 pens per treatment within each block and a total of 6 pens per treatment. Pens (1.5 × 4.9 m) were on expanded metal floors, and each ewe had access to at least 0.1 m of feed bunk space.

Dietary treatments were 1 of 3 winter-feeding systems, which differed in primary feed source (Table 1): ad libitum haylage (fiber; **HL**), limit-fed corn (starch; **CN**), and limit-fed corn dried distillers grains (fiber, fat, and protein; **DDGS**). Diets were formulated to meet or exceed NRC (1985) nutrient requirements for mid gestation (d 81 to 115) at 2.8 ME of Mcal/d and late gestation (d 115 to parturition) at 4.0 ME of Mcal/d. Intake of CN and DDGS were limited to achieve isoenergetic intake among dietary treatments relative to an ad libitum intake of haylage. Haylage used for the trials was first cutting alfalfa harvested in early June and contained 13.7% CP (DM basis). The DDGS used was obtained from production on 1 d from a single ethanol plant in Ohio. Diets were fed once daily and initially were formulated to meet mid-gestation nutrient requirements for 80 kg of BW ewes (light BW block) and 90 kg of BW ewes for medium and heavy BW blocks. At the start of the experiment, a 4-d adjustment period in which haylage was gradually decreased was used to acclimate ewes to CN and DDGS diets. Haylage intake was ad libitum for HL during mid gestation, whereas during late-gestation haylage intake was set to provide 1.30 kg of haylage for all pens and 0.40 kg of corn gluten feed was supplemented for pens in the light BW block; and 0.50 kg of corn gluten feed for those in the medium and heavy BW block (DM basis). Limit-fed CN and DDGS diets were fed once daily and initially formulated in mid gestation to provide 3.2 Mcal of ME per kg for 80 kg of BW ewe (light BW block) and 3.0 ME per kg for 90 kg of BW ewe (medium and heavy BW blocks). Intakes of the DDGS and CN diets were adjusted if needed to maintain similar BW gain of ewes receiving these diets with ewes fed HL during mid gestation. Feed intake was increased by 1.36% for CN and DDGS during late gestation, so that ME intake was similar to HL. Ewes fed HL diets had ad libitum access to trace mineral salt blocks. Haylage was provided to CN and DDGS diets at 21.2% of diet on DM basis to minimize ruminal health problems. In CN and DDGS diets, concentrations for CP (CN only), vitamins, and minerals were increased in the supplement to account for restriction of DMI and to meet or exceed NRC (1985) recommendations. Lasalosid (Alpharma Inc., Bridgewater, NJ) was added to minimize potential ruminal health problems associated with limit-feeding concentrate-based diets. Intake of CP was not balanced among treatments. Because DDGS has an increased concentration of CP, this feeding system exceeded the requirements of the gestating ewe. The addition of protein to CN and HL diets to make them equal to the DDGS diet would not be economically practical for winter-feeding systems for sheep.

During mid gestation, intake was recorded daily and diet samples were collected every 14 d and composited for nutrient analysis. Every 14 d during gestation, BW and BCS (1 = emaciated; 5 = obese; American Sheep

Table 1. Ingredient and nutrient content of mid and late-gestation ewe diets[1]

Item	HL[2]		CN	DDGS
	Mid gestation	Late gestation		
Ingredient, %, DM basis				
Haylage	100.00	76.50	21.20	21.20
Whole shelled corn	—	—	61.00	—
DDGS	—	—	—	75.901
Corn gluten feed	—	23.50	—	—
Ground corn	—	—	2.70	—
Soybean meal	—	—	12.06	—
Limestone	—	—	1.35	1.83
Urea	—	—	0.39	—
Trace mineral salt[3]	—	—	0.62	0.53
Animal and vegetable fat	—	—	0.19	0.18
Potassium chloride	—	—	0.26	0.24
Selenium, 201 mg/kg	—	—	0.064	0.060
Vitamin A, 30,000 IU/g	—	—	0.007	0.007
Vitamin D, 3,000 IU/g	—	—	0.007	0.007
Vitamin E, 44 IU/g	—	—	0.028	0.029
Lasalosid[4]	—	—	0.016	0.016
Analyzed nutrient content, %				
CP	13.73	15.73	14.31	25.28
NDF	53.51	49.34	18.77	30.70
ADF	38.69	30.86	7.24	12.40
Ether extract	3.24	3.48	4.48	8.36
Ca	1.14	1.10	0.82	0.93
P	0.27	0.57	0.28	0.68
S	0.23	0.28	0.15	0.68

[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]Ewes were provided ad libitum access to trace mineral block.
[3]Contained 98% NaCl, 0.35% Zn, 0.28% Mn, 0.175% Fe, 0.035% Cu, 0.007% I, and 0.007% Co.
[4]Provided 34 mg of lasalosid (Alpharma Inc., Bridgewater, NJ)/kg of dietary DM.

Industry Association, 1997) were collected; BCS was determined by palpation by the same person throughout the experiment. Ewes were sheared at approximately 115 d of gestation, combined into 2 pens per treatment (from the original 6 pens per treatment during mid gestation), housed in a barn with solid-floor pens, and fed their respective late-gestation diets until parturition. Ewes were removed from their expanded metal floor pens during this time to reduce risk of lameness and udder injuries and maintained on treatments until parturition. Ewe intake during the lambing period is not presented because ewe number per pen changed throughout the day as ewes lambed and were removed from the pens. Amount of feed offered per pen was adjusted daily to account for ewes removed after parturition. However, measurement of actual intake per ewe was problematic because some ewes in parturition consumed feed the day of lambing and some did not.

All feed samples were ground using a Wiley mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA) and analyzed for DM (100°C), NDF (using sodium sulfite and heat-stable α-amalyse; 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).

Postpartum Management

At parturition, ewe and offspring were housed in individual pens for 24 to 48 h postpartum. Lamb birth BW and vigor score (1 = weak, lethargic, unable to nurse; 2 = weak lamb, nursed with assistance; 3 = average vigor, nursed without assistance; 4 = above average vigor; 5 = vigorous lamb, nursed immediately) were recorded, and ewe BW and BCS were measured within 24 h after parturition. One same-sex twin lamb from each original mid-gestation dam pen (n = 18; 6 lambs/treatment) was randomly selected and killed 24 h after birth. Sex of these lambs was balanced among treatments with 3 males and 3 females per treatment. Lambs were induced into a surgical plane of anesthesia by intravenous injection of sodium pentobarbital (20 mg/kg of BW) followed by exsanguination of a jugular vein and carotid arteries. The hide was removed from the carcass, and the LM, semitendinosus muscle, and internal organs (kidney, lung, heart, and liver) were removed and weighed. The left leg was removed anterior to the aitchbone and distal to the tibia and weighed. The femur was removed, and femur length and weight were recorded. Bones removed from the remainder of the leg, and the remaining tissue was homogenized with a blender and frozen. A subsample of homogenized leg

muscle was collected, lyophilized, and analyzed for fat content by ether extract.

Experimental treatments were applied only during gestation; therefore, ewes and their progeny from all 3 gestation treatments were managed the same across treatments after lambing. Ewes and lambs representing all treatments were gathered into a total of 6 pens as the lambing season progressed. One-half of pens were assigned ewes rearing singles, and one-half were for ewes rearing twins. Ewes from all 3 gestation treatments were fed a common diet composed of corn silage, alfalfa haylage, and DDGS to meet requirements (NRC, 1985) during lactation. Before 2 wk of age, the lambs were tail-docked and males were castrated. At 3 wk of age, lambs were provided ad libitum access to a pelleted creep feed (consisting primarily of corn, alfalfa meal, and soybean meal) as described by Susin et al. (1995a), which was provided in a self-feeder in a creep area of the pen. Three weeks before weaning and at weaning (61 ± 4 d of age), lambs were vaccinated for *Clostridium chauvoei*, *Clostridium septicum*, *Clostridium novyi* Type B, *Clostridium hemolyticum*, *Clostridium tetani*, and *Clostridium perfringens* Types C and D (Schering-Plough, Kenilworth, NJ).

To assess potential gestation diet effects on subsequent milk production at mid lactation (28 d postpartum), ewes were separated from their lambs, given an injection of oxytocin (1 mL; 10 IU) into a jugular vein, and milked out by hand 28 ± 2 d after lambing. Ewes were then housed together for a 3-h period in 1 pen separate from their lambs, at which time lamb BW was collected. After the 3-h separation, ewes were given an injection of oxytocin, milked out by hand, and milk was weighed to determine 3-h milk yield. A subsample of milk was collected and treated with bronopol and natamycin as preservatives and held at 4°C until analyzed for CP, crude fat, lactose, and milk urea N composition by a commercial laboratory as described by Beckman and Weiss (2005). Ewe BW and BCS were collected before ewes were returned to their lactation pen.

Blood Collection and Analysis

At 80 and 122 d of gestation a subset of ewes (n = 2) was randomly selected from each of the 18 mid-gestation pens. Jugular blood samples (10 mL) were collected from each ewe at 0, 3, 6, and 9 h postfeeding. Blood was collected in 2 Vacutainer (Becton, Dickinson and Co., Franklin Lakes, NJ) collection tubes with 1 containing EDTA, and 1 containing 15 mg of sodium fluoride and 12 mg of potassium oxalate 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 −20°C for subsequent glucose analysis. Concentrations of insulin were measured using RIA as described previously (Benson and Reynolds, 2001; intraassay CV was 8.2%). A colorimetric assay was 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).

Statistical Analysis

Twenty-one ewes were removed from the trial due to various reasons, and data from these ewes and lambs were removed from statistical analysis. The GENMOD procedure (SAS Inst. Inc., Cary, NC) was used to analyze binominal data (pregnancy toxemia and mortality rates). The PROC MIXED procedure of SAS was used to analyze the remaining variables. Experimental unit was pen (n = 18) for ewe and lamb measurements. Block was included as a random variable in all analyses. For lamb variables, sex, age, sire, and type of birth were included as covariates when they represented a significant ($P \leq 0.10$) source of variation. When treatment was significant ($P \leq 0.10$), means were separated by PDIFF.

Repeated measures procedures were used for prepartum plasma measures, ewe BW, and ewe BCS. For each analyzed variable, 5 covariance structures were compared: compound symmetric, autoregressive order 1, heterogeneous autoregressive order 1, 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 feed source, time postfeeding (h), and the 2-way interaction were used in the model. Simple effects within time postfeeding (h), were generated by SLICE function of SAS. For ewe BW and BCS variables, maternal dietary feed source, time relative to parturition (d), and the 2-way interaction were tested. Simple effects within time relative to parturition (d) were generated by the SLICE function of SAS.

RESULTS AND DISCUSSION

Pre- and Postpartum Ewe Performance

At the beginning of the trial, intakes were calculated and diets were formulated to provide isoenergetic intake and to meet ewe energy requirements during mid to late gestation (NRC, 1985). By design, DMI among treatments was different to meet this objective. Dry matter intakes were reduced for ewes fed CN and DDGS during mid gestation to achieve similar BW gains as those of ewes fed HL. Therefore, from d 80 of gestation to parturition, calculated ME intake (NRC, 1985) was less for ewes fed DDGS and CN than ewes fed HL (Table 2). These diets were not intended to be isonitrogeneous because of the greater CP content of DDGS (27.3% on DM basis). Crude protein intake of ewes fed CN and HL was less than that for ewes fed DDGS. The supplement for the CN diet was initially formulated to meet CP

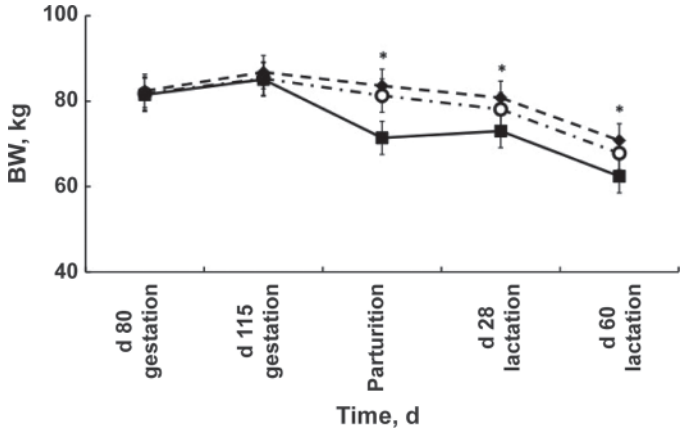

Figure 1. Pre- and postpartum BW in ewes fed haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within day ($P < 0.05$).

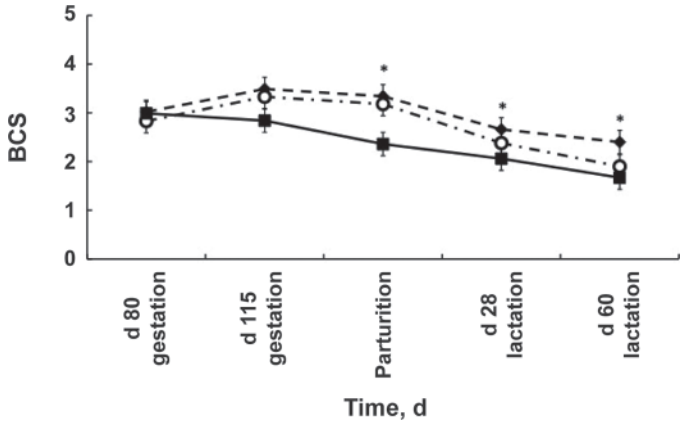

Figure 2. Pre- and postpartum BCS in ewes fed haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within day ($P < 0.05$).

intake requirements of the ewe (139 g/d; NRC, 1985). The HL and DDGS diets exceeded these requirements. Our objective was to determine potential consequences on ewes and lambs of utilizing feedstuffs in gestation diets that are commonly available at a reduced cost to meet nutrient requirements. In accordance with our objectives, ewes fed DDGS diets had less feed cost per day, which was \$0.011 to \$0.012 less per day than ewes fed CN and HL diets. Although excess protein may affect ewes and their progeny, it would be irrational from an economic perspective to feed supplemental protein to CN- and HL-fed ewes to make N intake equal to that of ewes fed DDGS. However, further research examining effects of excess protein and fat on pre- and postnatal fetal development may be warranted.

In accordance with the experimental objective, initial BW was similar ($P = 0.63$) among treatments during mid gestation (Figure 1). Ewes gained BW during mid gestation, but no difference was detected in BW gain among treatments ($P = 0.86$) during mid gestation. At parturition, ewe BW was greatest ($P < 0.001$) for ewes fed DDGS, least for those fed HL, and intermediate for those fed CN. These differences in BW among treatments were maintained through lactation until weaning (Figure 1).

At 115 d of gestation, BCS was greater ($P = 0.04$) in ewes fed CN and DDGS than for those fed HL (Figure 2). This was before ewe intake was increased to meet late-gestation energy requirements. The change in BCS during mid gestation was small, but suggested that ewes fed HL were in slight negative energy balance and were mobilizing body fat. Body condition score was still less ($P = 0.003$) for ewes fed HL than CN and DDGS at parturition. Ewes continued to lose body condition during lactation, and at mid-lactation, ewes previously fed HL during gestation still had smaller ($P = 0.04$) BCS than those fed DDGS during gestation. Ewes fed CN during gestation were intermediate to these 2 groups. At weaning, ewes previously fed DDGS had greater BCS than ewes previously fed CN or HL ($P < 0.01$). Feeding DDGS prepartum appeared to allow ewes to maintain a greater BCS during lactation compared with feeding CN or HL.

At similar caloric intakes in late gestation, excess protein has been shown to increase BW gain (Ocak et al., 2005; Engel et al., 2008), which could be due to greater N retention by maternal tissues as observed by McNeill et al. (1997). Fat supplementation in late-gestation diets was reported to have no effect on BW gain or BCS in ewes during late gestation, when fed at isocaloric intakes (Lammoglia et al., 1999; Encinias et al., 2004). These studies would indicate greater BW of ewes fed DDGS at parturition may be due to greater N retention of tissue. Glucogenic (starch-based) vs. lipogenic (fiber-based) energy sources have been shown in dairy cows to improve energy balance and reduce mobilization of body fat during early lactation when energy needs of a cow are greatest (Van Knegsel et al.,

Table 2. Nutrient intake during mid gestation (d 80 to 115)

	Treatment[1]		
Item	HL	CN	DDGS
DMI, kg/d	1.24	0.84	0.79
Haylage	1.24	0.09	0.08
Corn	—	0.58	—
DDGS	—	—	0.55
Supplement	—	0.18	0.17
ME intake,[2] Mcal/d	2.64	2.47	2.51
CP intake, g/d	170	121	201
Crude fat intake, g/d	40.0	37.8	66.4
Daily feed costs,[3] \$/ewe	0.038	0.037	0.026

[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

[2]Calculated from NRC (1985) values except for DDGS, which was assumed to be 110% the value of corn (Stock et al., 2000).

[3]Calculated with the following prices on a DM basis: corn = \$0.031/kg; haylage = \$0.031/kg; DDGS = \$0.029/kg; CN supplement = \$0.091/kg; and DDGS supplement = \$0.045/kg.

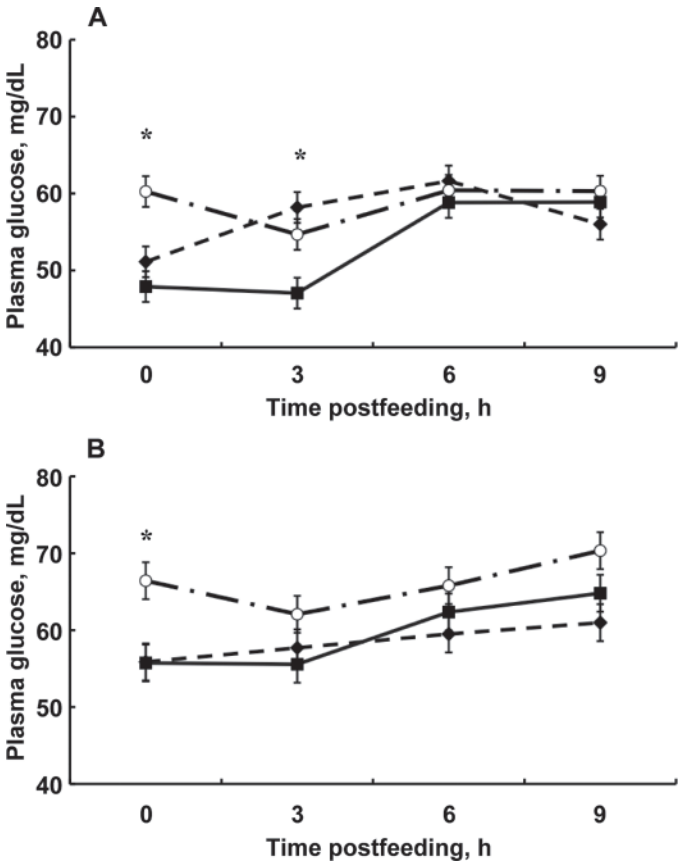

Figure 3. Plasma glucose concentration before and after feeding at approximately 80 (A) and 122 (B) d of gestation from ewes fed haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within hour ($P < 0.05$).

2008). Therefore, ewes fed CN and DDGS appear to have been in a greater positive energy balance at parturition than those fed HL as indicated by their greater BW and BCS.

Prepartum Ewe Plasma Measurements

On d 80 and 122 of gestation, plasma glucose concentrations were greater ($P \leq 0.003$) before feeding for ewes fed CN than for those fed DDGS or HL (Figure 3). In mid gestation (d 80), 3 h after feeding, glucose concentration was less ($P = 0.002$) for ewes fed HL than for those fed CN or DDGS, but no difference was detected ($P = 0.17$) postfeeding among treatments later in gestation (d 122). Greater prefeeding glucose concentrations were also reported in lactating (Susin et al., 1995a) and gestating (Susin et al., 1995b) sheep fed high-corn vs. forage diets. A greater plane of nutrition has also been associated with greater circulating glucose concentrations in gestating ewes (Luther et al., 2007; Muhlhausler et al., 2007). Greater glucose concentrations were likely due to increased ruminal production of propionate from starch, which then may be converted to glucose by the liver (Harmon, 1992).

Ewes fed DDGS had greater ($P \leq 0.05$) insulin concentrations at 3 h postfeeding on both d 80 and 122 of gestation and at 6 h postfeeding on d 122 of gestation (Figure 4) compared with those fed HL or CN. A similar response was reported in cows limit-fed DDGS in late-gestation diets (Radunz et al., 2010). Increased insulin concentration could be the result of AA or propionate stimulation of insulin secretion (Harmon, 1992). Supplementation of RUP has been associated with greater plasma insulin concentration in gestating cows (Sletmoen-Olson et al., 2000). Additionally, greater propionate production has been reported with 60% inclusion of DDGS in replacement of corn in beef cattle rations (Leupp et al., 2009). In the current study, ewes fed DDGS diets had a greater CP intake with a greater proportion of RUP [55 vs. 40% for the CN diet and 9% for the HL diet; calculated using NRC (2000) tabular values]. These differences in calculated RUP could have affected the amount of AA absorbed postruminally. Based on previous studies, greater circulating insulin concentrations after feeding would have been expected for ewes fed corn- vs. forage-based diets, and this has been associated with greater glucose concentrations prefeeding (Susin et al., 1995a,b). Despite greater glucose concentrations 3 h postfeeding for ewes fed CN vs. those fed HL, no differences ($P \geq 0.42$) in plasma insulin concentrations were observed. Similarly, previous studies in lactating dairy cows (Van Knegsel et al., 2008) and late-gestation beef cows (Radunz et al., 2010) fed isocaloric diets with starch vs. fiber-based diets have not reported alterations in circulating insulin associated with starch vs. fiber energy sources.

Prefeeding, BUN concentration was greatest ($P < 0.001$) in ewes fed DDGS than in those fed HL or CN, whereas postfeeding BUN concentrations were greater ($P \leq 0.05$) for ewes fed DDGS and HL than for those fed CN (Figure 5). The concentration of BUN for ewes fed DDGS was reflective of CP intake. As stated earlier, ewes fed DDGS had greater CP intake and likely had a greater amount of AA being absorbed postruminally. Excess CP intake by ewes in late gestation was observed previously to increase BUN concentration (McNeill et al., 1997). Decreased BUN for ewes fed CN likely reflects their reduced CP intake and could reflect a greater microbial uptake of protein in the rumen and reduced ruminal ammonia for this limit-fed high starch diet (Murphy et al., 1994).

In mid gestation (d 80), ewes fed DDGS and HL had greater ($P < 0.001$) prefeeding plasma NEFA concentrations than those fed CN, but by 6 h postfeeding ewes fed HL had the least ($P = 0.03$) NEFA concentrations (Figure 6). When plasma was collected in late gestation (d 122), no differences were detected ($P \geq 0.09$) in NEFA concentrations among treatments. Reduced BCS of ewes fed HL at 115 d of gestation was not associated with greater plasma NEFA concentrations at d 80 or 122 of gestation, which is contrary to the results reported in beef cows (Radunz et al., 2010). Early in gestation, greater NEFA concentration postfeeding for ewes fed DDGS could be reflective of fat intake, but this response was not observed in late gestation. In pre-

vious studies, dietary intake of fat has not always been associated with greater NEFA concentrations in gestating ewes (Encinias et al., 2004) or dairy cows (Grummer and Carroll, 1991).

During late gestation when energy demands are greatest for glucose by the fetus, NEFA represents a greater proportion of energy substrate in the liver than propionate and AA (Freetly and Ferrell, 2000). Ewes fed DDGS had a greater fat intake than ewes fed CN or HL, which may explain greater NEFA concentrations prefeeding during mid gestation, but this was not observed in late gestation. Decreased plasma NEFA concentrations in late gestation could reflect a greater uptake by liver of NEFA from postruminal absorption of fatty acids, which are then oxidized to acetyl CoA. Furthermore, incidence of pregnancy toxemia (Table 3) was greater in ewes fed DDGS during gestation ($P = 0.01$), whereas ewes fed CN and HL did not exhibit any signs of pregnancy toxemia. Dairy cows are more susceptible to metabolic disorders, such as ketosis in early lactation, whereas sheep have a greater incidence of ketosis in late gestation. In most cases, ketosis is the result of a negative energy balance that causes mobilization of body fat to compensate for this energy deficiency. When dairy cows were fed a lipogenic (fiber plus fat) diet during early lactation, increased subclinical ketosis (greater plasma β-hydroxybuturate and liver triglycerides) was observed compared with cows fed a glucogenic (starch) diet (Van Knegsel et al., 2008). The lipogenic characteristics of the DDGS diet would suggest ruminal propionate production, and postruminal supply of AA did not meet glucose demands of the gravid uterus and ewe; therefore, fat from DDGS was oxidized to produce energy by the liver. In contrast, ewes fed HL appeared to be mobilizing fat during late gestation, but this was not associated with greater plasma NEFA concentrations, which may indicate the mobilization of fat was not severe enough to induce ketosis.

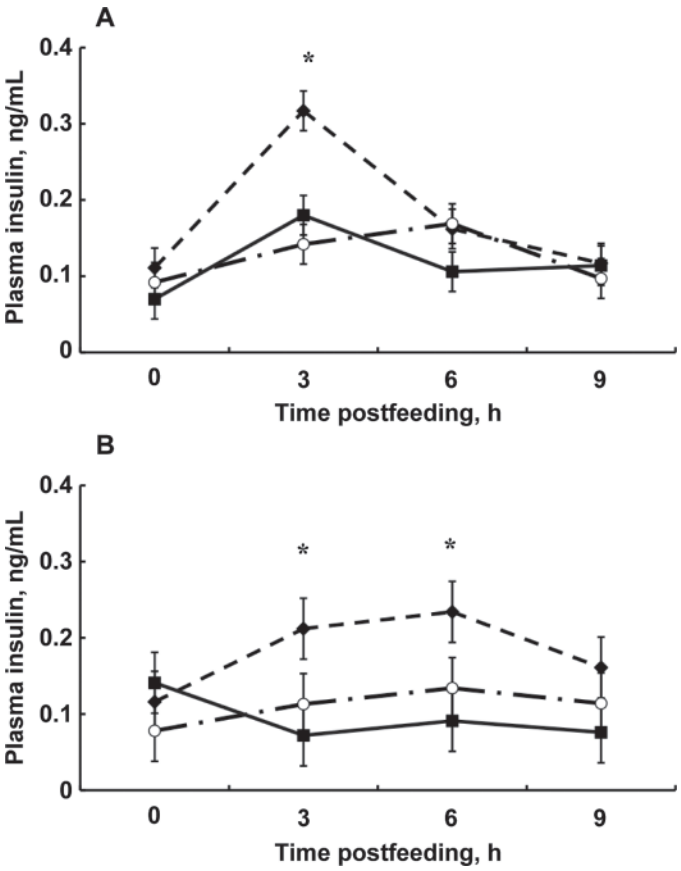

Figure 4. Plasma insulin concentration before and after feeding at approximately 80 (A) and 122 (B) d of gestation from ewes fed haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within hour ($P < 0.05$).

Progeny Preweaning Performance

Birth weight tended ($P = 0.09$) to be greater in lambs from ewes fed CN and DDGS than HL (Table 4), but this was not associated with increased lambing difficulty. Additionally, birth vigor score was not different among treatments. These results are similar to those reported in Radunz (2009) for beef cattle. Maternal intake of protein has been shown to be an important factor for fetal growth. When CP was fed at 1.4 times greater than amount required by ewes in late gestation, lamb birth weight was greater, but this was associated with greater lambing difficulty (Ocak et al., 2005). In contrast, lamb fetuses collected at 140 d of gestation had similar BW between dams consuming 141 vs. 215 g of CP during late gestation (McNeill et al., 1997). However, maternal intake of protein could have a different impact depending on stage of gestation.

Mid gestation is a critical period for placental growth and development. Abundance of arginine and associated AA increases amount of nitric oxide synthase, and thus, increases nitric oxide production, which is a vasorelaxing factor and plays a key role in regulating placental blood flow (Bird et al., 2000). Glucose supply to the fetus is determined by maternal blood glucose concentration and placenta blood flow (Baumann et al., 2002). Amino acids and glucose are the most important substrates for fetal growth, whereas acetate and other fatty acids represent less than 10% of fetal nutrient supply (Bell et al., 2005). Therefore, the greater birth weights observed could be explained by greater maternal glucose supply in ewes fed CN and greater maternal AA supply by ewes fed DDGS. The greater fat content of DDGS would appear to be a less likely explanation for this response, because previous studies have reported that fat supplementation at isocaloric intakes to dams did not affect progeny birth weight (Encinias et al., 2004; Small et al., 2004) and fat is a minor source of energy for the gravid uterus (Bell et al., 2005).

Reduced maintenance requirements of the dam due to restricted intake of DDGS and CN diets could also be a possible explanation for greater birth weights in progeny from these ewes. 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

Table 3. Reasons for ewes being removed from the trial

	Treatment[1]		
Item, n	HL	CN	DDGS
Initial ewes	30	30	30
Vaginal prolapse	—	3	2
Severe mastitis	1	—	—
Ketosis[2]	—	—	4
Triplets	1	—	1
Stillborn lambs	1	2	—
Postnatal lamb mortality	1	2	1
Postpartum unknown	1	—	1
Total removed	5	7	9

[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.

[2]Incidence of ketosis was significant ($P = 0.01$).

al., 1999). In the current study, ewes fed DDGS and CN maintained a heavier BW and greater BCS during late gestation than ewes fed HL in spite of similar estimated energy intakes (NRC, 2000). This, coupled with the trend for ewes fed HL to produce lambs with decreased birth BW, indicates ewes fed HL may have needed additional energy to maintain visceral tissues, which would reduce available energy for the fetus.

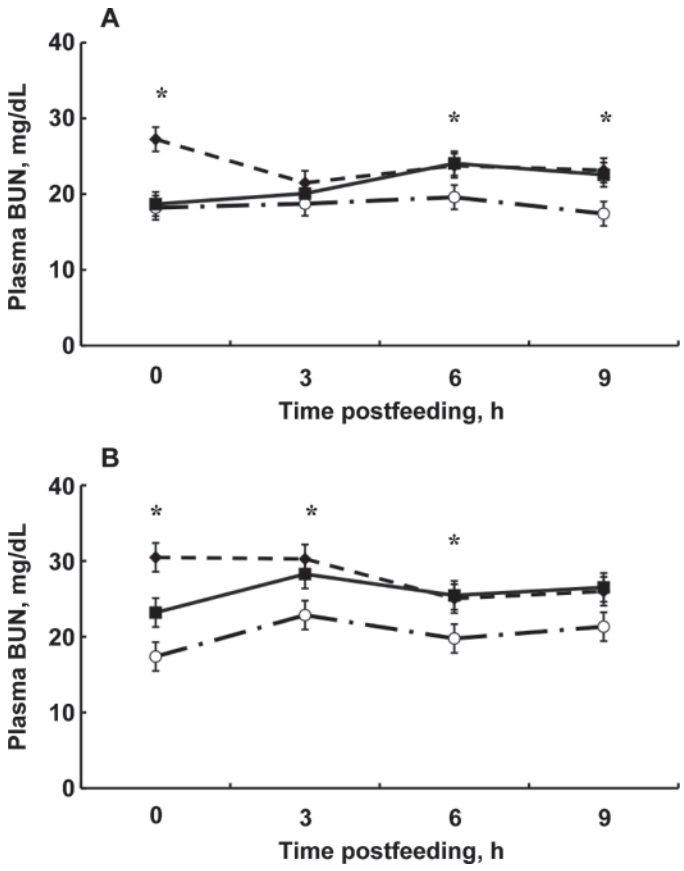

Figure 5. Plasma blood urea nitrogen (BUN) concentration before and after feeding at approximately 80 (A) and 122 (B) d of gestation from cows fed ad libitum haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within hour ($P < 0.05$).

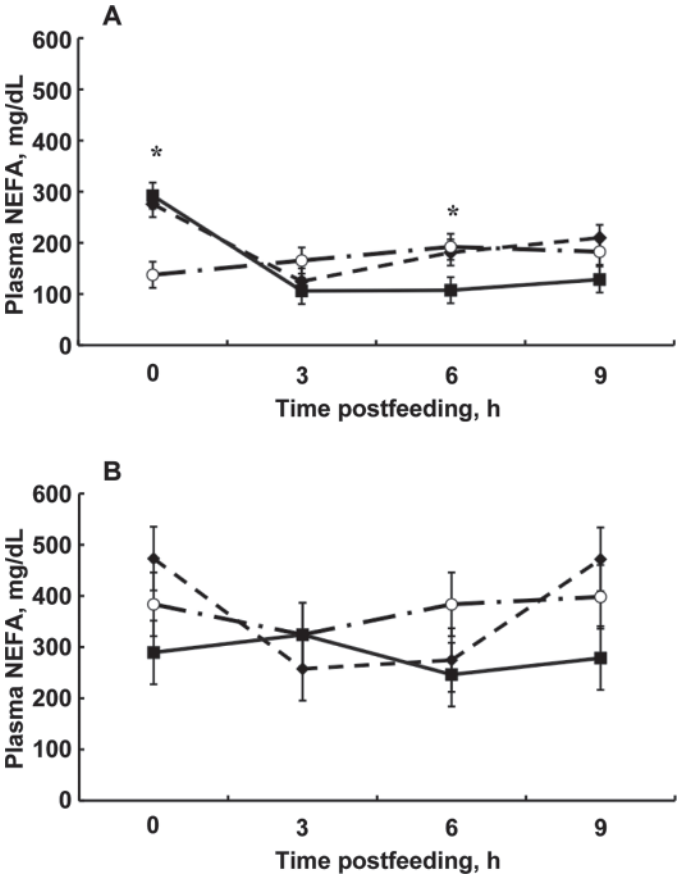

Figure 6. Plasma NEFA concentration before and after feeding at approximately 80 (A) and 122 (B) d of gestation from ewes fed haylage (■), limit-fed corn (○), and limit-fed dried distillers grains (◆) in late gestation. *Indicates a significant difference among treatments within hour ($P < 0.05$).

Prepartum ewe dietary winter feed source did not affect other muscle, organ, bone, or fat measures in progeny at birth (Table 5). Mid gestation, rather than early gestation appears to be a critical period for muscle and fat development, and nutrient restriction during this period has been reported to reduce fetal weight and muscle mass (Fahey et al., 2005). Additionally, infusion of glucose to the fetus has been reported to increase adipose deposition (Stevens et al., 1990). Neither maternal fat supplementation (Encinias et al., 2004) nor excess maternal CP intake (McNeill et al., 1997) has been shown to alter fetal fat deposition or nitrogen retention; therefore, diets with greater fat or protein content may not alter fetal muscle or adipose tissue growth in lambs from dams fed at similar energy intakes.

Milk production and composition at d 28 postpartum were similar among treatments (Table 6), which would be expected because postpartum diets were similar among ewes. Previous studies in sheep have investigated prepartum nutrition to determine effects on colostrum production and composition and effects on early postnatal lamb mortality. Undernourished ewes (Mellor et al., 1987; O' Doherty and Crosby, 1996) or ewes fed excess protein (Ocak et al., 2005) have been reported to have reduced colostrum yield. Colostrum yield or

Table 4. Effects of prepartum dam winter-feeding system on progeny preweaning performance

	Treatment[1]				
Item	HL	CN	DDGS	SEM	*P*-value
Lambs (pens), n	42 (6)	39 (6)	36 (6)		
Birth vigor score[2]	2.9	2.8	2.6	0.118	0.36
BW, kg					
Birth	5.46[b]	6.02[a]	6.11[a]	0.243	0.09
28 d	14.95	15.97	15.94	0.582	0.25
Weaning[3]	25.78	28.68	27.49	1.146	0.19
Growth rate, kg/d					
0 to 28 d	0.34	0.35	0.35	0.021	0.71
0 to weaning	0.35	0.37	0.37	0.023	0.44
Mortality rate,[4] %	8.7	13.3	10.0	—	0.76

[a,b]Within a row, means without a common superscript differ at $P < 0.10$.
[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]1 = weak; 5 = strong.
[3]Weaned at 61.4 ± 5.9 d of age.
[4]Mortality from birth to weaning and analyzed with GENMOD (SAS Inst. Inc., Cary, NC) and SEM not estimated.

composition was not measured in the current study, but collectively, these studies indicate mammary development can be affected by prepartum nutrition. Plane of nutrition in beef cows has been associated with changes in milk production (Corah et al., 1975); however, prepartum feed sources fed at isocaloric intakes did not affect postpartum milk production (Alexander et al., 2002; Radunz et al., 2010). Therefore, prepartum feed source does not appear to affect mammary gland development during gestation, such that subsequent postpartum milk production or composition is affected.

Prepartum dam feed source did not affect progeny preweaning growth rate, weaning weight, or mortality rate. In contrast, excess protein intake by ewes in late gestation has been observed to decrease lamb survival preweaning (Ocak et al., 2005), whereas fat supplementation during late gestation has been associated with increased lamb survival and greater number of lambs weaned per ewe (Encinias et al., 2004). The results reported here are similar to Radunz (2009), where postweaning growth rate and mortality was not affected by dam prepartum diet during late gestation; however,

Table 5. Effects of dam winter-feeding system on organ weights and leg composition of twin progeny slaughtered at birth

	Treatment[1]				
Item	HL	CN	DDGS	SEM	*P*-value
Lambs,[2] n	6	6	6		
LM, g	44.4	47.7	39.9	6.59	0.59
Semitendinosus, g	11.2	13.7	10.1	16.50	0.23
Leg, g	372	413	365	41.3	0.64
Liver, g	134	159	140	19.2	0.54
Kidney, g	30.5	35.2	35.0	3.79	0.55
Lung, g	116	123	127	17.9	0.85
Heart, g	54.6	54.2	53.7	3.87	0.98
Femur, g	53.9	53.8	53.0	4.91	0.98
BW, %					
LM	8.2	9.6	7.6	1.21	0.23
Semitendinosus	2.0	2.8	2.0	0.34	0.13
Leg	68.3	85.1	69.4	9.07	0.29
Kidney	5.7	7.3	6.6	0.88	0.35
Lung	21.6	26.1	24.0	4.17	0.68
Heart	10.1	11.2	10.3	1.02	0.72
Femur	9.8	11.2	10.0	1.13	0.60
Leg weight, %					
Semitendinosus	2.0	2.8	2.0	0.33	0.13
Femur	14.6	13.2	14.6	0.66	0.24
Fat	2.58	2.77	2.22	0.321	0.46

[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]One twin lamb was randomly selected per original treatment pen at birth to be slaughtered.

Table 6. Effects of dam winter-feeding system on 28-d milk production

	Treatment[1]				
Item	HL	CN	DDGS	SEM	*P*-value
Ewes (pens)	25 (6)	23 (6)	21 (6)		
Milk production,[2] kg/d	2.2	2.1	2.0	0.15	0.53
Fat, %	7.8	8.1	7.3	0.34	0.53
CP, %	3.9	4.0	4.0	0.10	0.76
Lactose, %	5.0	5.1	5.1	0.06	0.67
MUN,[3] mg/dL	10.8	10.1	10.0	0.76	0.64
Fat, g/d	175	172	153	16.0	0.57
CP, g/d	82	79	77	17.9	0.84
Lactose, g/d	112	106	103	8.0	0.52

[1]HL = haylage; CN = limit-fed corn; DDGS = limit-fed dried distillers grains.
[2]Milk production was calculated by multiplying 3-h milk measure by 8.
[3]MUN = milk urea nitrogen.

weaning weights were still greater in calves from dams fed DDGS and CN than in calves from dams fed HL. Differences in birth weights among treatments in the current experiment were less than those reported in calves in Radunz (2009); therefore, differences in weaning weight might have been too small to detect in the current study.

In summary, winter-feeding systems which differ in dietary energy source and protein concentration for pregnant sheep during mid to late gestation altered maternal metabolites, and this was associated with changes in fetal growth, but not preweaning progeny performance. Further research is warranted to determine if changes in maternal nutrient supply due to these mid- and late-gestation winter-feeding systems contributed to increased fetal growth, which may have long-term effects on postnatal growth and body composition. A ewe winter-feeding system in mid to late gestation did not result in detrimental effects on pre- or postpartum ewe performance. Gestation feed costs were reduced for ewes fed DDGS; however, ewes fed DDGS had an increased incidence of ketosis just before parturition.

LITERATURE CITED

Alexander, B. M., B. W. Hess, D. L. Hixon, B. L. Garrett, D. C. Rule, M. McFarland, J. D. Bottger, D. D. Simms, and G. E. Moss. 2002. Influence of prepartum fat supplementation on subsequent beef cow reproduction and calf performance. Prof. Anim. Sci. 18:351–357.

American Sheep Industry Association. 1997. Sheep Production Handbook. C&M Press, Denver, CO.

AOAC. 1997. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Baumann, M. U., S. Deborde, and N. P. Illsley. 2002. Placental glucose transfer and fetal growth. Endocrine 19:13–22.

Beckman, J. L., and W. P. Weiss. 2005. Nutrient digestibility of diets with different fiber to starch ratios when fed to lactating dairy cows. J. Dairy Sci. 88:1015–1023.

Bell, A. W., P. L. Greenwood, and R. A. Ehrhardt. 2005. Regulation of metabolism and growth during prenatal growth. Pages 7–31 in Biology of Metabolism in Growing Animals. D. G. Burrin and H. J. Mersmann, ed. Elsevier Limited, Edinburgh, UK.

Benson, J. A., and C. K. Reynolds. 2001. Effects of abomasal infusion of long-chain fatty acids on splanchnic metabolism of pancreatic and gut hormones in lactating dairy cows. J. Dairy Sci. 84:1488–1500.

Bird, I. M., J. A. T. Di Sullican, J. M. Cale, L. Zhang, J. Zheng, and R. R. Magness. 2000. Pregnancy-dependent changes in cell signaling underlie changes in differential control of vasodilator production in uterine artery endothelial cells. Endocrinology 141:1107–1117.

Corah, L. R., T. G. Dunn, and C. C. Kaltenbach. 1975. Influence of prepartum nutrition on the reproductive performance of beef females and the performance of their progeny. J. Anim. Sci. 41:819–824.

Encinias, H. B., G. P. Lardy, A. M. Encinias, and M. L. Bauer. 2004. High-linoleic acid safflower seed supplementation for gestating ewes: Effects on ewe performance, lamb survival, and brown fat stores. J. Anim. Sci. 82:3654–3661.

Engel, C. L., H. H. Patterson, and G. A. Perry. 2008. Effect of dried corn distillers grains plus solubles compared with soybean hulls, in late gestation diets, on animal and reproductive performance. J. Anim. Sci. 86:1697–1708.

Fahey, A. J., J. M. Brameld, T. Parr, and P. J. Buttery. 2005. The effect of maternal undernutrition before muscle differentiation on the muscle fiber development of the new born lamb. J. Anim. Sci. 83:2564–2571.

Ferrell, C. L., W. N. Garrett, N. Hinman, and G. Gritching. 1976. Energy utilization by pregnant and non-pregnant heifers. J. Anim. Sci. 42:937–950.

Fluharty, F. L., and K. E. McClure. 1997. Effects of dietary energy intake and protein concentration on performance and visceral organ mass in lambs. J. Anim. Sci. 75:604–610.

Fluharty, F. L., K. E. McClure, M. B. Solomon, D. D. Clevenger, and G. D. Lowe. 1999. Energy source and ionophore supplementation effects on lamb growth, carcass characteristics, visceral organ mass, diet digestibility, and nitrogen metabolism. J. Anim. Sci. 77:816–823.

Ford, S. P., B. W. Hess, M. M. Schwope, M. J. Nijland, J. S. Gilbert, K. A. Vonnahme, W. J. Means, H. Han, and P. W. Nathanielsz. 2007. Maternal undernutrition during early to mid-gestation in the ewe results in altered growth, adiposity, and glucose tolerance in male offspring. J. Anim. Sci. 85:1285–1294.

Freetly, H. C., and C. L. Ferrell. 2000. Net flux of nonesterified fatty acids, cholesterol, and glycerol across the portal-drained viscera and liver of pregnant ewes. J. Anim. Sci. 78:1380–1388.

Gardner, D. S., K. Tingey, B. W. M. Van Bon, S. E. Ozanne, V. Wilson, J. Dandrea, D. H. Keisler, T. Stephenson, and M. E. Symonds. 2005. Programming of glucose-insulin metabolism in adult sheep after maternal undernutrition. Am. J. Physiol. Regul. Integr. Comp. Physiol. 289:R947–R954.

Grummer, R. R., and D. J. Carroll. 1991. Effects of dietary fat on metabolic disorders and reproductive performance of dairy cattle. J. Anim. Sci. 69:3838–3852.

Harmon, D. L. 1992. Impact of nutrition on pancreatic exocrine and endocrine secretion in ruminants. A review. J. Anim. Sci. 70:1290–1301.

Johnson, M. M., and J. P. Peters. 1993. Technical note: An improved method to quantify non-esterified fatty acids in bovine plasma. J. Anim. Sci. 71:753–756.

Lammoglia, M. A., R. A. Bellows, E. E. Grings, and J. W. Bergman. 1999. Effects of prepartum supplementary fat and muscle hypertrophy genotype on cold tolerance in newborn calves. J. Anim. Sci. 77:2227–2233.

Loerch, S. C. 1996. Limit-feeding corn as an alternative to hay for gestating beef cows. J. Anim. Sci. 74:1211–1216.

Leupp, J. L., G. P. Lardy, K. K. Karges, M. L. Gibson, and J. S. Caton. 2009. Effects of increasing level of corn distillers dried grains with solubles on intake, digestion, and ruminal fermentation in steers fed seventy percent concentrate diets. J. Anim. Sci. 87:2906–2912.

Luther, J., R. Aitken, J. Milne, M. Matxuzaki, L. Reynolds, D. Redmer, and J. Wallace. 2007. Maternal and fetal growth, body composition, endocrinology and metabolic status in undernourished adolescent sheep. Biol. Reprod. 77:343–350.

McNeill, D. M., R. Slepetis, R. A. Ehrhardt, D. M. Smith, and A. W. Bell. 1997. Protein requirements of sheep in late pregnancy: Partitioning of nitrogen between gravid uterus and maternal tissues. J. Anim. Sci. 75:809–816.

Mellor, D. J., D. J. Flint, R. G. Vernon, and I. A. Forsyth. 1987. Relationships between plasma hormone concentrations, udder development and the production of early mammary secretions in twin-bearing ewes on different planes of nutrition. Q. J. Exp. Physiol. Cog. Med. Sci. 72:345–356.

Muhlhausler, B. S., J. A. Duffield, and I. C. McMillen. 2007. Increased maternal nutrition increases leptin expression in perirenal and subcutaneous adipose tissue in the postnatal lamb. Endocrinology 148:6157–6163.

Murphy, T. A., S. C. Loerch, and B. A. Dehority. 1994. The influences of restricted feeding on site and extent of digestion and flow of nitrogenous compounds to the duodenum in steers. J. Anim. Sci. 72:2487–2496.

NRC. 1985. Nutrient Requirements of Sheep. 6th rev. ed. Natl. Acad. Press, Washington, DC.

NRC. 2000. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

O' Doherty, J. V., and T. F. Crosby. 1996. The effects of diet in late pregnancy on progesterone concentration and colostrum yield in ewes. Theriogenology 46:233–241.

Ocak, N., M. A. Cam, and M. Kuran. 2005. The effect of high dietary protein levels during late gestation on colostrum yield and lamb survival rate in singleton-bearing ewes. Small Rumin. Res. 56:89–94.

Radunz, A. E. 2009. Effects of prepartum dam energy source on progeny growth, glucose tolerance, and carcass composition in beef and sheep. PhD Diss. The Ohio State University, Columbus.

Radunz, A. E., F. L. Fluharty, M. L. Day, H. N. Zerby, and S. C. Loerch. 2010. Prepartum dietary energy source fed to beef cows: I. Effects on pre- and postpartum cow performance. J. Anim. Sci. 88:2717–2728.

Radunz, A. E., F. L. Fluharty, I. Susin, T. L. Felix, H. N. Zerby, and S. C. Loerch. 2011. Winter-feeding systems for gestation sheep II: Effects on feedlot performance, glucose tolerance, and carcass composition of lamb progeny. J. Anim. Sci. 89:478–488. doi:10.2527/jas.2010-3037.

Sletmoen-Olson, K. E., J. S. Caton, K. C. Olson, D. A. Redmer, J. D. Kirsch, and L. P. Reynolds. 2000. Undegraded intake protein supplementation: II. Effects on plasma hormone and metabolite concentrations in periparturient beef cows fed low-quality hay during gestation and lactation. J. Anim. Sci. 78:456–463.

Small, W. T., S. I. Paisley, B. W. Hess, S. L. Lake, E. J. Scholljegerdes, T. A. Reed, E. L. Belden, and S. Bartle. 2004. Supplemental fat in limit-fed high grain prepartum diets of beef cows: Effects on cow weight gain, reproduction, and calf health, immunity, and performance. West. Sec. Am. Soc. Anim. Sci. 55:45–52.

Stevens, D., G. Alexander, and A. W. Bell. 1990. Effects of prolonged glucose infusion into fetal sheep on body growth, fat deposition, and gestation length. J. Dev. Physiol. 13:277–281.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim. Sci. 77:1-v–12-v.

Susin, I., S. C. Loerch, and K. E. McClure. 1995a. Effects of feeding a high-grain diet at a restricted intake on lactation performance and rebreeding of ewes. J. Anim. Sci. 73:3199–3205.

Susin, I., S. C. Loerch, K. E. McClure, and M. L. Day. 1995b. Effects of limit feeding a high-grain diet on puberty and reproductive performance of ewes. J. Anim. Sci. 73:3206–3215.

Van Knegsel, A. T. M., H. van den Brand, J. Dijkstra, W. M. van Straalen, and R. Jorrisma. 2008. Effect of glucogenic vs. lipogenic diets on energy balance, blood metabolites and reproduction in primiparious and multiparious dairy cows in early lactation. J. Dairy Sci. 90:3397–3409.

Vonnahme, K. A., B. W. Hess, and T. R. Hansen. 2003. Maternal undernutrition from early- to mid-gestation lead to growth retardation, cardiac ventricular hypertrophy, and increased liver weight in fetal sheep. Biol. Reprod. 69:133–140.