

# Corn supplementation as a winter-feeding strategy alters maternal feeding behavior and endocrine profiles in mid- to late-gestating beef cows<sup>1</sup>

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## INTRODUCTION

Maternal nutritional status is one of the key external factors influencing nutrient partitioning for fetal optimal fetal growth and compromised fetal growth results in impaired lifelong health (Godfrey and Barker, 2000). In livestock, inadequate maternal nutrition during pregnancy can lead to a decrease in carcass quality of the offspring, including altered fat deposition, muscle fiber type, and reduced meat quality (Wu et al., 2006). Gestating beef cows in northern climates often experience maternal nutrient restriction during winter months due to limited grazing opportunities. By increasing the forage quality fed to beef cows during late gestation, Underwood et al. (2010) improved carcass weights.

Evidently, poor carcass outcomes of progeny nutrient restricted *in utero* can be resolved by improving the forage quality fed to beef cows during late gestation, but if those resources are not available, an alternate feeding strategy could be employed including supplementation strategies. We observed supplementing dried distiller's grains plus solubles (DDGS) at 0.3% of BW during late gestation increased roughage intake and calf birth weights (Kennedy et al., 2016). In this study, we hypothesized that mid- to late-gestating beef cows receiving corn supplementation over winter would gain more BW and BCS, increase NE<sub>m</sub> consumption, have a less negative energy balance as evidenced by maternal endocrine and metabolic profiles, and give birth to heavier, faster growing calves. The objective of this study was to evaluate the effects of supplementing corn to gestating beef cows on feed intake and behavior, BW and BCS, endocrine and metabolic profiles, and birth parameters.

## MATERIALS AND METHODS

### *Experimental Design, Cows, and Dietary Treatments*

All procedures were approved by the North Dakota State University (NDSU) Animal Care

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and Use Committee. Forty-seven multiparous, Angus-based beef cows carrying bull calves were assigned randomly to two dietary treatments. Treatments were control (CON;  $n = 23$ ) receiving *ad libitum* access to a low-quality, forage-based total mixed ration (TMR; 57.54% TDN, 6.4% CP) and a treatment group (SUP;  $n = 24$ ) receiving corn at 0.2% of BW in addition to *ad libitum* access to the basal TMR. Cows were stratified by BW and BCS across treatments, weighing  $661 \pm 7.8$  kg and having a BCS of  $5.2 \pm 0.1$  at the start of the study. To monitor individual feeding behavior and intake, cows were fitted with radio-frequency identification tags, and intake was monitored and controlled via electronically controlled feeders (RIC feeding system; Insentec B.V., Marknesse, Netherlands) beginning on day 110 of gestation for 22 wk. Feeding behavior measurements with the Insentec feeder were characterized as described by [Islas et al. \(2014\)](#).

### ***BW, Condition, and Carcass Ultrasounds***

Beginning at day  $100 \pm 6$  of gestation, cows were weighed, and jugular blood samples were collected every 4 wk until day  $240 \pm 6$  of gestation. Body condition was scored using a 1 to 9 scale ([Wagner et al., 1988](#)) every 4 wk from days 100 to 240 of gestation by three technicians. Carcass ultrasound measurements were taken in accordance with [Wall et al. \(2004\)](#) by a single experienced technician on day 100 and 250 of pregnancy. After parturition, pairs were weighed, and jugular blood samples were collected at 0 h, 24 h, and 21 d postpartum.

### ***Feed Analysis***

The basal forage diet during gestation was sampled weekly and analyzed for DM, ash, N (Kjeldahl method), Ca, P, and ether extract by standard procedures ([AOAC, 1990](#)) and for NDF and ADF sequentially by methods of [Robertson and Van Soest \(1981\)](#) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). TDN was calculated as  $97.6 - (0.974 \times \text{ADF})$ ; D. R. Mertens, personal communication). CP was calculated as N concentration  $\times 6.25$ .

### ***Metabolite and Endocrine Analysis***

NEFA concentration in plasma samples was measured using an in vitro enzymatic colorimetric assay (HR Series NEFA-HR, Wako Chemicals USA, Richmond, VA). Glucose plasma concentrations were measured using a hexokinase-based

assay (Infinity Glucose Hexokinase; Thermo Trace, Louisville, CO). Urea concentration in plasma samples was measured by absorption of a urea-specific chromogen at 520 nm (QuantiChrom Urea Assay, BioAssay Systems, Hayward, CA) according to the manufacturer's specifications. Cow and calf serum cortisol, total T3, and total T4 concentrations were determined via solid-phase, competitive chemiluminescent enzyme immunoassay kits and evaluated according to manufacturer's instructions (IMMULITE 1000; Siemens, Los Angeles, CA). The average intra-assay and interassay coefficients of variation were 6.5% and 4.3%, 13.5% and 6.5%, and 7.7% and 5.4% for cortisol, T3, and T4, respectively. Plasma E2 and P4 concentrations were determined by RIA using methods described by [Perry and Perry \(2008\)](#). The average intra-assay and interassay CV were  $<15\%$ , 4.5% and 9.6% for E2 and P4, respectively.

### ***Statistical Analysis***

All cow gestational feed intake and behavior data were analyzed with repeated measures by weekly averages of daily observations using generalized least squares (MIXED procedure; SAS Institute Inc., Cary, NC). Gestational metabolite data were also analyzed with repeated measures (day of gestation) using generalized least squares. The model statements included cow, maternal diet, day of gestation, and a diet by day of gestation interaction. Sire ( $n = 4$ ) was treated as a random variable. Means were separated using the least significant difference approach (PDIF option of LSMEANS).

## **RESULTS**

As reported by [Tanner et al. \(2017\)](#), a day by treatment interaction was observed for cow BW ( $P < 0.01$ ) and BCS ( $P \leq 0.05$ ) as SUP cows gained more BW and BCS across gestation. Additionally, in accordance with [Tanner et al. \(2017\)](#), corn-supplemented cows also had a greater ( $P < 0.01$ ) ADG than control cows (0.68 vs.  $0.46 \pm 0.08$  kg/d). NRC estimates calculated using laboratory values for our roughage diets and Insentec DMI data conclude that both dietary treatments met and exceeded (CON = 110% NRC and SUP = 125% NRC ME, MCal/kg, respectively) their daily NRC requirements. Corn supplementation increased percentage of intramuscular fat ( $P < 0.01$ ; 4.29% vs.  $4.74\% \pm 0.38\%$ ), rump fat ( $P = 0.02$ ; 5.33 vs.  $6.13 \pm 1.12$  mm), and 12th rib ( $P = 0.08$ ; 5.52 vs.  $6.26 \pm 0.51$ ) over gestation (day 100 vs. day 250). At

parturition, 24 h postpartum and 21 d postpartum, cow BW and BCS were not influenced ( $P > 0.50$ ) by corn supplementation.

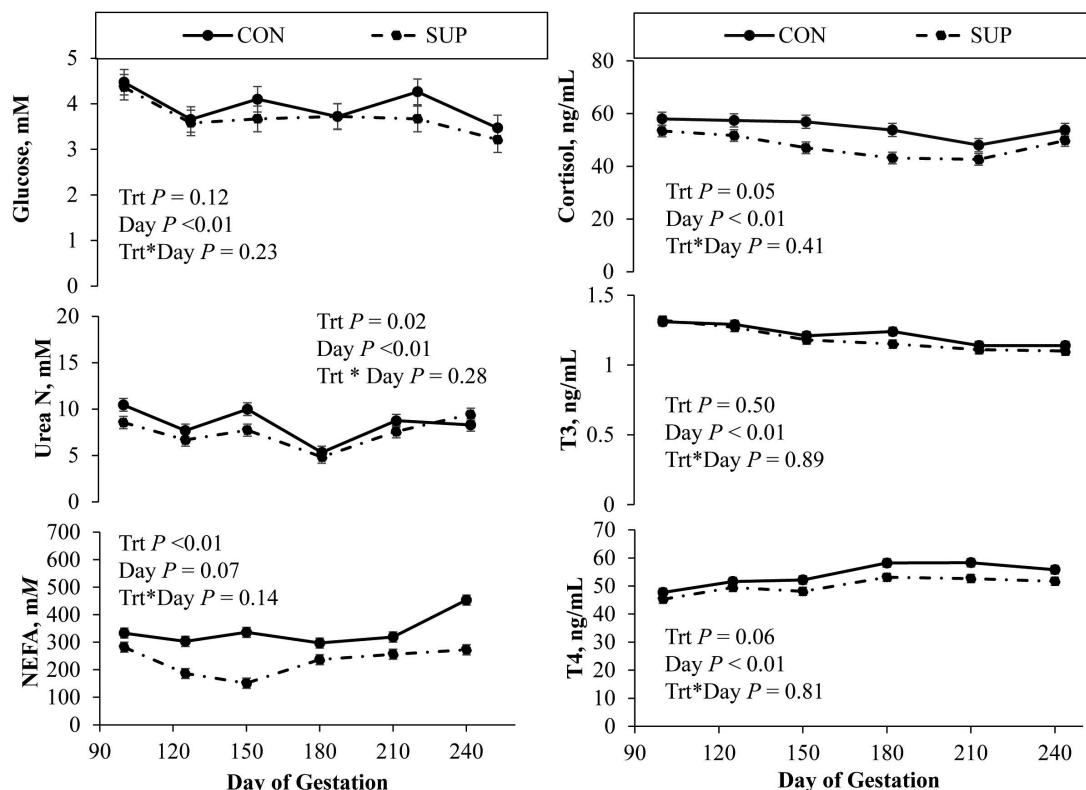
### Gestational Dietary Intake and Behavior

Corn-supplemented cows tended ( $P = 0.06$ ) to consume more TDN ( $8.86$  vs.  $8.36 \pm 0.18$  kg/d) and  $NE_m$  daily ( $P < 0.01$ ;  $13.74$  vs.  $11.54 \pm 0.31$  Mcal/d calculated by the 2016 NRC) compared with control cows. A week by treatment interaction was observed ( $P < 0.01$ ) for forage DMI, fluctuating over gestation, but the corn-supplemented dams had lower ( $P < 0.01$ ;  $14.45$  vs.  $12.80 \pm 0.3$  kg) DMI than the control dams. However, total DMI (roughage and corn) intake was not altered ( $P = 0.75$ ;  $14.45$  vs.  $14.31 \pm 0.30$  kg) as corn supplemented and control dams consumed similar quantities of total feed intake. A week by treatment interaction ( $P < 0.01$ ) was detected for time spent consuming roughage, but the interaction was not biologically relevant as the control dams consistently spent more ( $P < 0.01$ ;  $220.7$  vs.  $182.1 \pm 7.8$  min) time-consuming roughage than corn-supplemented dams. In addition, a week by treatment interaction ( $P < 0.01$ ) was also detected for roughage intake rate over gestation but was not altered ( $P = 0.13$ ;  $0.18$  vs.  $0.16 \pm 0.01$  kg/min) by diet with both corn-supplemented and

control dams consuming roughage at similar rates. Furthermore, a week by treatment interaction ( $P < 0.01$ ) was observed for number of visits/d but not influenced ( $P = 0.61$ ;  $85.1$  vs.  $81.7 \pm 5.5$ ) by treatment. For roughage meals consumed, a week by treatment interaction ( $P < 0.01$ ) was observed but appears to fluctuate sporadically during gestation. However, corn supplementation increased ( $P = 0.04$ ;  $6.6$  vs.  $7.6 \pm 0.3$ ) the roughage meals per day in the corn supplemented vs. control dams most of gestation. Roughage meal size was also influenced by a week by treatment interaction ( $P < 0.01$ ) with cows consuming similar meal sizes over gestation but supplemented cows consuming smaller ( $P < 0.01$ ;  $2.4$  vs.  $1.8 \pm 0.1$  kg/meal) roughage meals than control cows. Corn-supplemented dams spent less ( $P > 0.01$ ;  $1.4$  vs.  $1.2 \pm 0.2$  min/meal) time at the bunk per meal.

### Cow Blood Analytes

Corn supplementation decreased ( $P < 0.05$ ; Figure 1) circulating levels of NEFA and BUN but did not alter ( $P > 0.10$ ) glucose during gestation in SUP vs. CON cows. Additionally, the SUP cows had decreased ( $P = 0.05$ ; Figure 1) serum cortisol and tended to have reduced ( $P = 0.06$ ) serum T4 compared with CON cows during gestation. However,



**Figure 1.** Gestational plasma and serum analytes of beef cows from the control fed (CON) and corn supplemented (SUP) groups from days 100 to 240 of gestation.

maternal diet did not influence ( $P > 0.50$ ; [Figure 1](#)) circulating serum T3, T3:T4, or plasma progesterone as both SUP and CON dams had similar concentrations throughout gestation. Immediately after parturition, NEFA, BUN, glucose, T3, T3:T4 ratios, P4, and cortisol were not altered ( $P > 0.15$ ) by maternal diet. However, serum T4 was reduced in SUP cows ( $P = 0.04$ ; 37.0 vs.  $32.1 \pm 1.6$  ng/mL), whereas plasma E2 at birth was elevated ( $P = 0.02$ ) in SUP vs. CON cows (148.28 vs.  $116.44 \pm 9.69$  pg/mL). By 24 h postpartum, SUP cows tended ( $P = 0.06$ ) to have greater circulating NEFAs with suppressed T3 and T4 ( $P \leq 0.05$ ) in SUP vs. CON cows (1.05 vs.  $1.19 \pm 0.04$  ng/mL; T4: 48.9 vs.  $61.3 \pm 2.6$  ng/mL). Furthermore, at 21 d postpartum, maternal cortisol was reduced ( $P = 0.04$ ; 21.50 vs.  $28.38 \pm 3.30$  ng/mL) and T4 tended ( $P = 0.10$ ; 32.15 vs.  $35.31 \pm 1.3$  ng/mL) to be reduced in SUP vs. CON cows.

### Parturition Measurements

As reported by [Tanner et al., \(2017\)](#), calf birth weights and size measurements were unaffected ( $P > 0.50$ ) by maternal corn supplementation. Additionally, maternal corn supplementation did not alter ( $P > 0.15$ ) calving ease, mothering ability, or viability scores in SUP vs. CON pairs. Furthermore, corn supplementation did not influence colostrum production ( $P = 0.64$ ) or composition ( $P > 0.10$ ) as colostrum volume, fat, protein, and lactose were similar between SUP vs. CON dams. At birth and 24 h postpartum, calves from corn-supplemented dams did not have altered ( $P > 0.14$ ) blood pH or blood gasses. Furthermore, calf cortisol, T3, and T3:T4 profiles were not altered ( $P > 0.10$ ) by maternal corn supplementation as offspring from SUP and CON dams had similar circulating concentrations. However, maternal corn supplementation tended ( $P = 0.08$ ) to lower calf circulating T4 when compared with calves from control dams immediately after birth but not thereafter ( $P > 0.10$ ). At both 24 h and 21 d postpartum, no calf analytes were altered ( $P > 0.15$ ) by gestational maternal diet.

## DISCUSSION

We reject our hypothesis that corn supplementation will increase calf birth weights and growth. While TDN and  $NE_m$  intake were increased in corn-supplemented cows compared with control dams, DMI of roughage was suppressed in corn-supplemented cows. This negative effect of

corn supplementation on forage intake has been well demonstrated in beef cattle fed forage-based basal diets ([Loy et al., 2007](#)). This effect of reductions in forage intake resulting from energy supplementation is referred to as substitution ([Caton and Dhuyvetter, 1997](#)) which could be caused by several factors including decreased ruminal pH and altered forage digestibility. While previous studies have suggested that corn supplementation less than 0.25% of BW does not decrease forage utilization ([Matejovsky and Sanson, 1995](#)), we observed that corn supplementation even at 0.2% BW causes a substitution effect. It should be recognized that the variation in reductions of forage intake could be because of differing basal forage quality and sources. While corn supplementation suppressed maternal forage intake throughout the trial, total intake was unaffected by 0.2% of BW corn supplementation. This decrease can be explained physiologically through chemostatic or metabolic feedback that regulates intake to attempt to meet energetic and protein requirements of the ruminant ([Illius and Jessop, 1996](#)). The balance of protein and energy is essential to maintain because the animal integrates multiple feedbacks to regulate feed intake, and an imbalance can have detrimental impacts on intake ([Illius and Jessop, 1996](#)). When dietary imbalances between protein and energy exist, voluntary DMI of high-energy diets can be reduced because of the metabolic limitations to processing energy ([Fisher, 2002](#)). We observed not only suppressed roughage intake when corn was supplemented but also decreased time spent consuming forage (min/d), decreased intake rates (kg/min), smaller meals (kg/meal), less roughage consumed per visit (kg/visit), as well as decreased visit and meal time. Our trial suggests that maintaining the proper protein-to-energy ratio, not just increasing dietary calories, is necessary for positive impacts on calf growth as observed in [Kennedy et al. \(2016\)](#). This would also be supported by [Mordhorst et al. \(2017\)](#) that observed supplementing dietary protein without allowing the cows to increase their forage intake failed to alter calf growth.

From a nutrient catabolism perspective, increases in circulating NEFAs are generally associated with a negative energy balance. However, in the current study, NEFA concentrations were greater in control dams prior to starting the dietary treatments and remained elevated during gestation; thus, it is difficult to determine whether this is due to energetic status or other factors. Additionally, circulating concentrations of NEFA on this project were less than half the value of those reported in

Mordhorst et al. (2017) for cows that were nutrient restricted due to being fed low-quality forage. Combined with the NRC (2016), estimation of both dietary treatments exceeding their daily requirements, perhaps the difference detected between treatments, are not strictly an indicator of metabolic status and just a by-product of fatty acid metabolism. This is also supported by blood urea concentrations as an indicator of protein supplied in the diet, protein degradation in the rumen, and N utilization in the rumen (Reed et al., 2007). Although circulating urea could be from many sources including the diet, corn supplementation likely decreased circulating urea because more ammonia was utilized by the rumen for fermentation of the higher starch diet. The authors acknowledge that circulating concentrations of urea began lower in corn-supplemented cows prior to beginning dietary treatments on day 110 of gestation, and it is difficult to explain those differences. Lastly, the principal source of glucose in the ruminant is from gluconeogenesis, driven by the production of volatile fatty acids (propionate) by ruminal microbes. It is not surprising that no differences were observed in plasma glucose concentrations as both dietary treatments met their daily  $NE_m$  requirements.

From an endocrine perspective, cortisol is well recognized for its regulatory effects on energy metabolism, helping maintain blood glucose by enhancing gluconeogenesis and in high concentrations, exerting catabolic effects on body protein and lipid reserves. In the current study, while cortisol was increased in control dams, it is difficult, given the current parameters of the study, to determine whether this is due to social or behavioral stress or as a metabolic pro-gluconeogenic hormone. As reviewed in Chang and Zhang (2008), maternal plasma cortisol has been demonstrated to double over gestation, suggesting its physiological relevance in fetal growth. Surprisingly, serum cortisol at parturition was less than circulating cortisol during gestation in the dam. Conversely, sheep experience a spike in serum cortisol at parturition (Lemley et al., 2014) which would suggest that sheep and cattle production of cortisol diverges at parturition. The biologically critical thyroid hormones T3 and T4 play many diverse roles in regulating adult protein and energy metabolism. While they are critical for mobilizing maternal body reserves to supply nutrients to the developing conceptus, they cannot cross the placenta (Cappoen, 1989). In the current study, total maternal T3 decreased over gestation and did not differ according to dietary treatment which is supported by what is observed in pregnant

ewes (Lemley et al., 2014). Although it is surprising in this study that only T4 and not T3 levels were elevated in control dams, this elevation is expected as maternal intake is one of the key factors influencing thyroid activity (Lemley et al., 2014) which could potentially influence type-1 5'-deiodinase activity.

Despite the increase in maternal  $NE_m$  and changes in circulating metabolites and metabolic hormones, calf birth weights were not altered as result of maternal dietary corn supplementation. This is supported by previous data from Loerch et al. (1996) who also did not observe heavier birth weights from calves from corn-fed dams. The effects of maternal supplementation on calf birth weight are highly variable and dependent on many factors including forage source and quality, and many studies supplementing energy or protein did not observe increased calf weights until weaning if at all (Underwood et al., 2010; Mordhorst et al., 2017).

## IMPLICATIONS

While supplementation of additional dietary energy did increase TDN and  $NE_m$  consumed by the corn-supplemented dams, voluntary DM intake of roughage was reduced. This feeding strategy did not appear detrimental to the calf and effectively maintained cow BW and BCS, high-starch energy supplementation seems to have limited additive benefits on neonatal growth unless provided with supplemental protein. However, because the current feeding strategy did not harm fetal or neonatal performance, corn appears to be a good substitute for hay if the primary goal is to maintain BCS and prevent fetal growth restriction. In fact, this feeding strategy could be advantageous economically for the producer depending on the cost of feed inputs or availability of resources.

## LITERATURE CITED

- AOAC. 2010. Official methods of analysis, 18th ed. Arlington (VA): AOAC Int.
- Cappoen, J. P. 1989. Physiology of the thyroid during pregnancy. Various exploratory tests. Rev. Fr. Gynecol. Obstet. 84:893–897.
- Caton, J. S., and D. V. Dhuyvetter. 1997. Influence of energy supplementation on grazing ruminants: requirements and responses. J. Anim. Sci. 75:533–542. doi:10.2527/1997.752533x
- Chang, K., and L. Zhang. 2008. Steroid hormones and uterine vascular adaptation to pregnancy. Reprod. Sci. 15:336–348. doi:10.1177/1933719108317975
- Fisher, D. S. 2002. A review of a few key factors regulating voluntary feed intake in ruminants. Crop. Sci. 42:1651–1655. doi:10.2135/cropsci2002.1651

- Godfrey, K. M., and D. J. Barker. 2000. Fetal nutrition and adult disease. *Am. J. Clin. Nutr.* 71 (5 Suppl):1344S–1352S. doi:10.1093/ajcn/71.5.1344s
- Illius, A. W., and N. S. Jessop. 1996. Metabolic constraints on voluntary intake in ruminants. *J. Anim. Sci.* 74:3052–3062. doi:10.2527/1996.74123052x
- Islas, A., T. C. Gilbery, R. S. Goulart, C. R. Dahlen, M. L. Bauer, and K. C. Swanson. 2014. Influence of supplementation with corn dried distillers grains plus solubles to growing calves fed medium-quality hay on growth performance and feeding behavior. *J. Anim. Sci.* 92:705–711. doi:10.2527/jas.2013-7067
- Kennedy, V. C., M. L. Bauer, K. C. Swanson, and K. A. Vonnahme. 2016. Supplementation of corn dried distillers grains plus solubles to gestating beef cows fed low-quality forage: I. Altered intake behavior, body condition, and reproduction. *J. Anim. Sci.* 94:240–247. doi:10.2527/jas.2015-9615
- 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
- Loerch, S. C. 1996. Limit-feeding corn as an alternative to hay for gestating beef cows. *J. Anim. Sci.* 74:1211–1216. doi:10.2527/1996.7461211x
- Loy, T. W., J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2007. Effects of distillers grains or corn supplementation frequency on forage intake and digestibility. *J. Anim. Sci.* 85:2625–2630. doi:10.2527/jas.2005-750
- Matejovsky, K. M., and D. W. Sanson. 1995. Intake and digestion of low-, medium-, and high-quality grass hays by lambs receiving increasing levels of corn supplementation. *J. Anim. Sci.* 73:2156–2163. doi:10.2527/1995.7372156x
- Mordhorst, B. R., C. A. Zimprich, L. E. Camacho, M. L. Bauer, and K. A. Vonnahme. 2017. Supplementation of distiller's grains during late gestation in beef cows consuming low-quality forage decreases uterine, but not mammary, blood flow. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 101:e154–e164. doi:10.1111/jpn.12580
- National Academies of Sciences, Engineering, and Medicine (NRC). 2016. Nutrient requirements of beef cattle, 8<sup>th</sup> ed. Washington (DC): The National Academies Press. doi:10.17226/19014
- Perry, G. A., and B. L. Perry. 2008. Effects of standing estrus and supplemental estradiol on changes in uterine pH during a fixed-time artificial insemination protocol. *J. Anim. Sci.* 86:2928–2935. doi:10.2527/jas.2008-1181
- Reed, J. J., M. R. O'Neil, G. P. Lardy, K. A. Vonnahme, L. P. Reynolds, and J. S. Caton. 2007. Effect of undegradable intake protein supplementation on intake, digestion, microbial efficiency, in situ disappearance, and plasma hormones and metabolites in steers fed low-quality grass hay. *J. Anim. Sci.* 85:1092–1101. doi:10.2527/jas.2006-619
- Robertson, J. B., and P. J. Van Soest. 1981. The detergent system of analysis and its application to human foods. In: James, W. P. T., and O. Theander, editors. *The analysis of dietary fiber in foods*. New York (NY): Marcel Dekker. p. 123.
- Tanner, A. R., V. C. Kennedy, J. D. Kirsch, J. Gaspers, N. Negrin-Pereira, A. B. P. Fontoura, M. L. Bauer, K. C. Swanson, L. P. Reynolds, and G. Stokka, et al. 2017. Using corn supplementation for overwintered beef cows during mid-to late-gestation: uterine hemodynamics, placental vascularity, and neonatal performance. *Western Section American Society of Animal Science. J. Anim. Sci.* 94:57–62. doi:10.2527/asasws.2017.0017
- Underwood, K. R., J. F. Tong, P. L. Price, A. J. Roberts, E. E. Grings, B. W. Hess, W. J. Means, and M. Du. 2010. Nutrition during mid to late gestation affects growth, adipose tissue deposition, and tenderness in crossbred beef steers. *Meat Sci.* 86:588–593. doi:10.1016/j.meatsci.2010.04.008
- Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Carcass composition in mature hereford cows: estimation and effect on daily metabolizable energy requirement during winter. *J. Anim. Sci.* 66:603–612. doi:10.2527/jas1988.663603x
- Wall, P. B., G. H. Rouse, D. E. Wilson, R. G. Tait, Jr, and W. D. Busby. 2004. Use of ultrasound to predict body composition changes in steers at 100 and 65 days before slaughter. *J. Anim. Sci.* 82:1621–1629. doi:10.2527/2004.8261621x
- Wu, G., F. W. Bazer, J. M. Wallace, and T. E. Spencer. 2006. Board invited review. Intrauterine growth retardation: implications for the animal sciences. *J. Anim. Sci.* 84:2316–2337. doi:10.2527/jas.2006-156