Effects of feeding stockpiled tall fescue versus summer-baled tall fescue-based hay to late gestation beef cows: I. Cow performance, maternal metabolic status, and fetal growth¹

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ABSTRACT: We hypothesized that cows grazing stockpiled tall fescue (STF) during late gestation would have increased nutrient intake, resulting in improved metabolic status and fetal growth compared with cows consuming summer-baled tall fescue hay. Multiparous, spring-calving, crossbred beef cows (year 1: $n = 48$, year 2: $n = 56$) were allocated by body weight (BW), body condition score (BCS), age, service sire, and expected calving date to 1 of 2 forage systems (4 rep/system) in mid-November on day 188 of gestation: strip-graze endophyte-infected STF in 4.05 ha pastures or consume ad libitum endophyte-infected summer-baled tall fescue-based hay in uncovered dry lots. Treatments were terminated 1 wk postpartum, and cow-calf pairs were managed together until weaning. Data were analyzed with forage system, year, and their interaction as fixed effects. Sampling day was a repeated effect for cow metabolites and hormones. Calf date of birth was in the model when $P < 0.25$; pasture or pen was the experimental unit. Cow prepartum BW was not affected ($P \geq 0.424$) by forage system, but cows grazing STF tended ($P = 0.09$) to have greater BCS at day 35 and had greater ($P = 0.03$) final precalving

12th rib fat thickness tended ($P = 0.09$) to be greater for STF than hay-fed cows. Calves born to cows fed hay only weighed 10.2% less ($P = 0.03$) at birth than calves born to cows consuming STF, indicating reduced fetal growth. Postpartum cow BW, BCS, first service conception rate, and overall pregnancy rate were not affected ($P \geq 0.15$) by late gestational forage system. After day 0, serum urea N was greater ($P < 0.001$) in cows consuming STF on all days measured. Cows grazing STF also tended ($P = 0.08$) to have greater plasma glucose than cows consuming hay. Serum nonesterified fatty acids (NEFA) were greater ($P < 0.001$) in cows grazing STF on day 56 in year 1 and on day 77 and 99 in year 2. Serum triiodothyronine was less ($P = 0.03$) on day 0, but greater ($P = 0.004$) on day 99, in cows grazing STF. Cows grazing STF tended ($P = 0.06$) to have greater thyroxine on day 77 in year 1. Serum cortisol was greater ($P = 0.003$) on day 35 and tended ($P = 0.10$) to be greater on day 99 in cows grazing STF. Calf birth weight was positively correlated with prepartum maternal serum urea N ($r = 0.31$, $P = 0.002$) and NEFA ($r = 0.12$, $P = 0.005$). In this study, cows grazing STF had increased nutrient intake during late gestation, resulting in greater fetal growth.

Key words: developmental programming, fetal growth, grazing system, metabolism, pregnancy, winter grazing

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INTRODUCTION

Nutrient requirements of beef cows increase dramatically with fetal growth during the last third of pregnancy, as protein and energy requirements for pregnancy increase 4.8- and 4.4-fold during this period (NASEM, 2016). These increasing fetal nutrient demands account for >30% of the dam's total nutrient requirements during this time and make fetal growth sensitive to late gestational nutrition. Developmental programming is the theory that the maternal environment during gestation, which is affected by maternal nutrition among other factors, impacts fetal development and can have lasting effects on offspring postnatally (Barker et al., 1993; Reynolds et al., 2010). Much of the beef cattle data in this area come from research conducted in the western United States, such as the Nebraska Sandhills, where low protein forages are supplemented with protein-based supplements. These data have demonstrated improved calf performance due to dam late gestational protein supplementation (Stalker et al., 2006; Martin et al., 2007; Larson et al., 2009).

Despite this research, little is known about how poor late gestational nutrition in production systems common to other regions impacts fetal growth. In the lower Midwest or "Fescue Belt," it is common for cow-calf producers to feed poor-quality, summer-baled grass hay during winter, which often does not meet maternal and fetal nutrient requirements for spring-calving cows. Extending the grazing season is another option that can be more cost-effective than harvesting or purchasing hay while reducing or eliminating the need for grain-based supplementation (D'Souza et al., 1990). Tall fescue is the most widely available cool-season forage in the lower Midwest. When its fall growth is stockpiled, or deferred for winter grazing, it is often higher in quality than grass hay fed to beef cows (Kallenbach et al., 2003), and can improve performance of late gestation cows (Meyer et al., 2009). Despite this, it is unknown how maternal metabolic status and fetal growth are impacted by this forage system. Therefore, we hypothesized that cows grazing stockpiled tall fescue (STF) would have increased nutrient intake, which would result in improved metabolic status and fetal growth compared with cows consuming summer-baled tall fescue-based hay during late gestation. The primary objective of this study was to investigate the effects of grazing STF versus feeding summer-baled hay during late gestation on beef cow performance, circulating metabolites and metabolic hormones,

and fetal growth during late gestation. A secondary objective was to determine the relationship of prepartum cow circulating metabolites and hormones with calf birth weight.

MATERIALS AND METHODS

The University of Missouri Animal Care and Use Committee approved animal care and use in this study (protocol #7936).

Animal Management and Forage Systems

A 2-yr study was conducted at the University of Missouri Beef Research and Teaching Farm (Columbia, MO) utilizing multiparous, spring-calving, crossbred beef cows [year 1: $n = 48$, initial body weight (BW) = 678 ± 80 (SD throughout) kg, initial body condition score (BCS) = 5.8 ± 0.6 , initial age = 5.7 ± 2.3 yr; year 2: $n = 56$, initial BW = 640 ± 73 kg, initial BCS = 5.6 ± 0.5 , initial age = 4.9 ± 3.0 yr]. Cows were allocated by BW, BCS, age, service sire ($n = 4$), and expected calving date [artificial insemination (AI) due date: year 1 = February 8, 2014; year 2 = February 7, 2015] to 1 of 2 forage systems during late gestation (Table 1): endophyte-infected STF pasture or endophyte-infected tall fescue-based hay. There were 4 replications (pens or pastures) per forage system in each year, and the study was initiated on November 15, 2013 (day 187 ± 13 of gestation) and November 14, 2014 (day 188 ± 14 of gestation) in year 1 and 2, respectively. Gestational forage system treatments were terminated at 6.4 ± 3.3 d (year 1) and 6.7 ± 2.5 d (year 2) postpartum, and cow-calf pairs grazed tall fescue-based pastures together (1 group per year) until weaning.

The spring prior to the study's initiation in both years, estrus was synchronized and cows were artificially inseminated (2 sires per year) using a fixed-time AI 7-day co-sync + controlled internal drug release device protocol. Cows were exposed to bulls (2 bulls per year, ≤ 50 cows per bull) for natural service beginning 10 d after AI, resulting in a calving season of 46 d in year 1 and 79 d in year 2. These methods were also utilized for breeding of cows on study (postforage system) in both years.

Endophyte-infected tall fescue-based pastures (approximately 4.05 ha each) were used to stockpile the fall growth of forage for the STF forage system (Table 1). In mid-August of each year, 45 kg of N/ha (as ammonium nitrate) were applied to previously grazed pastures, and pastures were allowed to accumulate forage until study initiation in each

Table 1. Nutrient composition, digestibility, and yield of stockpiled tall fescue (STF) and summer-baled tall fescue hay (Hay) offered to beef cows during late gestation in both years

Variable	STF ¹ , year 1	Hay ² , year 1	STF ¹ , year 2	Hay ² , year 2
DM, %	45.5	91.5	44.7	85.7
DM basis				
Crude protein, %	12.1	6.2	12.4	7.6
Neutral detergent fiber, %	61.4	64.9	66.4	68.3
Acid detergent fiber, %	33.4	36.6	37.8	38.3
Ash, %	8.5	9.7	13.7	9.0
In vitro true digestibility, %	61.4	59.4	64.1	57.7
Estimated DM intake ³ , kg/d	11.4	11.6	12.0	13.1
Calculated DM intake ⁴ , kg/d	13.6	11.7	12.6	11.7
Yield, kg DM/ha	4,668	--	5,622	--
Forage utilization, %	80.4	--	70.8	--

DM = dry matter.

¹Average STF includes pregrazing forage samples from all 4 pastures throughout the study in each year.

²Average hay includes core samples collected from each hay bale prior to feeding.

³Estimated forage DM intake before calving began, based on STF and hay disappearance data.

⁴Calculated DM intake before calving began, based on 1.2% body weight in neutral detergent fiber.

year. STF pastures were strip-grazed using electric polytape and lightweight step-in posts. A new strip of forage was allocated approximately every 3.5 d (2×/wk) with a utilization goal of 75 to 80% of available forage. When weather conditions such as excessive ice or snow prevented grazing, cows consuming STF were fed rye haylage [year 1: 59.7% neutral detergent fiber (NDF), 36.6% acid detergent fiber (ADF), 12.3% crude protein (CP); year 2: 54.4% NDF, 29.6% ADF, 15.1% CP; all dry matter (DM) basis] until conditions improved and forage was available for grazing. Rye haylage had similar nutrient composition to STF, making it a viable substitution for STF. Feeding rye haylage was necessary for 17 d in year 1 and 0 d in year 2 while cows were grazing STF pasture. Cows grazing STF were moved in groups (by expected calving date) to dry lots adjacent to hay pens at 10.2 ± 8.6 d (year 1) and 9.2 ± 4.3 d (year 2) prepartum to allow for data collection at calving and to ensure calves born to cows from both forage systems were treated similarly postnatally. During this time, cows in the STF forage system were fed rye haylage used during inclement weather, as described previously.

Summer-baled endophyte-infected tall fescue-based grass hay (Table 1) was fed ad libitum in round bale rings with cone chains. Reproductive growth of tall fescue-based pastures (first cutting) was baled during July or August of a preceding year, and then stored under cover prior to use. This hay was selected to represent poor-quality hay fed in the lower Midwest and Fescue Belt that generally does not meet nutrient requirements of late

gestation cows. Cows were confined in 18×61 m uncovered dry lot pens that were well-drained and limestone-based. Each pen contained a 9.1×9.1 m concrete pad near the center where hay was fed to prevent excessive mud accumulation around feeders. When the quantity of hay remaining in a feeder appeared to be limiting within 24 h, a new bale was weighed and core sampled for nutrient analysis before feeding. All bales fed were core sampled and composited per study period.

Cows in both forage systems had ad libitum access to water and were allowed a mineral and vitamin supplement (Gold Star MFA Breeder 12 Mineral; MFA Incorporated, Columbia, MO) to provide the recommended $56.8 \text{ g} \cdot \text{animal}^{-1} \cdot \text{d}^{-1}$, with additional salt to limit intake when necessary.

Animal Performance Measurements

Prepartum cow data collection was divided into 2 periods: period 1 consisted of day 0 to 35, and period 2 consisted of day 36 to 78 of study in each year. Period 2 ended 1 wk prior to the first expected calving date and 1 d before calving began in both years. Cow performance measurements were taken at the beginning and end of these periods. At these points, cow 2-d BW (without feed or water removal) were recorded in the morning (0700 to 1100), and cows were assigned BCS (1 to 9 scale, 1 = emaciated and 9 = obese) by 3 trained technicians. In addition, 12th rib fat thickness was determined by a trained technician using an Aloka SSD-500V ultrasound machine (Wallingford, CT). Rib fat measurements

were taken at the 12th rib, measuring fat thickness at a location three-quarters down the length of the longissimus dorsi from the spine.

Fetal growth was assessed using calf birth weight. After parturition, calves were weighed, tagged, and sex was determined within 8 h of birth. Gestation length was calculated based on days between fixed-time AI breeding date and date of calving for calves conceived by AI, but was not calculated for calves resulting from natural service mating.

Postpartum cow 2-d BW was recorded and BCS assigned at the subsequent fixed-time AI breeding date (year 1: May 1, 2014; year 2 May 7, 2015) and at weaning (year 1: October 2, 2014; year 2: September 30, 2015). Pregnancy was determined by transrectal ultrasound using an Aloka SSD-500V ultrasound machine 35 d post-AI to determine first service conception rate, and 30 d after bull removal for overall pregnancy rate.

Late Gestation Blood Collection and Analyses

Jugular blood samples were obtained from cows in both years on d 0 [before study initiation; day 187 (year 1) or 188 (year 2) of gestation], 20, 35, 56, and 77 (day of final precalving BW and BCS) of the study. Blood samples were also obtained for remaining prepartum cows on day 99 of study (year 1: $n = 10$ STF, $n = 10$ Hay; year 2: $n = 10$ STF, $n = 7$ Hay).

At each sampling time, blood samples were collected into 4 collection tubes [2 Vacutainer serum collection tubes containing no additives (10 mL draw; Becton Dickinson, Franklin Lakes, NJ), 1 Monoject plasma collection tube containing 0.10 mL of 15% K_3 EDTA (10 mL draw; Covidien, Mansfield, MA), and 1 Vacutainer plasma collection tube for glucose determination containing 15 mg of sodium fluoride and 12 mg of potassium oxalate (6 mL draw; Becton Dickinson, Franklin Lakes, NJ). Plasma tubes were inverted as directed and placed on ice immediately following collection, and serum tubes were allowed to clot prior to placing on ice. Samples were centrifuged within 6 h of collection at $1,500 \times g$ at 4°C for 30 min. Serum or plasma was then pipetted into 2 mL microcentrifuge tubes and stored at -20°C until analysis.

Serum samples collected on all sampling days were analyzed for urea N using a commercially available urea N kit (Urea Nitrogen Procedure Number 0580; Stanbio Laboratory, Boerne, TX) based on the diacetylmonoxime method. Samples were read in duplicate in 96-well polystyrene plates

(Corning Inc., Corning, NY) on a microplate reader (Biotek Synergy HT, Biotek Instruments Inc., Winooski, VT) at 520 nm. The intraassay and interassay CV were 3.42 and 8.64%, respectively, for a commercially available control serum (Data Trol Normal Control Serum, Thermo Fisher Scientific, Waltham, MA).

Glucose concentration was determined in plasma samples (collected in treated tubes described above) from all sampling days using the Infinity glucose hexokinase kit (Cat. # TR15421, Fisher Diagnostics, Middletown, VA) based on the glucose-6-phosphate dehydrogenase method. Samples were read in duplicate in 96-well plates as described above at 340 nm. The intraassay and interassay CV were 3.97 and 6.94%, respectively, for a commercially available control serum as previously described.

Serum concentrations of nonesterified fatty acids (NEFA) from all sampling days were measured using a modified procedure of the NEFA C kit (Wako Pure Chemical Industries, Ltd., Osaka, Japan) based on the acyl-CoA synthetase-acyl-CoA oxidase method. Samples were read in duplicate in 96-well plates as described above at 550 nm. The intraassay and interassay CV were 4.06 and 6.79%, respectively, for a pooled bovine serum control.

Serum total triiodothyronine (T_3), thyroxine (T_4), and cortisol concentrations were determined in day 0, 35, 77, and 99 of study serum samples in duplicate using an Immulite 1000 (Siemens, Los Angeles, CA) and commercially available kits (Diagnostic Products Corp., Los Angeles, CA) as previously described (Vonnahme et al., 2013). The intraassay and interassay CV were 9.72 and 9.46%, respectively for T_3 ; 6.18 and 9.71%, respectively for T_4 , and 7.50 and 2.55%, respectively for cortisol.

Forage Measurements

Each STF pasture was sampled 3 times in year 1 (day -7, 62, and 131 of grazing) and 4 times (day 5, 29, 62, and 119 of grazing) during year 2. Pregrazing samples collected on day -7 and 62 of year 1 as well as day 5, 29, and 62 of year 2 were used to determine pregrazing forage yield and quality during late gestation. Postgrazing samples collected on day 62 and 131 of year 1 as well as day 29, 62, and 119 of year 2 were used to determine postgrazing forage yield and quality. The initial goal was to sample STF pastures every 30 d, but snow and ice accumulation prevented timely sampling, especially in year 1. At sampling, pre- and postgrazing forage samples were collected

before and after each pasture section was offered to cows using a flail-type harvester pulled by a tractor and previously described methods (Curtis and Kallenbach, 2007; Meyer et al., 2009). Ten random 0.8×4.6 m sample strips were clipped to a height of 2 cm to determine the pregrazing nutrient composition and forage yield. The clipped sections were weighed and subsampled for nutrient analysis. Postgrazing samples of grazed sections were taken in the same manner as pregrazing samples to estimate forage disappearance and grazing residue nutrient composition. Forage utilization for STF was calculated as percentage of forage disappearance [(pregrazing DM yield – postgrazing DM yield)/pregrazing yield] $\times$ 100. Overall, approximately 1.5 and 1.7 ha for year 1 and 2, respectively, were grazed in each replicate pasture by precalving measures. Cows not moved to calving pens at this time continued to graze STF until closer to parturition.

Precalving DM intake was estimated from study initiation until precalving cow measurements, as cow numbers changed in pastures and pens after this point when STF cows were moved to calving pens and cow-calf pairs were removed from treatment pens. Cow estimated DM intake was calculated as the difference in the pregrazing and postgrazing forage yield using pasture area and grazing days for STF. Estimated DM intake of hay was calculated as total bale weights delivered divided by total number of animals, using DM percent of hay subsamples and estimated hay waste. Hay waste was estimated to be 18.9% using methods of Moore and Sexten (2015), performed once monthly. Dry matter intake was also calculated using 1.2% BW intake of NDF (Mertens, 1987), and shown in Table 1.

Both hay core samples and clipped STF samples were first dried in a 55 °C oven for a minimum of 48 h. Samples were then ground through a 5 mm screen, followed by a 2 mm screen using a Thomas Wiley Mill (Thomas Scientific, Swedensboro, NJ), and finally ground through a 1 mm screen using a Cyclotec sample mill (Model 1093, Cyclotec Tecator, Höganäs, Sweden). Neutral detergent fiber and ADF were sequentially analyzed using an ANKOM Fiber Analyzer (Model 200, ANKOM Technology Corp., Fairport, NY). In vitro true digestibility (IVTD) was determined by a 48-h in vitro digestion followed by washing with NDF solution as described by Ankom Technology (Daisy Incubator, ANKOM Technology Corp., Fairport, NY). Nitrogen content of forages was

determined by thermoconductivity using an Elementar Nitrogen Analyzer (Vario Macro Cube, Elementar Americas, Mt. Laurel, NJ) and used to calculate CP (N $\times$ 6.25). To determine total DM, samples were dried in a 105 °C oven for 24 h, then put into a 500 °C oven for 16 h to determine ash content.

During year 2, STF and hay samples were freeze-dried for analysis of ergovaline concentration (Rottinghaus et al., 1991; Hill et al., 1993). In the STF, ergovaline concentrations ranged from < 25 to 140 parts per billion in December and from 30 to 120 parts per billion in January. The ergovaline concentration in hay was 25 parts per billion.

Statistical Analysis

Cows were removed from the study due to failure to calve (year 1: $n = 1$; year 2: $n = 1$), twin pregnancy (year 2: $n = 1$), calving prematurely (year 2: $n = 1$), or calving outside of a 60-d calving window (year 2: $n = 3$), resulting in 47 cows and calves included in year 1 and 50 cows and calves in year 2.

Data were analyzed using the MIXED procedure of SAS (SAS version 9.3, SAS Inst. Inc., Cary, NC) with pasture or pen as the experimental unit. Forage system, year, and their interaction were considered fixed effects for cow performance and calf birth weight data. Effects of forage system, sampling day, year, and all interactions were fixed effects in the model for all cow metabolite and hormone data, where sampling day was analyzed as a repeated measure using the best-fit covariance structure (compound symmetry, autoregressive, heterogeneous compound symmetry, or heterogeneous autoregressive). For both cow and calf measures, calf date of birth (as day of study) was included in the model if $P < 0.25$ to account for differences in prepartum exposure to forage system treatment. For calf data, calf sex was included in the model if $P < 0.25$. Cow conception and pregnancy rates were compared using chi-squared analysis of the GENMOD procedure of SAS 9.3. Correlations were determined between calf birth weight and the last prepartum maternal metabolite or hormone concentration collected prior to calving using the CORR procedure of SAS 9.3. Main effects of year were not of interest except for initial cow measures, so these will not be discussed. In the absence of the highest order interactions ($P > 0.10$), significant main effects are reported; otherwise, highest order interactive means are discussed.

RESULTS AND DISCUSSION

Cow Performance

Prepartum. There was no effect ($P \geq 0.38$) of the forage system $\times$ year interaction or forage system main effect for cow initial BW, BCS, or 12th rib fat thickness (Table 2), but cows in year 1 weighed more ($P = 0.02$) and tended ($P = 0.06$) to have more body condition compared with cows in year 2. There was also no effect ($P \geq 0.24$) of forage system $\times$ year on any cow BW, BCS, or rib fat measure.

Cow prepartum BW was not affected ($P \geq 0.44$) by forage system in this study. Despite this, BCS taken 35 d into the forage system tended ($P = 0.09$) to be greater for cows grazing STF than those fed hay. Additionally, cows grazing STF also had greater ($P = 0.03$) final precalving BCS than hay-fed cows. Although forage system did not affect ($P = 0.76$) mid 12th rib fat thickness, final precalving rib fat tended ($P = 0.09$) to be greater for cows grazing STF than cows fed hay.

STF was higher quality than hay (greater CP and less NDF) in both years and had similar

nutrient composition to that in previous studies (Curtis et al., 2008; Meyer et al., 2009). The fact that hay-fed cows gained similar BW to cows grazing STF, which had greater BCS and rib fat, is likely attributed to gut fill. Hay IVTD was less than that of STF (Table 1); thus, decreased digestibility may have reduced passage rate of fiber particles from the rumen, especially in year 2, resulting in a greater ruminal fill during BW data collection. Others have observed that cows consuming tall fescue hay lost less BW than cows consuming STF, despite hay having less CP and being lower digestibility (Curtis et al., 2008). Conversely, cows should have had greater intake of STF based on NDF, even though intake estimates based on forage disappearance show similar (year 1) or greater (year 2) intake in hay-fed cows (Table 1).

Previous research utilizing STF versus hay in spring-calving cows reported that cows consuming STF gained or lost less BW overall during late gestation than cows consuming summer-baled tall fescue hay (Meyer et al., 2009). Differences in results between these studies may be due to longer treatment periods and a later calving date in the Meyer et al. (2009) study. Additionally, overall

Table 2. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on prepartum cow performance and calf birth weight

	Forage system ¹			<i>P</i> -values		
Variable	STF	Hay	SEM	Forage system	Year	Forage system × year
Cow						
Body weight, kg						
Initial	666	662	11	0.80	0.02	0.69
Mid ²	666	678	11	0.44	0.04	0.24
Final precalving ³	683	680	11	0.89	0.28	0.26
Body condition score ⁴						
Initial	5.68	5.72	0.08	0.78	0.06	0.38
Mid ²	5.81	5.61	0.07	0.09	0.27	0.95
Final precalving ³	5.64	5.35	0.07	0.03	0.001	0.97
Rib fat ⁵ , cm						
Initial	0.77	0.74	0.04	0.63	0.16	0.99
Mid ²	0.61	0.60	0.04	0.76	0.84	0.80
Final precalving ³	0.56	0.48	0.03	0.09	0.30	0.31
Calf						
Birth weight, kg	38.2	34.3	1.0	0.03	0.78	0.81
Date of birth, day of study	96.4	92.9	2.1	0.26	0.69	0.68
Gestation length ⁶ , day	283	281	1	0.18	0.20	0.97

¹Cows either strip-grazed STF pastures or consumed summer-baled tall fescue hay in dry lots. Forage systems began on day 187 ± 13 and 188 ± 14 of gestation in year 1 and year 2, respectively, and all cows remained in respective forage systems through gestation.

²Mid = day 35 of forage system, day 222 ± 13 of gestation in year 1, day 223 ± 14 of gestation in year 2.

³Final precalving = day 78 of forage study, day 265 ± 13 of gestation in year 1, day 266 ± 14 of gestation in year 2.

⁴Body condition scores evaluated on a 1 to 9 scale, where 1 = emaciated and 9 = obese.

⁵12th rib fat thickness.

⁶Fixed-time artificial insemination bred cows only.

BW changes included early lactation in the previous study, and increased nutrient needs during this period likely influenced cow performance. Because forage system treatments were terminated before spring pasture turnout to assess effects on calves as a result of late gestational treatments only, cow performance postpartum may have been impacted if treatments had been continued. Grazing STF after early February calving is possible in many years in the Fescue belt, although quality of STF is known to decrease in late winter (Kallenbach et al., 2003; Curtis and Kallenbach, 2007; Meyer et al., 2009).

Body weight gain was expected prepartum, as cows should be gaining fetal weight along with placental and fluid weight during late gestation. The fact that cows from both forage systems gained minimal BW and maintained or lost minimal BCS overall is not surprising given they were well-conditioned prior to the study's initiation. These data are in agreement with previously reported data where cows consuming STF during late gestation lost less BCS than cows consuming tall fescue hay alone (Meyer et al., 2009). Our data also agree with previous studies where cows consuming low protein forages and supplemented during late gestation had greater BCS precalving than nonsupplemented cows (Stalker et al., 2006; Martin et al., 2007; Larson et al., 2009). Although the cows in this study were not supplemented, those consuming STF did have access to greater nutrient intake during late gestation, reflecting an increased nutritional plane. Furthermore, weather experienced by cows in both forage systems, neither of which

had access to cover or wind breaks, increased energy requirements during this period. These data suggest that cows grazing STF fared these conditions better during late gestation, based on greater precalving body reserves in these cows. Likely these results would have been more dramatic if cows had begun the study with a BCS ≤ 5 , as suggested by differences between years in Meyer et al. (2009). Furthermore, hay used in this study could have been supplemented with energy and protein, allowing cows to meet nutrient requirements of late pregnancy and perform similarly to cows grazing STF (Meyer et al., 2009).

Postpartum. There was no effect ($P \geq 0.38$) of forage system or the forage system $\times$ year interaction for cow BW or BCS at the subsequent breeding or weaning (Table 3). Cows consumed hay with supplement and then grazed lush spring forage growth before breeding, which provided the necessary nutrients to negate any late gestation BW or BCS differences. These results are similar to previous research with late gestation cows consuming STF or hay over winter, where minimal carryover effects were observed (Meyer et al., 2009).

Cow first service conception and overall pregnancy rates were not affected ($P \geq 0.15$) by late gestation forage system or the forage system $\times$ year interaction. Although first service conception rates approach a tendency ($P = 0.15$) where cows that grazed STF during winter were more likely to conceive, numbers in this study were not large enough to detect differences. Precalving BCS is a major

Table 3. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on postpartum cow performance

Variable	Forage system ¹		SEM	P-value		
	STF	Hay		Forage system	Year	Forage system $\times$ year
Body weight, kg						
Breeding ²	598	589	10	0.55	0.22	0.44
Weaning ³	606	603	10	0.82	0.48	0.54
Body condition score ⁴						
Breeding	5.2	5.2	0.1	0.96	0.95	0.60
Weaning	5.2	5.1	0.1	0.90	0.003	0.38
AI conception rate, %	58.7 (27/46)	43.8 (21/48)	--	0.15	0.87	0.81
Overall pregnancy rate, %	89.1 (41/46)	87.5 (42/48)	--	0.81	0.80	0.78

AI = artificial insemination.

¹Cows either strip-grazed STF pastures or consumed summer-baled tall fescue hay in dry lots. Forage systems began on day 187 ± 13 and 188 ± 14 of gestation in year 1 and year 2, respectively and all cows remained in respective forage systems through calving until moved to a common pasture at 6.4 ± 3.3 d (year 1) and 6.7 ± 2.5 d (year 2) postpartum, and were then managed as 1 group through weaning.

²Year 1: May 1, 2014; year 2: May 8, 2015.

³Year 1: October 2, 2014; year 2: September 30, 2015.

⁴Body condition scores evaluated on a 1 to 9 scale, where 1 = emaciated and 9 = obese.

indicator of resumption of estrus (Wettemann et al., 2003); however, mean precalving and breeding BCS from both forage systems were > 5 , suggesting that this was not a concern in the current study.

Calf Fetal Growth

Calves born to cows consuming hay during late gestation weighed 10.2% less ($P = 0.03$) at birth than calves born to cows consuming STF (Table 2), with no forage system $\times$ year interaction ($P = 0.81$). Cows consuming hay during late gestation lost more BCS compared with cows grazing STF, suggesting that the hay-fed cows were not meeting the nutrient requirements of late gestation. Thus, calves born to cows fed hay likely had decreased fetal growth due to reduced nutrient availability during gestation, not allowing these calves to reach their genetic potential for fetal growth in utero. Minimal cases of dystocia occurred in this study (2 assisted calvings in year 2; 1 due to size or lack of cervical dilation and 1 due to malpresentation), as the result of intensive selection for calving ease and birth weight in the cowherd. Although increased birth weight is often interpreted negatively in the beef industry, intrauterine growth restriction caused by nutrient restriction can have long-lasting consequences (Fowden et al., 2006; Wu et al., 2006; Caton and Hess, 2010). For example, these calves could have had altered fetal development resulting in decreased organ size or function, leading to poor postnatal health and survivability. Additionally, two-thirds of the nonpredator preweaning death loss of beef calves occurs in the first 21 d of life (USDA-APHIS, 2011), often due to issues at calving, cold or heat stress, or disease acquired due to failure of passive transfer. Poor fetal development, decreased organ maturation, and reduced calf vigor possible with this fetal growth restriction can present major problems during the difficult neonatal period.

Calf date of birth, calculated as the day of study (Table 2), was not impacted by late gestation forage system ($P = 0.26$) or the forage system $\times$ year interaction ($P = 0.68$). This indicates that differences in BW at birth in our study were not due to differences in length of dam exposure to forage system treatments. Gestation length was not affected by forage system ($P = 0.18$) or the forage system $\times$ year interaction ($P = 0.97$). Calves born to cows grazing STF had numerically longer gestation length than hay-fed cows. This gestation length difference may be biologically relevant, but not detectable with the statistical power of the current study. Despite

this, the possible difference in gestation length was not enough to cause the birth weight difference observed between forage systems.

Our findings are in agreement with others reporting that maternal nutrient restriction during late gestation resulted in reduced offspring birth weight (Corah et al., 1975; Houghton et al., 1990; Freetly et al., 2005). Despite this, similar research utilizing STF versus hay during late gestation resulted in no differences in offspring birth weight despite improved BW and BCS in cows consuming STF (Meyer et al., 2009). The disparity in results could have been influenced by cows being fed hay on pasture in the previous study, allowing them access to higher quality residual forage and forage growth prior to parturition, or poor allocation to treatment based on genetic potential for birth weight (Meyer et al., 2009). Winter forage system of spring-calving cows has previously affected calf birth weight, where cows that grazed corn residue gave birth to calves that weighed more than those which grazed winter range (Larson et al., 2009; Funston et al., 2010). Conversely, protein supplementation of spring-calving cows consuming low protein forages during late gestation did not alter calf birth weight, but did improve later calf performance (Stalker et al., 2006; Martin et al., 2007). Although the current study did not involve concentrate protein supplementation, forage CP differences were substantial and likely the overall nutritional plane improvement of females in the current STF forage system and protein supplemented treatment of the Stalker et al. (2006) and Martin et al. (2007) studies was similar. The impact of maternal nutrition during late gestation on offspring birth weight has had conflicting results, potentially dependent on severity and length of restriction, breed and genetic makeup, dam parity, influence of cold or heat stress, and forage or supplement sources.

It is likely that the decreased fetal growth observed in hay-fed cows could have been mitigated by supplementation with protein and energy to meet increased nutrient demands of late pregnancy, solidifying the importance of forage testing and matching forage quality to animal requirements. It is also interesting to note that cows consuming hay were confined to a smaller area during late gestation, with less distance to travel from forage to water. In fact, cows grazing STF had twice as many steps as cows consuming hay, as measured using IceQube activity monitors (IceRobotics, Edinburgh, UK; data not shown). Thus, cows grazing STF likely had greater relative energy requirements based on this increased movement, but also had greater forage

nutrient availability. Harris et al. (2013) observed that exercise during mid- to late gestation increased umbilical blood flow in pregnant gilts, although this did not result in greater litter weights or piglets born alive. This suggests that additional steps taken by grazing cows may have played a role in the greater birth weight observed, despite the increase in energy expenditure.

Maternal Circulating Metabolites and Hormones

Effects of forage system, sampling day, year, and all forage system interactions are shown in Table 4 for cow circulating metabolites and hormones. The interaction of forage system $\times$ day $\times$ year affected ($P < 0.001$) serum NEFA and tended to affect ($P = 0.06$) serum T_4 . Forage system $\times$ day $\times$ year and forage system $\times$ year interactions did not affect ($P \geq 0.23$) other metabolites or hormones. Forage system $\times$ day affected ($P \leq 0.006$) serum urea N, T_3 , and cortisol, and plasma glucose was affected ($P < 0.001$) by the main effect of day and tended to be affected ($P = 0.08$) by forage system.

Serum urea nitrogen. The forage system $\times$ day interaction ($P < 0.001$) for cow serum urea N concentrations during late gestation is shown in Fig. 1. Forage system did not affect ($P = 0.77$) serum urea N at study initiation (day 0). However, by day 20 and throughout the remainder of gestation, serum urea N was greater ($P < 0.001$) in cows grazing STF compared with cows consuming hay.

The greater CP content of STF, being nearly twice that of the hay, likely resulted in both an increase in ammonia N absorbed from amino acids deaminated in the rumen and excess amino acids deaminated by the animal itself after absorption in the small intestine. Carbon skeletons from this latter deamination also provided energy for animals grazing STF. Ruminant degradable protein is used

most efficiently for microbial protein synthesis when the N to energy ratio is optimized. In this study, STF cows likely had adequate to excess N relative to digestible carbohydrate available in the rumen, increasing the ruminal ammonia concentration for absorption and conversion to urea (Hammond, 1992). It has been previously reported that when circulating urea N concentrations in forage-fed beef cattle are less than 7 mg/dL, protein is deficient compared with energy available (Hammond, 1992). This indicates that cows consuming hay in this study were likely deficient in protein from day 35 of the forage system through the remainder of gestation, whereas cows grazing STF were well above the 7 mg/dL threshold.

In agreement with the current study, research in pregnant ewes and heifers has indicated that as nutritional plane increases, circulating urea N increases during late gestation (Vonnahme et al., 2013; Gunn et al., 2014). Another study in ewes

Figure 1. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow serum urea N concentrations. There was a forage system $\times$ day interaction ($P < 0.001$). Least squares means $\pm$ SEM are presented. * indicates that means differ between forage systems for that day ($P < 0.05$).

Table 4. Effects of forage system, day of sampling, and year of study on cow circulating metabolites and metabolic hormones during late gestation

Item	P-value ¹					
	Forage system	Day	Forage system $\times$ day	Year	Forage system $\times$ year	Forage system $\times$ day $\times$ year
Serum urea N	<0.001	0.58	<0.001	0.02	0.61	0.28
Plasma glucose	0.08	<0.001	0.61	0.03	0.28	0.23
Serum nonesterified fatty acids	0.01	<0.001	<0.001	0.42	0.003	<0.001
Serum triiodothyronine	0.69	<0.001	<0.001	0.38	0.60	0.63
Serum thyroxine	0.94	<0.001	0.31	0.70	0.63	0.06
Serum cortisol	0.12	0.001	0.006	0.89	0.36	0.54

¹Probability values for forage system, day, year, and their interactions. Bold, italic P-values are highest order interactions with forage system in the model or main effects for each item ($P < 0.10$), and are shown in figures.

resulted in nutrient intake not impacting urea N concentrations during late gestation, however these results may have been due to protein catabolism that occurred when protein was restricted (Lekatz et al., 2010). In the current study, the increase in serum urea N and maternal metabolic status resulted from the increase in CP intake from STF compared with cows consuming hay with less CP intake.

Glucose. The main effects of forage system ($P = 0.08$) and day ($P < 0.001$) on cow plasma glucose concentrations are shown in Fig. 2. Cows grazing STF tended ($P = 0.08$) to have greater plasma glucose compared with cows consuming hay. Additionally, plasma glucose increased ($P = 0.002$) from day 0 to 20, remained similar ($P = 0.56$) from day 20 to 35, and increased ($P < 0.001$) from day 35 to 56. Glucose decreased ($P < 0.001$) from day 56 to 77 of study then remained similar ($P = 0.80$) through day 99.

In grazing ruminants, less than 10% of the total glucose utilized is absorbed as glucose in the small intestine; thus, most of the glucose that is available to tissues is supplied by gluconeogenesis (Otchere et al., 1974; Young, 1976). Because of this, ruminant circulating glucose is not generally considered to be altered by small diet changes. The greater digestible nutrient intake in cows grazing STF is likely to have increased glucose concentrations during late gestation compared with cows consuming hay, even though it is unlikely to be due to increased small intestinal glucose absorption. Other studies have also observed increased circulating glucose in

Figure 2. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow plasma glucose concentrations. There was a main effect of day ($P < 0.001$; main) and tended to be a main effect of forage system ($P = 0.08$; inset). Least squares means $\pm$ SEM are presented. ^{a,b,c} items lacking a common superscript differ among day ($P < 0.05$).

pregnant ruminants with greater nutrient intake (Mellor et al., 1987; Luther et al., 2007).

During late gestation, placental uptake of glucose increases in ruminants (Bell and Bauman, 1997), which may account for the increased circulating glucose observed in the current study. Data from our study indicate that gluconeogenesis may change with glucose demands, as forage quality did not improve at day 56 for either forage system. Although glucose release from the portal drained viscera was unchanged as pregnancy advanced, splanchnic glucose release tended to increase in late gestation ewes in one study (Freetly and Ferrell, 1998). Despite this, others have observed static (Reynolds et al., 1990) or decreased (Doornenbal et al., 1988) circulating glucose concentrations during late gestation in beef cattle.

Nonesterified fatty acids. The forage system $\times$ day $\times$ year interaction ($P < 0.001$) for serum NEFA concentrations is shown in Fig. 3. In year 1, cows grazing STF had greater ($P < 0.001$) circulating

Figure 3. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow serum nonesterified fatty acid (NEFA) concentrations. There was a forage system $\times$ day $\times$ year interaction ($P < 0.001$). Least squares means $\pm$ SEM are presented for year 1 (Panel A) and year 2 (Panel B). * indicates that means differ ($P < 0.05$) or + tend to differ ($P < 0.10$) between forage systems for that day, in that year.

NEFA on day 56 than cows consuming hay, but NEFA were similar ($P \geq 0.20$) on all other sampling days. In year 2, cows grazing STF tended ($P = 0.10$) to have greater serum NEFA on day 35 and had greater ($P < 0.001$) NEFA on day 77 and 99 of study compared with cows consuming hay.

We hypothesized that cows consuming hay would have increased NEFA concentrations due to cows consuming hay only having decreased nutrient intake and greater mobilization of body fat, as shown in BCS and rib fat precalving. Circulating NEFA generally increase when fat stores are mobilized in order to meet energy demands; thus, they typically increase if requirements are not met by the animal's plane of nutrition. Contrary to this study, nutrient restriction during mid- and late pregnancy has been reported to increase circulating NEFA concentrations in ewes (Luther et al., 2007; Lekatz et al., 2010; Vonnahme et al., 2013). There may be a number of reasons why NEFA concentrations were not different between forage systems during much of gestation in both years. At the onset of the study, the average BCS was 5.7 for both treatments, indicating well-conditioned cows with similar amount of adipose that could be mobilized. Although cows grazing STF appeared to consume more nutrients, they also had an increase in locomotion due to grazing, as well as a greater distance to walk on blood collection days (data not shown). Additionally, the exposure to cold stress during the winter months of late gestation may have impacted NEFA concentrations of both forage systems by increasing fat mobilization in order to meet energy demands of thermoregulation in year 1.

In early lactation, when there is likely to be a negative energy balance, circulating NEFA often increase when the high nutrient demand of lactation is not met by the diet. In this study, postpartum NEFA was greater at 7 d postpartum (taken just before forage system treatment termination) for cows consuming hay during late gestation compared with cows grazing STF (data not shown). This supports our original hypothesis, although it is unclear why late gestational data show the opposite results.

Thyroid hormones. The forage system $\times$ day interaction ($P < 0.001$) for cow serum T_3 during late gestation is shown in Fig. 4, and the forage system $\times$ day $\times$ year interaction ($P = 0.06$) for cow serum T_4 is shown in Fig. 5. At study initiation, serum T_3 was greater ($P = 0.03$) for cows consuming hay during late gestation, but at day 35 and 77, serum T_3 was not different ($P \geq 0.21$) between forage systems. On day 99 of study, cows grazing STF had greater ($P = 0.004$) serum T_3 compared

Figure 4. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow serum triiodothyronine (T_3) concentrations. There was a forage system $\times$ day interaction ($P < 0.001$). Least squares means $\pm$ SEM are presented. * indicates that means differ between forage systems for that day ($P < 0.05$).

Figure 5. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow serum thyroxine (T_4) concentrations. There tended to be a forage system $\times$ day $\times$ year interaction ($P = 0.06$). Least squares means $\pm$ SEM are presented in (Panel A) for year 1 and (Panel B) for year 2. * indicates that means differ between forage systems for that day ($P < 0.05$).

with cows consuming hay; however, this only represents the subset of cows that had not calved by day 99 of study. In year 1, cows grazing STF tended

($P = 0.06$) to have greater serum T_4 on day 77 of study, but were not different ($P \geq 0.18$) between forage systems on any other sampling day in year 1 or 2. There was a forage system $\times$ day interaction ($P = 0.02$) for serum $T_3:T_4$ (data not shown). The ratio was not different ($P = 0.45$) on day 0 of study, but day 35 $T_3:T_4$ was greater ($P = 0.04$) in cows fed hay compared with STF. The $T_3:T_4$ ratio was not different ($P = 0.52$) on day 77 of study, but on day 99 cows grazing STF had a greater ($P = 0.03$) ratio. This indicated that cows grazing STF had greater conversion to the active form T_3 on day 99, despite hay-fed cows have greater conversion on day 35 of the forage system.

From these data, we conclude that the difference in nutrient intake between the forage systems in this study had minimal impacts on maternal thyroid hormone secretion or conversion during late gestation. Thyroid hormones play an important role in fetal development (McNabb and King, 1993) and determining available energy (Fowden and Forhead, 2004). Previous studies in mid- and late gestation ewes have observed that both circulating T_3 and T_4 increase with nutrient intake (Ward et al., 2008; Vonnahme et al., 2013; Lemley et al., 2014), indicating that the increase in maternal T_3 and T_4 observed in this study for cows grazing STF in late gestation may also have been caused by nutrient intake. These may have been less sustained responses because the difference in nutrient intake was less dramatic than in previous studies cited here. Despite this, ewes in late gestation had minimal differences due to current or previous plane of nutrition in another study (Lekatz et al., 2010); thus, late gestational nutritional treatments alone may not be enough to alter thyroid hormones greatly.

Cortisol. The forage system $\times$ day interaction ($P = 0.01$) for cow serum cortisol concentrations is shown in Fig. 6. There was no difference ($P = 0.42$) in serum cortisol between forage systems at study initiation; however, by day 35 serum cortisol was greater ($P = 0.003$) in cows grazing STF compared with cows consuming hay. Serum cortisol was not different ($P = 0.47$) on day 77 between forage systems, but serum cortisol tended ($P = 0.10$) to be greater in cows grazing STF compared with cows consuming hay on day 99.

Studies conducted in pregnant ewes have reported similar results with circulating cortisol increasing as nutrient intake increased (Vonnahme et al., 2013; Lemley et al., 2014). The reduction of maternal cortisol during nutrient restriction may promote lipolysis and maximize nutrient supply to

Figure 6. Effects of feeding stockpiled tall fescue (STF) versus summer-baled tall fescue hay (Hay) during late gestation on cow serum cortisol concentrations. There was a forage system $\times$ day interaction ($P < 0.006$). Least squares means $\pm$ SEM are presented. * indicates that means differ or + tend to differ ($P < 0.10$) between forage systems for that day ($P < 0.05$).

the growing fetus during late gestation (Bispham et al., 2003), although NEFA data from the current study do not support this. Other studies have reported that cortisol concentrations increase during nutrient restriction because of the metabolic role of cortisol, including increasing gluconeogenesis, lipolysis, and protein catabolism (Guyton, 1991), which would increase circulating cortisol. However, prolonged exposure to nutrient restriction has been reported to reduce cortisol concentrations gradually over time (Sticker et al., 1995).

Maternal Prepartum Metabolite and Hormone Correlations With Calf Birth Weight

Partial correlation coefficients between calf birth weights and the last prepartum maternal metabolite or hormone concentrations, taken at 6.6 ± 1.0 d (year 1) and 8.4 ± 0.6 d (year 2) precalving, are shown in Table 5. Serum urea N ($P = 0.002$) and NEFA ($P = 0.005$) both had a weak positive correlation with calf birth weight. No other metabolites and hormones analyzed (plasma glucose, T_3 , T_4 , and cortisol) were correlated ($P \geq 0.15$) with calf birth weight.

These correlations indicate that as maternal prepartum serum urea N and NEFA concentrations increased in the current study, calf birth weight increased. The positive correlations of maternal serum urea N and NEFA with calf birth weight may be due to a greater transfer of nutrients to the fetus. The increased nutrient intake of the dam or mobilization of fat may have resulted in increased fetal growth and heavier calves. In the current

Table 5. Partial correlation coefficients between final prepartum maternal metabolite or hormone concentration and calf birth weight

Maternal metabolite or hormone ¹	Partial correlation coefficient with calf birth weight (<i>r</i>)	<i>P</i> -value
Serum urea N	0.31	0.002
Plasma glucose	-0.07	0.47
Serum nonesterified fatty acids	0.12	0.005
Serum triiodothyronine	-0.05	0.41
Serum thyroxine	0.08	0.15
Serum cortisol	0.04	0.46

¹Last prepartum maternal circulating metabolite or hormone concentration, collected 6.6 ± 1.0 d (year 1) and 8.4 ± 0.6 d (year 2) precalving.

study, serum urea N and birth weight were likely correlated due to protein intake of cows in each forage system, suggesting that protein availability limited fetal growth in the hay treatment. Moreover, the difference in serum urea N between forage systems was evident by 20 d into the treatment period, suggesting that CP intake drove differences in birth weight. Further research is necessary to determine if this relationship exists without a nutrient intake difference. Previously, circulating NEFA concentrations have been reported to be greater during the last 4 wk of gestation in cows that gave birth to larger calves compared with cows with medium and light weight calves (Guedon et al., 1999). The relationship of NEFA and birth weight is very weak in the current study, however. Because metabolites were more altered than hormones by forage system (nutrient intake), it is not surprising that metabolites were correlated with birth weight rather than hormones. Although these relationships are not often studied, more research may allow for identification of an indicator for intrauterine growth restriction before parturition occurs, which in turn would allow for altered management of those neonates postnatally.

CONCLUSION

Overall, results of this study indicate that grazing STF during late gestation increases nutrient intake and circulating metabolites of cows compared with those consuming summer-baled tall fescue-based hay only. Grazing STF during late gestation allowed for normal fetal growth in spring-calving cows, but consuming summer-baled tall fescue-based hay alone did not result in adequate nutrient intake for fetal growth. Additionally, prepartum maternal circulating serum urea N and NEFA were positively correlated with calf birth weight. Cow performance was not impacted greatly by these forage systems in the current study, but cows entering late gestation with less body condition may show greater response to grazing STF. Although supplementing

summer-baled hay with energy and protein is an option for wintering spring-calving beef cows, grazing STF can also meet nutrient requirements of late gestation.

LITERATURE CITED

- Barker, D. J., P. D. Gluckman, K. M. Godfrey, J. E. Harding, J. A. Owens, and J. S. Robinson. 1993. Fetal nutrition and cardiovascular disease in adult life. *Lancet* 341:938–941. doi:10.1016/0140-6736(93)91224-A
- Bell, A. W., and D. E. Bauman. 1997. Adaptations of glucose metabolism during pregnancy and lactation. *J. Mammary Gland Biol. Neoplasia* 2:265–278. doi:10.1023/A:1026336505343
- Bispham, J., G. S. Gopalakrishnan, J. Dandrea, V. Wilson, H. Budge, D. H. Keisler, F. Broughton Pipkin, T. Stephenson, and M. E. Symonds. 2003. Maternal endocrine adaptation throughout pregnancy to nutritional manipulation: consequences for maternal plasma leptin and cortisol and the programming of fetal adipose tissue development. *Endocrinology* 144:3575–3585. doi:10.1210/en.2003-0320
- Caton, J. S., and B. W. Hess. 2010. Maternal plane of nutrition: impacts on fetal outcomes and postnatal offspring responses. In: B. W. Hess, T. DelCurto, J. G. P. Bowman, and R. C. Waterman, editors. *Proc. 4th grazing livestock nutrition conference*. West. Sect. Am. Soc. Anim. Sci., Champaign, IL. p. 104–122.
- 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. doi:10.2527/jas1975.413819x
- Curtis, L. E., and R. L. Kallenbach. 2007. Endophyte infection level of tall fescue stockpiled for winter grazing does not alter the gain of calves nursing lactating beef cows. *J. Anim. Sci.* 85:2346–2353. doi:10.2527/jas.2006-848
- Curtis, L. E., R. L. Kallenbach, and C. A. Roberts. 2008. Allocating forage to fall-calving cow-calf pairs strip-grazing stockpiled tall fescue. *J. Anim. Sci.* 86:780–789. doi:10.2527/jas.2007-0525
- Doornenbal, H., A. K. Tong, and N. L. Murray. 1988. Reference values of blood parameters in beef cattle of different ages and stages of lactation. *Can. J. Vet. Res.* 52:99–105.
- D'Souza, G., E. Maxwell, W. Bryan, and E. Prigge. 1990. Economic impacts of extended grazing systems. *Am. J. Alternative Agr.* 5:120–125. doi:10.1017/S0889189300003428
- Fowden, A. L., and A. J. Forhead. 2004. Endocrine mechanisms of intrauterine programming. *Reproduction* 127:515–526. doi:10.1530/rep.1.00033

- Fowden, A. L., D. A. Giussani, and A. J. Forhead. 2006. Intrauterine programming of physiological systems: causes and consequences. *Physiology* (Bethesda). 21:29–37. doi:10.1152/physiol.00050.2005
- Freetly, H. C., and C. L. Ferrell. 1998. Net flux of glucose, lactate, volatile fatty acids, and nitrogen metabolites across the portal-drained viscera and liver of pregnant ewes. *J. Anim. Sci.* 76:3133–3145. doi:10.2527/1998.76123133x
- Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2005. Nutritionally altering weight gain patterns of pregnant heifers and young cows changes the time that feed resources are offered without any differences in production. *J. Anim. Sci.* 83:916–926. doi:10.2527/2005.834916x
- Funston, R. N., J. L. Martin, D. C. Adams, and D. M. Larson. 2010. Winter grazing system and supplementation of beef cows during late gestation influence heifer progeny. *J. Anim. Sci.* 88:4094–4101. doi:10.2527/jas.2010-3039
- Guedon, L., J. Saumande, and B. Desbals. 1999. Relationships between calf birth weight, prepartum concentrations of plasma energy metabolites and resumption of ovulation postpartum in limousine suckled beef cows. *Theriogenology* 52:779–789. doi:10.1016/S0093-691X(99)00171-5
- Gunn, P. J., J. P. Schoonmaker, R. P. Lemenager, and G. A. Bridges. 2014. Feeding excess crude protein to gestating and lactating beef heifers: impact on parturition, milk composition, ovarian function, reproductive efficiency and pre-weaning progeny growth. *Livest. Sci.* 167:435–448. doi:10.1016/j.livsci.2014.05.010
- Guyton, A. C. 1991. Textbook of medical physiology. Philadelphia, PA: Harcourt College Publishing.
- Hammond, A. C. 1992. Update on bun and mun as a guide for protein supplementation in cattle. In: 3rd Annual Florida Ruminant Nutrition Symposium; January 1992; Gainesville, FL: University of Florida. p. 9–18.
- Harris, E. K., E. P. Berg, E. L. Berg, and K. A. Vonnahme. 2013. Effect of maternal activity during gestation on maternal behavior, fetal growth, umbilical blood flow, and farrowing characteristics in pigs. *J. Anim. Sci.* 91:734–744. doi:10.2527/jas.2012-5769
- Hill, N. S., G. E. Rottinghaus, C. S. Agee, and L. M. Schultz. 1993. Simplified sample preparation for HPLC analysis of ergovaline in tall fescue. *Crop Sci.* 33:331–333. doi:10.2135/cropsci1993.0011183X003300020024x
- Houghton, P. L., R. P. Lemenager, K. S. Hendrix, G. E. Moss, and T. S. Stewart. 1990. Effects of body composition, pre- and postpartum energy intake and stage of production of energy utilization by beef cows. *J. Anim. Sci.* 68:1447–1456. doi:10.2527/1990.6851447x
- Kallenbach, R., G. Bishop-Hurley, M. Massie, G. Rottinghaus, and C. West. 2003. Herbage mass, nutritive value, and ergovaline concentration of stockpiled tall fescue. *Crop Sci.* 43:1001–1005. doi:10.2135/cropsci2003.1001
- Larson, D. M., J. L. Martin, D. C. Adams, and R. N. Funston. 2009. Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. *J. Anim. Sci.* 87:1147–1155. doi:10.2527/jas.2008-1323
- Lekatz, L. A., J. S. Caton, J. B. Taylor, L. P. Reynolds, D. A. Redmer, and K. A. Vonnahme. 2010. Maternal selenium supplementation and timing of nutrient restriction in pregnant sheep: effects on maternal endocrine status and placental characteristics. *J. Anim. Sci.* 88:955–971. doi:10.2527/jas.2009-2152
- Lemley, C. O., A. M. Meyer, T. L. Neville, D. M. Hallford, L. E. Camacho, K. R. Maddock-Carlin, T. A. Wilmoth, M. E. Wilson, G. A. Perry, D. A. Redmer, et al. 2014. Dietary selenium and nutritional plane alter specific aspects of maternal endocrine status during pregnancy and lactation. *Domest. Anim. Endocrinol.* 46:1–11. doi:10.1016/j.domaniend.2013.09.006
- Luther, J., R. Aitken, J. Milne, M. Matsuzaki, 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. doi:10.1095/biolreprod.107.061440
- Martin, J. L., K. A. Vonnahme, D. C. Adams, G. P. Lardy, and R. N. Funston. 2007. Effects of dam nutrition on growth and reproductive performance of heifer calves. *J. Anim. Sci.* 85:841–847. doi:10.2527/jas.2006-337
- McNabb, F. M., and D. B. King. 1993. Thyroid hormone effects on growth, development and metabolism. The endocrinology of growth, development, and metabolism of vertebrates. New York, NY: Academic Press. p. 393–417.
- 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.* 72:345–356. doi:10.1113/expphysiol.1987.sp003080
- Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. *J. Anim. Sci.* 64:1548–1558. doi:10.2527/jas1987.6451548x
- Meyer, A. M., M. S. Kerley, R. L. Kallenbach, and T. L. Perkins. 2009. Comparison of grazing stockpiled tall fescue versus feeding hay with or without supplementation for gestating and lactating beef cows during winter. *Prof. Anim. Sci.* 25:449–458. doi:10.15232/S1080-7446(15)30741-5
- Moore, W. A., and W. J. Sexten. 2015. Effect of bale feeder and forage on hay waste, disappearance, and sorting. *Prof. Anim. Sci.* 31:248–254. doi:10.15232/pas.2014-01365
- NASEM. 2016. Nutrient requirements of beef cattle. 8th rev. ed. The National Academies Press, Washington, DC.
- Otchere, C. E., A. D. McGilliard, and J. W. Young. 1974. Quantitation of alpha-linked glucose polymers passing to the small intestine in cattle. *J. Dairy Sci.* 57. doi:10.3168/jds.S0022-0302(74)85035-6
- Reynolds, L. P., P. P. Borowicz, J. S. Caton, K. A. Vonnahme, J. S. Luther, C. J. Hammer, K. R. Maddock Carlin, A. T. Grazul-Bilska, and D. A. Redmer. 2010. Developmental programming: the concept, large animal models, and the key role of uteroplacental vascular development. *J. Anim. Sci.* 88 (13 Suppl):E61–E72. doi:10.2527/jas.2009-2359
- Reynolds, L. P., C. L. Ferrell, D. A. Robertson, and J. Klindt. 1990. Growth hormone, insulin and glucose concentrations in bovine fetal and maternal plasmas at several stages of gestation. *J. Anim. Sci.* 68:725–733. doi:10.2527/1990.683725x
- Rottinghaus, G. E., G. B. Garner, C. N. Cornell, and J. L. Ellis. 1991. Hplc method for quantitating ergovaline in endophyte-infested tall fescue: seasonal variation of ergovaline levels in stems with leaf sheaths, leaf blades, and seed heads. *J. Agric. Food Chem.* 39:112–115. doi:10.1021/jf00001a022

- Stalker, L. A., D. C. Adams, T. J. Klopfenstein, D. M. Feuz, and R. N. Funston. 2006. Effects of pre- and postpartum nutrition on reproduction in spring calving cows and calf feedlot performance. *J. Anim. Sci.* 84:2582–2589. doi:10.2527/jas.2005-640
- Sticker, L. S., D. L. Thompson, Jr, J. M. Fernandez, L. D. Bunting, and C. L. DePew. 1995. Dietary protein and(or) energy restriction in mares: plasma growth hormone, IGF-I, prolactin, cortisol, and thyroid hormone responses to feeding, glucose, and epinephrine. *J. Anim. Sci.* 73:1424–1432. doi:10.2527/1995.731136x
- USDA-APHIS. 2011. Cattle and calves nonpredator death loss in the united states, 2010. Fort Collins, CO: USDA Animal and Plant Health Inspection Service- Veterinary Service- Centers for Epidemiology and Animal Health.
- Vonnahme, K. A., T. L. Neville, G. A. Perry, D. A. Redmer, L. P. Reynolds, and J. S. Caton. 2013. Maternal dietary intake alters organ mass and endocrine and metabolic profiles in pregnant ewe lambs. *Anim. Reprod. Sci.* 141:131–141. doi:10.1016/j.anireprosci.2013.07.010
- Ward, M. A., T. L. Neville, J. J. Reed, J. B. Taylor, D. M. Hallford, S. A. Soto-Navarro, K. A. Vonnahme, D. A. Redmer, L. P. Reynolds, and J. S. Caton. 2008. Effects of selenium supply and dietary restriction on maternal and fetal metabolic hormones in pregnant ewe lambs. *J. Anim. Sci.* 86:1254–1262. doi:10.2527/jas.2007-0509
- Wettemann, R. P., C. A. Lents, N. H. Ciccio, F. J. White, and I. Rubio. 2003. Nutritional- and suckling-mediated anovulation in beef cows. *J. Anim. Sci.* 81 (E. Suppl. 2):E48–E59. doi:10.2527/2003.8114_suppl_2E48
- Wu, G., F. W. Bazer, J. M. Wallace, and T. E. Spencer. 2006. Intrauterine growth retardation: Implications for the animal sciences. *J. Anim. Sci.* 84:2316–2337. doi:10.2527/jas.2006-156
- Young, J. W. 1976. Gluconeogenesis in cattle: significance and methodology. *J. Dairy Sci.* 60. doi:10.3168/jds.S0022-0302(77)83821-6