4-2018

Supplementation and Reproductive Strategies for Beef Females as Part of a May-Calving Herd in the Nebraska Sandhills

Alicia Caitlin Lansford
University of Nebraska-Lincoln, alansford155@gmail.com

SUPPLEMENTATION AND REPRODUCTIVE STRATEGIES FOR BEEF FEMALES AS PART OF A MAY-CALVING SYSTEM IN THE NEBRASKA SANDHILLS

By

Alicia Caitlin Lansford

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professors Richard N. Funston and Jennifer R. Wood

Lincoln, Nebraska

April, 2018

SUPPLEMENTATION AND REPRODUCTIVE STRATEGIES FOR BEEF FEMALES AS PART OF A MAY-CALVING SYSTEM IN THE NEBRASKA SANDHILLS

Alicia Caitlin Lansford, M. S.

University of Nebraska, 2018

Advisors: Richard N. Funston and Jennifer R. Wood

The objective of these 4 studies was to evaluate the effects of management decisions on reproductive performance of beef females. Experiment 1 evaluated the efficacy of a novel s.c. prostaglandin $F_{2\alpha}$ injection on estrus synchronization and pregnancy success in yearling beef heifers. Heifers receiving a 2 mL s.c. injection of Lutalyse *HighCon* had similar estrus response and pregnancy rates compared to 5 mL Lutalyse i.m. within 2 different estrus synchronization programs. In experiment 2, May-calving heifers and primiparous cows were allotted to receive either no supplementation or supplement (0.45 or 0.91 kg/d per animal, heifers or primiparous cows, respectively) throughout the breeding season. Although supplementation increased BW, pregnancy rates were not impacted. In experiment 3, May-calving females were allotted to graze either sub-irrigated meadow or upland range throughout the breeding season. No differences in pregnancy rate were detected, despite differences in BW and BCS gain over the breeding season. Finally, experiment 4 examined the effects of varying levels of late gestation nutrition on dam and subsequent progeny performance. Multiparous, May-calving dams were allotted to graze either meadow or range forage and then to receive either no supplement or 0.45 kg/d per cow of a 33% CP supplement during late gestation. Prepartum meadow grazing tended to increase dam rebreed pregnancy rates. Heifer progeny had increased rebreed pregnancy rates as a primiparous cow, and steer progeny had increased marbling score if their dam grazed meadow. Dam supplementation increased BW of progeny over 2 generations. In summary, these experiments

demonstrate the following findings: 1) a higher concentrate s.c. injection of prostaglandin $F_{2\alpha}$ is effective in synchronizing estrus of beef heifers, 2) supplementation or differing forage type during the breeding season of a May-calving herd does not impact reproductive response, and 3) differences in late gestation nutrition of a May-calving herd results in altered progeny growth and performance.

ACKNOWLEDGEMENTS

I have been fortunate to be blessed by many opportunities and challenges while completing my graduate program that have helped me to grow immensely as a young professional. The challenges have helped me to refine and improve my critical thinking skills, and have reinforced in me the value of people and my relationships with them. I look forward to utilizing my newfound connections as I pursue the expansion of my cattle company.

Of all the individuals involved in supporting me, I have my husband to thank the most. He has quietly listened to my complaints and supported my big dreams. His belief in my abilities has been a driving force in my professional career. Perhaps most importantly, his constant reminder there is more to life than a job has been a saving grace. Levi, thank you for being my inspiration, my rock, my adventurer, and most importantly, my person.

A big thank you also goes to many of the other graduate students I have befriended throughout my program. The ability to consult with and seek advice from such knowledgeable, humble people has been rewarding, to say the least. Each of you are such driven, compassionate, and caring individuals who are destined to be successful by any measure. Dr. MacDonald, your support and insight into nutritional matters has been invaluable. You embody the type of person I aspire to be; you find value in everyone, and take time to encourage and support them in their endeavors. I would also like to thank Dr. Wood for your expertise in fetal matters and for providing assistance with classes.

Of course, I would like to thank my advisor, Dr. Funston, for the opportunity to work in such a distinguished program. Your research holds such merit, and it is exciting to be associated with your program. I admire your ability to translate research into something useful for

producers; I feel too many people miss out on this connection. I look forward to continuing that legacy as I pursue my consulting career goals.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I: LITERATURE REVIEW

INTRODUCTION

Central to a producer's profitability and continued way of life is the productivity of the cowherd. The ideal cow would attain puberty early so as to have her first calf at 2 yr of age. She would breed early in the calving season each subsequent year, so as to wean more total pounds of calf throughout her lifetime and maintain a 365-d calving interval. She would also have excellent mothering skills, but be gentle enough to allow for necessary human intervention. All of these tasks must be performed with minimal supplementation and interference on the producer's behalf (Hohenboken, 1988). Such a cow does not exist to date; however, research-based strategies to improve her efficiency and productivity exist.

When evaluating the herd for intervention points, the whole system, from conception to sale and beyond, must be considered. This begins with proper genetic selection, based on environment and future marketing plans, and spans to feedlot or breeding season management for steers or heifers, respectively. Events *in utero* directly impact postnatal growth and performance, possibly through post-translational modifications to DNA and consequent protein expression. Once born, sufficient development of progeny to maximize genetic potential is warranted. Frequently, the genetic potential of an animal is not maximized due to environmental deficits, primarily in the form of nutrition (Collier et al., 2005; Gluckman and Liggins, 1984).

Reproductive technologies used to synchronize heifers and cows allows for greater calf uniformity, shorter calving seasons, and increased pounds of calf weaned (Perry, 2004). Furthermore, strategic nutritional intervention at critical time points is key

to designing the ideal cow herd and maximizing efficiency. An increasing plane of nutrition during the peri-conceptual period is necessary to achieving a successful pregnancy (Arias et al., 2012; Kruse et al., 2017). Once pregnant, nutritional insults within the maternal environment can result in altered placental development, fetal myogenesis, and postnatal metabolism, growth and health (Du et al., 2011; Funston et al., 2010; Moriel et al., 2016; Summers et al., 2015a; Vonnahme et al., 2007).

ESTRUS SYNCHRONIZATION

Estrous Cycle

In *Bos taurus* cattle, the estrous cycle lasts 18 to 24 d, and is comprised of two oscillating phases: follicular phase (4 to 6 d) and luteal phase (14 to 18 d; Forde et al., 2011). These phases are characterized by distinctly different ovarian structures. Several hormones play important roles in initiation of the estrous cycle and resumption of estrus following parturition. Attainment of puberty at an earlier age increases the value of the heifer to a producer and results in a greater proportion of females calving in the first portion of the calving season, which positively influences cow longevity within the herd (Cushman et al., 2013). Cows who resume cyclicty after parturition earlier, and consequently breed earlier in the season, wean heavier calves and produce more total calves during their lifetime (Cushman et al., 2017).

Follicular Phase

The follicular phase begins following luteolysis of the corpus luteum (CL) and spans until ovulation of the dominant follicle (Forde et al., 2011). During this phase, 5 to 20 new follicles are recruited and selected in 2 to 3 waves by a similarly-patterned secretion of follicle stimulating hormone (FSH) from the anterior pituitary gland (Adams

et al., 1992; Vassena et al., 2003). As follicles are recruited and selected within a wave, a dominant follicle (DF) emerges. Emergence of a DF results in atresia of any remaining follicles in the cohort. This is thought to be a result of follicular competition to attain receptors for luteinizing hormone (LH; Vassena et al., 2003). Decreasing FSH concentrations allow the DF to become more responsive to the actions of LH, which will be required for ovulation (Adams, 1999). Concentrations of estrodial (E2) and inhibin, from DF follicular fluid, will increase as the DF increases in size (Forde et al., 2011). Inhibin will act at the level of the anterior pituitary to decrease FSH concentrations, as low levels of E2 provides negative feedback to the hypothalamus (Ginther et al., 2000). As ovarian follicles mature, estradiol concentrations will increase until they reach a threshold where feedback to the hypothalamic center become positive. Once an appropriate threshold of estradiol is reached, neurosecretory cells promote a surge of GnRH. In addition to a high level of GnRH available in the hypophyseal portal blood system, estradiol has also primed the anterior pituitary for recognition by upregulating synthesis of GnRH receptors. These two mechanisms of action result in a much higher than normal magnitude of LH secretion (Hess et al., 2005). Provided progesterone (P4) levels are basal, the surge of GnRH will cause a high-amplitude surge of LH (Forde et al., 2011). High-amplitude pulses of LH occurring every 40 to 70 minutes for 2 to 3 days will cause ovulation in beef cattle (Roche, 1996).

Surges of GnRH, through activation of the hypothalamic-pituitary-gonadal axis, will induce behavioral estrus in cattle. During this time, heifers or cows are sexually receptive and will stand to be mounted (Senger, 2005). Estradiol levels are highly correlated with estrus behavior. Peak E2 levels coincide with the highest behavioral

estrus scores (Lyimo et al., 2000). Additional behavioral cues from the female included increased locomotion, vocalization, and flagging of the tail (Senger, 2005)

Luteal Phase

Following ovulation of the DF, thecal and granulosal cells undergo luteolysis to form small and large luteal cells, respectively, which make up a CL (Senger, 2005). Together, these cells possess steroidogenic capabilities and will secrete P4 (Fields and Fields, 1996). Formation of a CL, and consequent P4 secretion, is critical to maintaining pregnancy in ruminants. Follicular development is still ongoing during the luteal phase; however, the selected DF's will not ovulate due to the negative feedback of P4 on the hypothalamus (Forde et al., 2011). Presence of high levels of P4 combined with low levels of E2 suppresses both the tonic and pulsatile hypothalamic centers, reducing GnRH secretion, and does not allow for sufficient LH surges to induce ovulation (Goodman and Karsch, 1980). Initially, P4 will block synthesis of estrogen receptors and oxytocin receptors in the uterine endometrium; however, after prolonged exposure, P4 will lose this ability. Binding of E2 to its receptor results in upregulation of oxytocin receptors. Increased binding of oxytocin will result in secretion of prostaglandin $F2_{\alpha}$ (PG) from the uterine lumen (Dorniak et al., 2012). Prostaglandin will act to regress the CL, causing a decrease in P4 concentrations, and allowing for initiation of the follicular phase (Hansel and Convey, 1983).

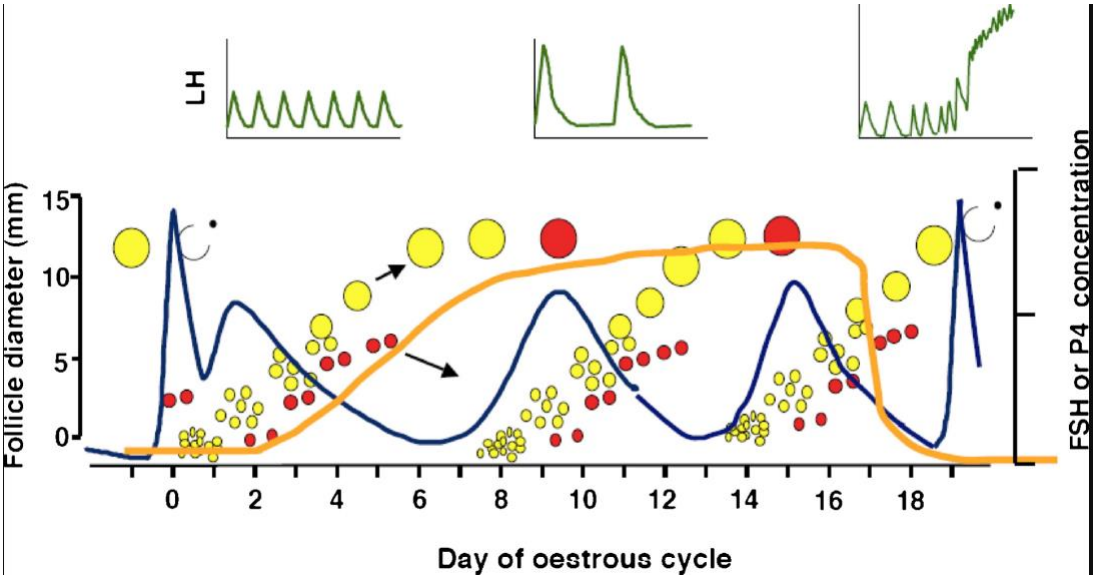

Figure 1. Patterns of hormone secretion regulating follicular growth throughout the bovine estrous cycle. Follicle selection and recruitment (yellow dots) follow a wave-like pattern, preceded by follicle stimulating hormone (FSH, blue). Progesterone (P4, orange) concentrations increase following ovulation of the dominant follicle (DF), but sharply decline around d 17 to allow for ovulation of another DF if pregnancy does not occur. At top, patterns of luteinizing hormone (LH) secretion throughout the estrous cycle are depicted. Preceding ovulation, a high-amplitude surge of LH is released to cause ovulation (adapted from Forde et al., 2010).

Maternal Recognition of Pregnancy

Under normal conditions following a successful mating, the blastocyst will secrete bovine interferon-τ (bIFN-τ) from the trophectoderm prior to implantation. This will occur on approximately d 16 of gestation, with implantation in cattle occurring between d 16 and 17 (Norman and Henry, 2015). Secretion of bIFN-τ will block expression of the estrogen receptor, preventing upregulation of oxytocin receptors. This will not allow subsequent PG upregulation, and allows the CL to be maintained (Dorniak

et al., 2012). With continuation of the CL, progesterone levels are maintained and uterine quiescence is promoted, resulting in successful establishment of pregnancy (Dorniak et al., 2012). Secretion of P4 from the CL will be necessary to maintain pregnancy until placental secretion of P4 is sufficient, around 6 to 8 months of gestation in cattle (Senger, 2005).

Follicular waves will continue throughout the first two trimesters of pregnancy, but will decrease in duration and number of follicles recruited as pregnancy progresses. For the last 30 d of gestation, follicular waves cease (Ginther et al., 1996). In late pregnancy, high levels of P4 from both the CL and placenta, as well as increased E2 levels of placental origin, result in strong negative feedback and appear to suppress FSH release almost completely (Crowe et al., 1998).

Estrus Synchronization

Without reproduction, there is no operation, thus reproductive efficiency is considered the single most important factor in the success of a herd (Lauderdale, 2009). Controlling the estrous cycle benefits cattle producers by allowing the induction of better managed calving seasons and potential use of superior genetics through AI and/or embryo transfer. Estrous synchronization protocols can lead to an optimization of time, labor and profitability by increasing calf uniformity, decreasing length of the calving season and enabling the use of AI (Lamb et al., 2009). Currently, AI accounts for less than 5% of all replacement beef animals, which is confined largely to the seed stock sector (Vishwanath, 2003).

Early work by Ulberg et al. (1951) reported daily doses of P4 inhibited estrus and formation of a CL. At increased concentrations of P4, follicular growth was impaired,

leading researchers to believe P4 inhibited ovarian function. This was followed by successive identification of the functions of PG (Wiltbank and Casida, 1956), oxytocin (Armstrong and Hansel, 1959), and estrogens (Wiltbank et al., 1961). These studies provided the basis that hormones could be used to manipulate the estrous cycle in cattle.

Nellor and Cole (1956) injected beef heifers s.c. with a P4 emulsion, followed by equine chorionic gonadotropin (eCG) 15 d after P4 injection. Estrus was detected in 84% of heifers 24 to 96 h following equine gonadotropin injection.

In the 1960s, investigation and development of an orally effective progestins for commercial use were of greatest interest. Hansel et al. (1961) and Zimbelman (1963) investigated the use of medroxyprogesterone acetate (MAP), while Wiltbank et al. (1965) investigated dihydroxyprogesterone acetophenonide (DHPA) for their effectiveness in estrus synchronization. While successful in causing expression of estrus after removal of MAP or DHPA from the diet, AI pregnancy rates were highly variable. Finally, Zimbelman and Smith (1966) examined the use of melengestrol acetate (MGA) as a means to inhibit estrus. Interestingly, heifers fed MGA appeared to have improved ADG, and as a result, MGA was investigated for use in feedlot rations for heifers to improve efficiency (Bloss et al., 1966).

Although most heifers exhibit estrus following removal of MGA from the diet, AI at this time results in reduced success rates compared with MGA feeding plus PG 19 d after discontinuation of MGA (Lauderdale, 2009; Moody et al., 1978). Feeding of MGA may result in a persistent follicle, which is of poor quality when it is ovulated following MGA removal from the diet. To date, use of MGA is prohibited in mature cattle (Lauderdale, 2009) due to lack of approval by the federal drug administration (FDA).

Early work by Roche (1976) into the use of an intra-vaginal coil impregnated with P4 led to development of the controlled internal drug-releasing (CIDR) device. Lucy et al. (2001) demonstrated the efficacy of the CIDR when inserted for 7 d with PG injection on d 6 in synchronizing estrus in beef heifers and cows. Alternately, 2 injections of 25 mg prostaglandin tromethamine were successful in synchronizing estrus in beef cattle due to the luteolytic nature of PG (Lauderdale, 2001; Lauderdale et al., 1977). The injections were given 10 to 12 d apart in an attempt to cause regression of the CL in all cattle, as a young CL is does not have receptors for PG on d 0 to 5 of the estrous cycle.

Many options are available to producers for estrus synchronization in beef cows and heifers. Previous research has indicated improved pregnancy success in heifers when using a longer progestin protocol (Johnson and Jones, 2004; Vraspir et al., 2014). Furthermore, pregnancy rates to fixed time AI (FTAI) are comparable to heat detection and AI (Tibbitts et al., 2017). For estrus synchronization, beef heifers may be fed MGA for 14 d followed by a PG injection on d 33, with FTAI and GnRH injection at AI given 72 ± 2 hr after PG injection (Figure 2, MGA-PG protocol). If consistent intake of MGA is a concern, producers may use a CIDR insert for 14 d, followed by a PG injection on d 30, with FTAI and GnRH injection 66 ± 2 hr after PG injection (Figure 3, 14-day CIDR-PG protocol). For beef cows, use of a 7-day CO-Synch + CIDR protocol is effective in synchronizing estrus. In this protocol, and injection of GnRH is given at CIDR insertion on d 0, followed by CIDR removal and PG injection on d 7. Cows are AI 60 to 66 hr after PG injection and given an injection of GnRH at AI (Figure 4). There are a number of options available to producers for estrus synchronization and can be selected based on time required to implement, intensity of labor involved, and use of AI or natural service.

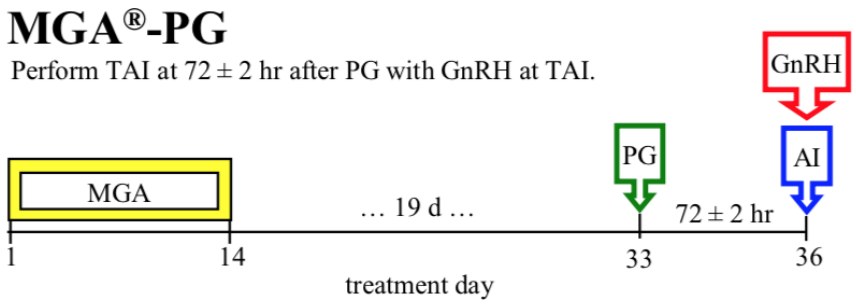

Figure 2. Melengesterol acetate (MGA) – prostaglandin $F_{2\alpha}$ (PG) protocol used for estrus synchronization in beef heifers. MGA is fed d 1 to 14, followed by a PG injection on d 33. Heifers are heat detected and AI until d 39 (adapted from Applied Reproductive Strategies in Beef Cattle, beefrepro.unl.edu).

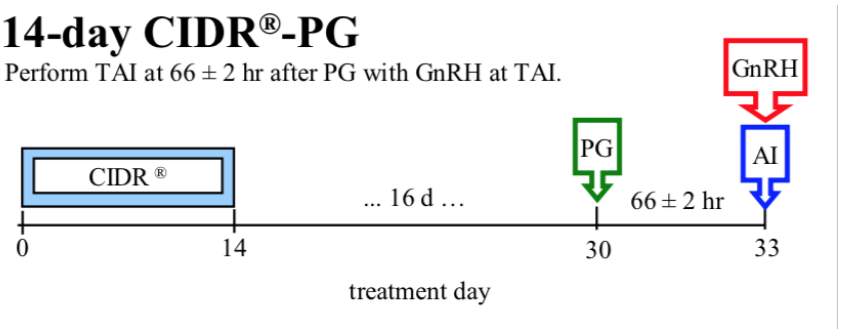

Figure 3. 14-day controlled internal drug releasing (CIDR) – prostaglandin $F_{2\alpha}$ (PG) protocol for beef heifers. A CIDR is placed in the vagina for 14 d, followed by injection of PG 16 d later. Heifers are AI 66 ± 2 hr after PG and administered an injection of gondadotropin-releasing hormone (GnRH) at AI (adapted from Applied Reproductive Strategies in Beef Cattle, beefrepro.unl.edu).

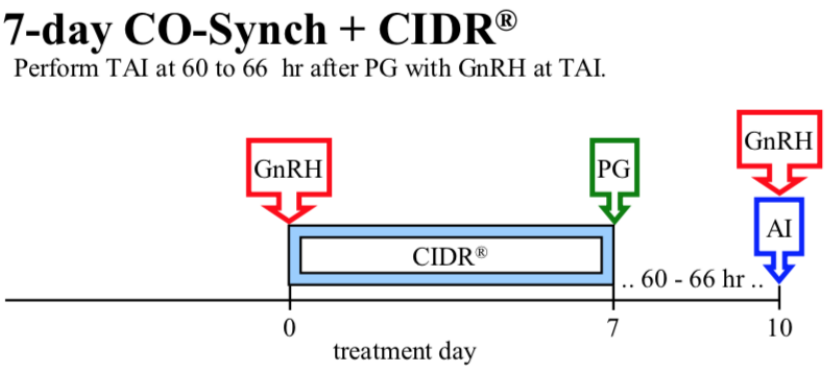

Figure 4. 7-day CO-Synch + controlled internal drug releasing (CIDR) protocol for beef cows. Gondadotropin-releasing hormone (GnRH) is administered and a CIDR placed vaginally on d 0 followed by injection of prostaglandin $F_{2\alpha}$ (PG) and CIDR removal on d 7. Cows are AI 60 to 66 hr following PG and an injection of GnRH administered at AI (adapted from Applied Reproductive Strategies in Beef Cattle, beefrepro.unl.edu).

RUMINANT DIGESTION AND ABSORPTION OF NUTRIENTS

Carbohydrates

For ruminant dams, the majority of dietary energy is obtained from volatile fatty acids (VFA; Bergman, 1990). Ruminal bacteria breakdown and digest dietary carbohydrates into VFA's, which are absorbed across the rumen wall. Proportions of ruminal VFAs as a percentage of total VFA production for forage-based diets are approximately 65% acetate, 25% propionate, and 10% butyrate (Krehbiel, 2014). Ruminants rely heavily on gluconeogenesis for survival. Acetate and butyrate, both even-carbon organic acids, are lipogenic, while propionate, an odd-chain organic acid, is gluconeogenic (Hall and Eastridge, 2014). The principal product of fiber digesting bacteria is acetate (Krehbiel, 2014).

Ruminal production of VFAs is affected by many factors, including fraction of structural carbohydrates and protein availability of the forage. The total yield of bacteria that process nonstructural carbohydrates is increased as much as 18.7% with the inclusion of protein to the diet (Russell et al., 1992). Some carbohydrates escape the rumen and are digested in the small intestine by pancreatic enzymes, and are absorbed as glucose, though this does not substantially contribute to the energy requirements of a ruminant on a forage-based diet. For forage-based animals, a high ratio of acetate to propionate is experienced. Acetate does not contribute to gluconeogenesis; however, in sheep fed gluconeogenic precursors, acetate clearance rate was increased (Cronje et al., 1991). Better utilization of acetate can lead to increased animal growth and increased fatty acid synthesis in the mammary glands of lactating cattle (Rogers and Kleiber, 1957). Accumulation of excess acetate, which often results from lack of glucose precursors, resulted in production of ketone bodies and free fatty acids (FFA), further increasing the metabolic imbalance (Dresner et al., 1999; Tardiff et al., 2001). Furthermore, limited gluconeogenesis results in limited secretion of LH, which may impair ovulation (Hess et al., 2005).

Proteins

Ruminant protein requirements are met through a combination of rumen undegradable protein (RUP) and microbial crude protein (MCP). Both upland range and sub-irrigated meadow forages of the Nebraska Sandhills are high in rumen degradable protein (RDP), which can be used for MCP synthesis (Geisert, 2007; Lardy et al., 1997). In many situations, the composition of the protein reaching the small intestine of the ruminant differs from dietary composition, due to MCP (Russell et al., 1992). Both RUP

and MCP enter the small intestine and are digested and absorbed as amino acids that can be used for dam maintenance and protein accretion, as well as fetal growth and development. Supplementation of RUP may be necessary to meet the higher nutrient demands of lactation, and can be obtained from forage or supplement (Klopfenstein, 1996).

The ability of microbes to produce MCP relies upon the availability of RDP and carbon skeletons in the forage. As a proximate, total digestible nutrients (TDN) can be used to estimate microbial efficiency and consequent MCP yield. As forage TDN values decline, microbial efficiency declines (Patterson et al., 2006). Rumen degradable protein is deaminated quickly in the rumen and the carbon backbone used for VFA production or gluconeogenesis for the bacterium. Without an adequate carbon source for transamination, excess deaminated NH_3 is absorbed across the rumen wall and converted to urea in the liver (Pacheco and Waghorn, 2008). In many cases, greater than 25% of protein is lost as ammonia (Nolan, 1975).

Supplementation of protein has been shown to shorten the interval to conception (Vanzant and Cochran, 1994), increase DMI (Moriel et al., 2012), improve BCS (Stalker et al., 2006), and tended to increase diameter of the dominant follicle (Lents et al., 2008). The tendency for an increase in dominant follicle diameter, was accompanied by a 16.5% increase in pregnancy rate to AI despite a lack of significance. It should be noted both treatment groups had adequate (11 to 15 mm diameter; Perry et al., 2005) dominant follicle size (Lents et al., 2008).

It has been suggested by Hess et al. (2005), regions of the brain regulating LH secretion are influenced by a variety of serum metabolites, and that detection by the brain of amino acid (AA) imbalances may negatively impact LH secretion and ovulation of a DF.

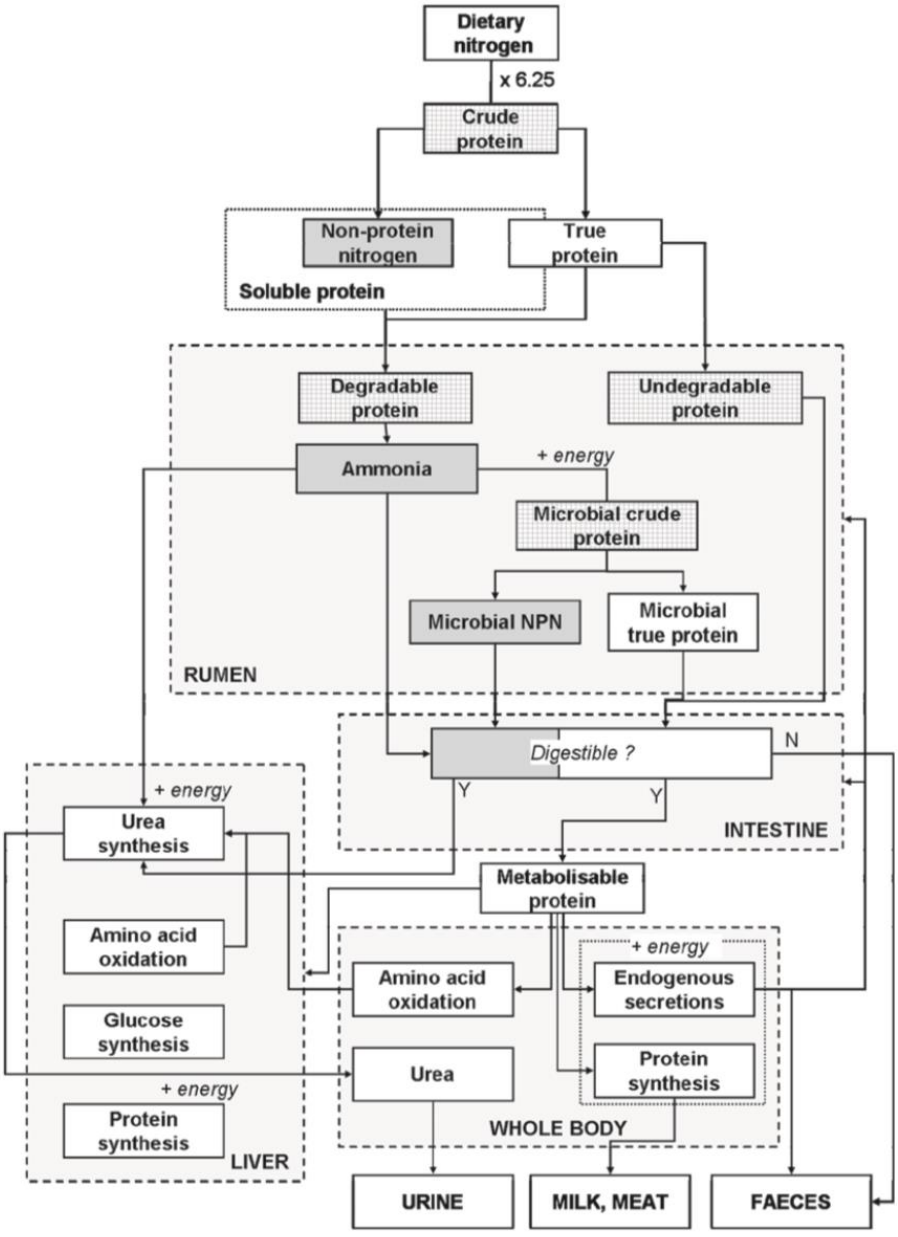

Figure 5. Dietary nitrogen usage and translocation in the ruminant. Solid line boxes indicate different fractions of dietary nitrogen. Dashed line boxes (large) represent

anatomical locations of nitrogen metabolism, use or absorption. The shading of boxes indicates protein composition: gray is for non-protein nitrogen, white is for true protein, and hatched is for a combination of the two (adapted from Pacheco et al., 2008).

Lipids

Ruminants in forage-based systems typically have low levels (< 5%) of dietary fat intake (Newell, 1968). Primarily, inclusion of fat in the diet is used to increase energy density (Hall and Eastridge, 2014); however, supplemental fat may decrease intake and interfere with the digestion of other nutrients (Coppock and Wilks, 1991). In the rumen, triglycerides will undergo lipolysis and any unsaturated FFA will be biohydrogenated (Hall and Eastridge, 2014). High dietary intake of polyunsaturated fatty acids (PUFA) has long been associated with decreases in milk fat production, likely a byproduct of decreased acetate synthesis in the rumen (Hall and Eastridge, 2014). Provided there is an adequate source of carbohydrates and consequent VFA production, fat will be absorbed and stored in adipose tissue to be used during times of limited nutrient intake. During states of limited nutrient availability, mobilization of stored fats results in ketone body synthesis, which can help to generate energy for the ruminant (Hall and Eastridge, 2014). While moderate levels of ketone bodies are normal between meals, excess levels could lead to ketoacidosis. Research on feeding supplemental fat to cows either pre- or postpartum is largely inconclusive (Funston, 2004).

FETAL AND PLACENTAL DEVELOPMENT AND METABOLISM

Early Gestation and Placental Function

In early gestation, maximal placental differentiation, vascularization, and development occur, in addition to fetal organ development (Funston et al., 2010). The

placenta functions as the conduit between the mother and fetus, serving to deliver oxygen and macronutrients, while removing waste products (McNanley and Woods, 2008). Adequate placental growth is essential for maximized fetal growth (Bazer et al., 2012). In ruminants, the placenta attaches to aglandular sites along the uterine wall known as caruncles (Dunlap et al., 2015). Fetal cotylededonary villi interlock with caruncular tissue to form the primary site of feto-maternal nutrient exchange, known as the placentome. (Dunlap et al., 2015; Mott, 1982). Thus, efficiency of nutrient exchange is highly correlated with blood flow capacity of the placentome (Reynolds et al., 2006). Under normal conditions, uteroplacental blood flow increases throughout gestation to keep pace with growth of the fetus, increasing as much 4.5 fold in the last half of gestation (Reynolds et al., 1986; Reynolds et al., 2006) Several studies have found a correlation between reduced uteroplacental blood flow and incidence of fetal intrauterine growth restriction (IUGR) (Karsdorp et al., 1994; Reynolds et al., 2006). During placental development, fetal organogenesis also takes place. The bovine heartbeat is detectable as early as 21 d following ovulation. This is followed by successive development of other vital organs such as the heart, brain, pancreas, liver, lungs, and kidneys (Funston et al., 2010).

Respiratory gases, oxygen and carbon dioxide, diffuse freely through placentome due to their small size and neutral charge (McNanley and Woods, 2008). The expression of placental nutrient transporters for hexose sugars and amino acids is the rate-limiting step in fetal growth (Jones et al., 2007).

Glucose

Glucose is the most important nutrient for fetal growth. The gravid uterus requires increasing amounts of glucose as pregnancy progresses, which increases the necessity of maternal hepatic gluconeogenesis (Bell and Bauman, 1997). Fetal uptake of glucose is dependent upon a concentration gradient across the placenta. In general, maternal serum concentrations exceed fetal concentrations, so glucose is passively diffused using GLUT transporters (Crouse et al., 2017; McNanley and Woods, 2008). The placenta will metabolize the majority (50 to 70%) of incoming glucose to lactate for diffusion into the maternal or fetal circulation (Simmons et al., 1979). Early in gestation, the fetus has little use for lactate; however, as pregnancy progresses, the fetus is thought to utilize lactate as an important energy substrate and precursor to glycogen (Aldoretta and Hay, 1995; McNanley and Woods, 2008). If fetal concentrations of glucose are low, placental consumption decreases and diffusion to the fetus is increased (Hay, 1991). The fetus will utilize glucose for growth; however, a portion will be retained and stored as either glycogen or triglycerides (Aldoretta and Hay, 1995). In late gestation, glucose uptake by the gravid uterus accounts for 30 to 50% of glucose utilization in the ruminant (Leury et al., 1990). When the dam is provided adequate nutrition, nearly all fetal glucose utilization is of maternal origin (Bell and Bauman, 1997); however, for undernourished dams, the fetus relies on increasing amounts of fetal endogenous gluconeogenesis (Dalinghaus et al., 1991), presumably derived from amino acids (Bell and Bauman, 1997).

Amino Acids

The fetus utilizes amino acids for tissue synthesis and growth, as well as a source of energy in times of excess (Aldoretta and Hay, 1995). There is evidence the fetus is

able to utilize amino acids as an energy source, either through oxidation or conversion to glucose, in times of glucose limitation, as evidenced by increased fetal urea concentrations (Aldoretta and Hay, 1995; Lemons, 1979). Transport of amino acids across the placenta relies on an energy-dependent mechanism (Molina-Font, 1998). There is evidence suggesting placental insufficiency decreases amino acid transport to the fetus and reduces fetal growth (Aldoretta and Hay, 1995; Molina-Font, 1998).

The placenta readily takes up glutamate (McNanley and Woods, 2008) and evidence in human placental tissue suggests it is converted to glutamine before transfer to the fetus (Malek et al., 1993). Other branched amino acids, such as leucine, isoleucine, and valine are metabolized to glutamate by the placenta before conversion to glutamine (McNanley and Woods, 2008). Research by Vaughn et al. (1995) suggests the placenta will metabolize as much as 80% of glutamate. These strategies result in two important consequences for the fetus: production of NADPH for use in fatty acid synthesis, and a reduction in glutamate concentration in fetal fluid, which may be a potential neurotoxin (McNanley and Woods, 2008). Amino acids are shuttled to the fetal liver once diffused across the placenta. There, any acidic or branched chain amino acids that escaped placental metabolism are deaminated and converted to their subsequent keto acid (Vaughn et al., 1995).

Arginine, a substrate for nitric oxide and polyamine synthases, is highly abundant in fetal fluids. Additionally, precursors to arginine, including ornithine, citrulline, and glutamine, are associated with high concentrations of nitric oxide during the first half of pregnancy in ovine placentae (Kwon et al., 2003). Nitric oxide has been identified as a key regulator of utero-placental blood flow (Bird et al., 2003), while polyamines are

critical regulators of DNA and protein synthesis (Flynn et al., 2002). Thus, nitric oxide and polyamines will function as important elements to placental and fetal growth.

Lipids

The fetus may utilize lipids as a stored energy source, incorporate them into phospholipid membranes, or utilize them for endogenous hormone synthesis (Molina-Font, 1998). In humans, research has shown maternal lipoproteins dock on placental lipoprotein receptors and FFA's are hydrolyzed by a lipoprotein lipase (Dutta-Roy, 2000; Lindegaard et al., 2005). Free fatty acids will diffuse across the plasma membrane through transporters involving plasma membrane binding proteins, fatty acid translocase, and fatty acid transport proteins (FATP; Dutta-Roy, 2000). In the placenta, FFA's are esterified, oxidized, or allowed to diffuse across the basal membrane to fetal tissue (Jones et al., 2007). Although the fetus has limited carnitine concentrations, an intermediate necessary for long-chain fatty acid oxidation (Molina-Font, 1998), the percentage composition of long-chain polyunsaturated fatty acids (LC-PUFA) is enhanced in fetal plasma (Cetin and Koletzko, 2008). In monogastric species, LC-PUFA are a critical component of fetal growth, brain development, and maintenance of the vascular system (Cetin and Koletzko, 2008). In humans, maternal diets deficient in polyunsaturated fatty acids have been correlated with intrauterine growth retardation (Crawford et al., 1993). The majority (70 to 95%) of unsaturated fatty acids will undergo biohydrogenation in the rumen (Beam et al., 2000), thus it is unclear if the ruminant fetus has a requirement for LC-PUFA, and how a deficit would impact fetal growth.

DEVELOPMENTAL PROGRAMMING

Introduction

Epigenetics refers to the study of changes made to chromatin, which are often caused by environmental factors such as stress, maternal nutrition *in utero*, nutritional level of the individual animal, and any combination of the aforementioned (Gonzalez-Recio, 2011). Foundational work by Barker, 1991 determined a relationship between onset of adult cardiovascular disease and low birth weight. This and other studies (Barker and Osmond, 1986; Barker et al., 1989, 1990; Lucas, 1991), led Hales and Barker, 1992 to propose the idea of the thrifty fetus phenotype hypothesis; in that a fetus could be programmed to be thrifty with nutrients if the intrauterine supply of nutrients was low during gestation. There is increasing evidence of maternal nutrition effects on offspring in animal models, and that this can influence animal health, postnatal growth, and carcass quality (reviewed in Holemans, et al., 2003; Wu et al., 2006). In summation, epigenetics is the mechanism that allows for plasticity of the phenotype, while maintaining a fixed genotype (Zeisel, 2009).

Mechanisms of Developmental Programming

Several modifications can be made to DNA structure or packaging, without changing DNA sequence. These changes to the epigenome can increase or decrease expression of the target gene (Momoko et al., 2015). To give a brief overview, DNA is packed as chromatin, which associates with acidic proteins known as histones. The tighter the chromatin is condensed, the less expression of the gene. Protruding from the histone proteins are long tails, which are subject to different modifications (Fazzari and Greally, 2009). Histone tails have a positive charge, and thus promote tighter packing of the negatively charged chromatin.

Among the most common epigenetics modifications are cytosine methylation or histone tail acetylation. Addition of a methyl (CH_3) group to a 5-carbon ring of cytosine will result in inhibition of transcription of a gene due to recruitment of repressor proteins. Conversely, when a negatively-charged acetyl (C_2H_3O) group is added to a lysine residue on the histone tail, chromatin is not associated as tightly with the histone, and gene expression is enhanced. Not only can negation of a positive charge on a histone tail lead to less condensed chromatin, but can also act as a recruiter of a transcription activation protein.

Early Gestation Maternal Undernutrition

Robinson et al. (1977) reported 75% of fetal growth occurs during the last trimester of pregnancy, so maternal nutrition during early gestation was thought to be of little impact. Conversely, Rhind et al. (1989) showed nutritional deficits as early as d 11 negatively impacted the conceptus in sheep. The early phase of gestation is most impactful to placental growth, cell differentiation, and vascularization (Funston et al., 2010). Nutrient restriction from d 30 to 125 of gestation, follow by realimentation, negatively impacts placental vascularity and placental angiogenic mRNA abundance (Vonnahme et al., 2007). Even following realimentation, cotyledon capillary flow, density, and nutrient exchange were reduced in previously nutrient restricted dams. Adequate development of the placenta is critical to nutrient exchange to support fetal growth. Placental insufficiency caused by undernutrition, over nutrition, or extreme environmental conditions results in decreased uterine and umbilical blood flow (Reynolds et al., 2006).

Maternal undernutrtion affects placental growth, and reduces amino acid and glucose transport to the fetus (Zhang et al., 2015). Prior to establishment of hemotrophic nutrition, the embryo utilizes increasing quantities of glucose and amino acids (Bazer et al., 2011). After establishment of the placenta, fructose is the most prevalent sugar in fetal fluids, due to conversion of glucose by the placenta (Kim et al., 2012). In early gestation, nutrient restricted (40% global restriction) dams, gene expression of cationic amino acid transporter CAT-3 in carcuncular tissue, and high-affinity glucose transporter GLUT3 in intercaruncular tissue tended to be lower than in control females from d 16 to 50 of gestation. Interestingly, glucose concentration in the allantoic and amniotic fluid samples was lower for fetuses exposed to maternal nutrient restriction (Crouse et al., 2017). These results indicate a modified nutrient transporter profile of the placenta in nutrient restricted dams, which could significantly alter fetal growth and development as gestation progresses.

Nutrient restriction in early gestation has been shown to be detrimental to postnatal muscle mass and increase postnatal fat accumulation (Zhu et al., 2006). Male progeny born to early gestation (d 28 to 78) nutrient restricted ewes had increased blood glucose levels and decreased insulin response to a glucose tolerance test postnatally. This coincided with increased hot carcass weight (**HCW**), and kidney and pelvic fat (Ford et al., 2007). Long et al. (2012), allotted pregnant ewes to 1 of 3 treatments from d 45 to 185 of gestation: control (CON), 70% of NEm and CP (NR), or 70% NEm and CP + RDP supplement (NRP). Progeny born to NR dams had increased yield grade and decreased semitendinosus muscle weight compared to CON and NRP progeny. Additionally, NR progeny had globally increased adipose tissue DNA concentration.

These results agree with previous research by Du et al. (2011) and Ford et al. (2007). It is possible the fetus was able to benefit from increased rumen microbe efficiency and byproducts.

Late Gestation Maternal Undernutrition

Most fetuses are not allowed full expression of their genetic potential due to deficiencies within the maternal environment, often caused by maternal undernutrtion (Gluckman and Liggins, 1984). Factors such as age of the dam, number of fetuses, production demand, and environmental stressors affect nutrient partitioning between the dam and fetus, and have been shown to play a critical role in programming the fetus for future growth and performance (Funston and Summers, 2013). During the third trimester, fetal growth is most rapid and maternal undernutrtion will likely have the greatest impact (Wu et al., 2004). Moreover, nutrient restricted dams may compete with the fetus for nutrients (Wu et al., 2004), further decreasing fetal nutrient availability.

Many studies conducted in human epidemiology suggest *in utero* exposure to certain environmental factors increases the risk for development of behavioral disorders and adult chronic diseases (Jirtle and Skinner, 2007). A classic example is the 1944 to 1945 Dutch Famine. Children *in utero* during this time were exposed to maternal undernutrition, and later in life, had increased incidences or coronary heart disease and obesity (Painter et al., 2005). Additionally, suppressed methylation of insulin-like growth factor II (IGF-II) was found to be associated with this exposure (Heijmans et al., 2008). This early data indicates there is a correlation between early life gene expression and adult life expression, which may have a large impact on the development of lipid and muscle tissue in beef cattle.

Fetal BW and pancreas weight were reduced by d 135 of gestation in ewes receiving 30% global nutrient restriction from gestational d 26 to term when compared with controls (Osgerby et al., 2002). Additionally, allantoic glucose concentrations, fetal insulin-like growth factor I (IGF-I), and fetal insulin were reduced in nutrient restricted dams by d 135. These results suggest fetuses exposed to maternal undernutrition likely have disruptions in tissue accretion and cell proliferation, leading to alterations in postnatal growth (Osgerby et al., 2002). In rats, dams exposed to a dietary protein deficiency throughout gestation gave birth to female progeny that were smaller at birth and at 21 d of age. Body composition of female pups at 70 d of age was altered in nutrient restricted offspring. These alterations resulted in a decreased percentage of protein relative to body composition, but increased lipid relative to body composition. At 110 d of age, leptin concentrations were increased in male, but decreased in female pups. Finally, a glucose tolerance test was performed on both male and female pups at 110 d. Initial glucose and insulin concentrations were increased in nutrient restricted fetuses. Insulin levels remained significantly higher throughout the test for nutrient restricted fetuses (Zambrano et al., 2006). Combined, this data suggests nutrient restriction in late gestation may be sex specific, and alters female progeny growth and metabolic function postnatally.

Following weaning, calves exposed to 30% nutrient restriction *in utero* for the last 40 d of gestation had decreased cortisol and haptoglobin concentration in plasma postnatally. In addition, BVDV-1a titers were reduced in restricted calves, suggesting maternal nutrition prepartum may impact immune response of offspring postnatally

(Moriel et al., 2016). This agrees with research indicating an increase in calf morbidity and mortality previously reported by Stalker et al. (2006) and Larson et al. (2009).

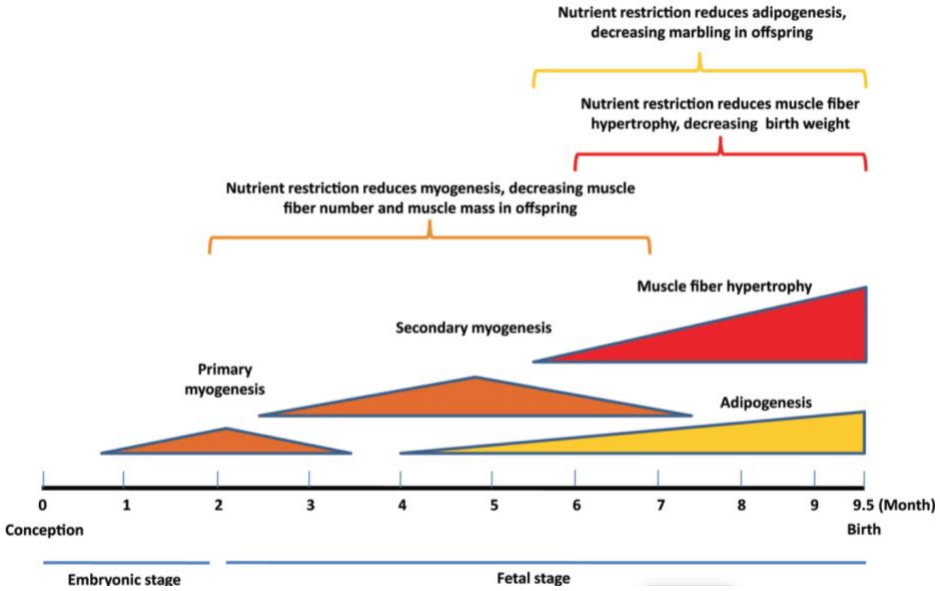

Figure 6. Bovine fetus myogenesis and adipogenesis from conception to parturition. Maternal nutrient restriction during mid-gestation may decrease the number of muscle fibers, while restriction in late gestation may impact both muscle fiber size and adipocyte number and diameter (adapted from Du et al., 2010).

Maternal Overnutrition

Over-nutrition may be the result of overconsumption of energy, protein, or a combination of both. Physiological changes in the ovine placenta and consequent fetal growth are negatively impacted by excess maternal nutrition (Wallace et al., 2003). In cases of maternal obesity, the fetus exhibits a similar phenotype to that of maternal nutrient limitation. This is likely caused by a combination of maternal inflammatory response, and/or hyperglycemia due to maternal insulin insensitivity. Glucose availability is critical to fetal development (Funston et al., 2010). In humans, diabetic mothers give

birth to a higher proportion of offspring that become obese and have impaired glucose tolerance (Silverman et al., 1995). The mechanisms of action for maternal obesity are still being elucidated; however, there is an increased occurrence of IUGR fetuses, and neonatal morbidity (Castro and Avina, 2002). Severe maternal hyperglycemia, caused by maternal insulin deficiency or resistance, results in overstimulation of fetal pancreatic β-cells, which causes these cells to become insensitive to stimuli (Aerts and Assche, 1977). This results in fetal hypoinsulinemia (Aerts et al., 1990), and reduced fetal growth (Aerts and Assche, 1977). Furthermore, maternal over-nutrition has been shown to reduce ovarian follicle numbers in female offspring (Da-Silva et al., 2002).

Although placental weight was not reduced in obese dams compared with control dams, fetal weight was significantly reduced in obese dams (McPherson et al., 2015). This suggests maternal obesity impacts placental nutrient transporters, like maternal undernutrition.

For human mothers consuming excess dietary protein during late gestation, infant ponderal index is increased (Andreasyan et al., 2007), resulting in a leaner neonate. The ponderal index refers to the relationship between height and weight - a lower score indicates a greater weight at a given height, and vice versa. A 10 g increase in daily maternal dietary protein resulted in a 17.8 g decrease in fetal weight at birth (Andreasyan et al., 2007). Arginine, considered an essential amino acid for the fetus, is a critical to fetal and placental development (Flynn et al., 2002). Research is warranted to examine the effects of excess dietary protein in ruminants, due to alternate digestion and metabolic functions.

Maternal Inflammation

Maternal inflammation increases fetal exposure to circulating cytokines, chemokines, and/or lipid mediators (Goldenburg et al., 2000). Common metabolic disorders, such as obesity and diabetes mellitus result in chronic maternal stress (Gluckman and Hanson, 2004). It has been hypothesized fetal exposure to maternal glucocorticoids results in IUGR fetuses' (Lesage et al., 2001). Exposure to inflammatory cytokines is known impair translocation of GLUT4 receptors to the plasma membrane of muscle and adipose tissue (Lorenzo et al., 2008). Additionally, it has been hypothesized cytokines inhibit downstream signaling of insulin receptors (Lumeng and Saltiel, 2011).

Undernourished mothers and their fetuses have increased plasma cortisol levels (Fowden, 1995; Goland et al., 1993). Placental 11-βHSD, the enzyme that converts glucocorticoids to inactive 11-keto products (Murphy et al., 1974), is reduced in malnourished dams, which led to increased plasma concentrations of free corticosterone in newborn rats (Lesage et al., 2001). Moreover, sows exposed to heat stress during early gestation altered progeny postnatal blood metabolites and decreased progeny insulin concentrations (Boddicker et al., 2014).

Nitrate, the primary form of N in forage, is converted to ammonia in the rumen via nitrite as an intermediary (Lee and Beauchemin, 2014). In cases of excess nitrate consumption in ruminants, incomplete reduction of nitrite to ammonia may be a cause of nitrate poisoning (Leng, 2008). Both nitrate and nitrite can be absorbed through the rumen wall (Jones, 1972). Although nitrate is not toxic in the blood, nitrite is (Ishigami and Inoue, 1976), binding to hemoglobin and oxidizing it to methemoglobin (Lundberg et al., 2008). Methemoglobin is incapable of carrying oxygen in the blood (Lee and Beauchemin, 2014) and is a known activator of pro-inflammatory cytokines IL-6, IL-8,

and E-Selectin (Umbreit, 2007). Additionally, sodium nitrite can cross the placenta and induce methemoglobin of the fetus (Fan et al., 1987; Gruener et al., 1973) and induce fetal cytokine expression. Prolonged exposure to the cytokine IL-6 has been shown to induce insulin resistance in muscle (Marette et al., 2014) and reduce fetal growth.

Impact of Maternal Nutrition on Reproductive Performance of Progeny

Characteristics of the ovary are closely related to fertility (Sullivan et al., 2009). Development of the testicles begins at d 45 of gestation, while ovarian development begins by d 50 (Funston et al., 2010). At d 80 of gestation for females, follicular development and primordial follicular assembly begins in cattle (Nilsson and Skinner, 2009). These follicles are the complete number of oocytes a female will have throughout her lifetime, and thus, their development greatly impacts her future reproductive capabilities (Hirshfield, 1994). Six-yr old female progeny born to ovine dams fed 50% of NRC recommendations from d 28 to 78 of gestation had lower circulating P_4 in blood serum and lower total P_4 concentration in luteal tissue, despite no changes in CL number or weight (Long et al., 2013). Previously, these progeny had decreased circulating P_4 at 1- and 2-yrs of age, as well as decreased lambing rates (Long et al., 2010). Production, secretion, and clearance of P_4 is critical to estrous cycle regulation and maintenance of pregnancy. Reduced P_4 concentrations have been shown to increase embryonic mortality (Inskeep, 2004), due to their role in suppression of PGF2α.

Limiting maternal nutrition had been shown to increase expression of ovarian apoptotic genes (Lea et al., 2006), increase oxidative DNA damage in oocytes (Murdoch et al., 2003), and impair fetal ovarian vasculature development (Grazul-Bilska et al., 2009). These findings could provide mechanisms for reduced ovarian follicle pools in

female offspring postnatally, as well as reduced follicle quality due to impaired vascularization. Reduced numbers of sertoli cells and consequent impaired testicular development was observed in infant male lambs born to nutrient restricted dams (Alejandro et al., 2002).

Heifers born to late gestation protein supplemented dams had increased pregnancy rates, and increased percentage of heifers calving in the first 21 d of the season when compared with non-supplemented controls (Martin et al., 2007). Although follicle development begins early in gestation, it is not completed until late gestation (Rhind et al., 2001), indicating protein supplementation may have an impact on follicle quality, and consequent embryonic viability. Maternal protein supplementation in the last third of pregnancy also improved pubertal rates in heifer progeny (Larson et al., 2009)

Impact of Maternal Nutrition on Feedlot Performance and Carcass Composition of Progeny

Maternal malnutrition or overproduction of inflammatory molecules can lead to an IUGR fetus, resulting in impaired growth and development postnatally (Wu et al., 2014). These alterations can impact postnatal growth, body composition, meat quality, and health (Wu et al., 2014). Skeletal muscle is of low importance in nutrient partitioning for the fetus, and is particularly sensitive to maternal deficiencies. Progeny are born with a fixed number of muscle fibers, thus skeletal muscle development *in utero* is critical to postnatal growth (Zhu et al., 2006). Offspring born to dams fed a high-energy diet during late gestation may be prone to hyperinsulemia, which impacts adipose development as an adult (Bach, 2011). In steer and heifer progeny whose dams were nutrient restricted from d 45 to 185 of gestation, adipocyte diameter in mesenteric and omental tissue was

increased; however, DNA concentration was decreased in the former (Long et al., 2012). Gene expression of FATP1, an insulin-sensitive fatty acid transporter (Wu et al., 2006), was increased in subcutaneous adipose tissue of nutrient restricted offspring. Relative mRNA abundance of lipoprotein lipase, or of the insulin-sensitive GLUT4 were not altered in the same tissue (Long et al., 2012), indicating increased adiposity may be due to increased fatty acid accumulation via upregulated fatty acid transporter synthesis, regardless of increased insulin levels in plasma. Additionally, weight of the semitendinosus muscle as a percentage of HCW tended to be reduced in progeny of the nutrient restricted model, suggesting decreased muscle mass (Long et al., 2012). Skeletal muscle is the main energy utilizer in the body, thus a reduction in muscle mass is expected to increase lipid accumulation (Du et al., 2011; Zhu et al., 2006).

Dams offered supplementation during late gestation had heavier offspring at slaughter and increased marbling scores (Summers et al., 2011). Although nonsignificant, differences in weaning BW resulted in increased returns in both scenarios if calves were sold at weaning or retained throughout the feedlot period (Summers et al., 2011). Interestingly, these offspring were not heavier at birth (Martin et al., 2007). Alternatively, offspring born to protein-supplemented primiparous dams had decreased DMI and residual feed intake (RFI) values, indicating a greater level of efficiency. These offspring also had decreased marbling scores, empty body fat percentage, yield grades, and 12th rib fat (Summers et al., 2015b). These studies suggest differences in nutrients offered to the dam during late gestation may result in opposing effects, and may be subject to metabolic factors.

Differences in the maternal environment due to maternal nutrition resulted in alterations to the function and structure of pancreatic islet cells in rodents (Fowden and Hill, 2001). Ruminants do not obtain most of their energy through glucose, and as such, it is thought insulin plays a non-significant role in ruminant metabolism; however, in a high productivity environment, such as lactating dairy cows, milk production was influenced by minor changes in nutrient metabolism (Murphy et al., 2000). It is possible pancreatic function is of more importance in a feedlot environment due to greater availability of glucose and a greater productivity level.

Finally, maternal nutrient restriction of 50% in early- to mid-gestation resulted in female offspring with reduced ACTH and cortisol in response to a stressful stimulus (Long et al., 2010). In a feedlot setting, this may be advantageous to growth, due to the decreased performance and carcass qualities of animals with elevated cortisol levels. Moreover, stress may lead to increased DNA methylation and alter metabolic function of the ruminant through less expression of enzymes key to digestion (Gonzalez-Recio, 2011).

CALVING DATE SELECTION

Introduction

When choosing a calving date, producers must make several considerations that will ultimately impact the profitability and viability of their operation. Calving season will impact when other production events will occur, such as re-breeding, weaning, and marketing of offspring. Additionally, physiological state of the cow during different seasons of the year will be influenced by calving date selection. Labor management and lifestyle preferences are also important factors to consider. Ability to harvest forage for

overwinter feeding, pasture movement of cattle, and marketing time points will all impact selection of a date. Due to these factors, a universal calving date cannot be set and will vary among regions and production goals.

Once a calving date is selected, producers must adhere to the set date and will not have the ability to adjust production events for weather patterns, forage availability, or marketing opportunities. Geographical location of the operation will determine the type and level of external factors cattle are subjected to. Such factors include seasonal variations in wind, ambient temperature, rainfall, and humidity. Not only do these influences directly impact the cow and calf, but will cause differences in available forage characteristics. Disparities in plant seasonality, species, maturity, and growing season will influence forage quality and quantity available to the cow.

Physiological state of the cow influences nutritional requirements and is determined by calving and weaning (NRC, 2000). For cattle whose diet quality or intake do not meet nutrient demands, a negative energy balance may be entered, marked by a loss in BW and BCS. This is often seen during periods of high energy requirements, such as early lactation. Mobilization of body stores to meet energy requirements results in an altered metabolic profile (Hobbs et al., 2017). When cattle are not supplied with enough dietary glucose, metabolic pathways are activated in the liver to produce ketone bodies to produce energy for the brain and skeletal muscle. β-hydroxybutyrate (BHB) is the predominant ketone body in blood serum, and can be used as a proxy for fatty acid oxidation (Wathes et al., 2007). Lower BHB levels would indicate greater dietary glucose and should predict maintenance of BW and BCS of the cow (Hobbs et al., 2017). If levels of ketone bodies are too high, ketoacidosis may occur, causing loss of appetite,

keratinization of rumen papillae, increased blood pH, and decreased VFA absorption (Krehbiel et al., 1995). During a negative energy balance, intense mobilization of fat stores occurs, leading to high levels of nonesterified fatty acids (NEFA) present in the blood serum (Wathes et al., 2007).

Livestock operations in arid to semi-arid environments often report loss of BW and BCS, which can alter oxidative metabolism. This negatively impacts length of postpartum interval (PPI), and increases dystocia rates and embryonic mortality (Waterman and Butler, 2010). During late gestation and early lactation, nutrient availability is often limited and cattle utilize body stores to make up the deficit (Freetly et al., 2008). Hobbs et al. (2017) concluded higher serum BHB levels have a negative impact on pregnancy after timed AI, more so in cattle 4 years and younger. In multiparous cows, BHB and insulin concentrations were negatively correlated with peak milk yield; however, in primiparous cows, BHB levels were positively correlated with peak milk yield, suggesting differences in tissue mobilization strategies between primiparous and multiparous cows (Wathes et al., 2007).

Management of Condition (BCS)

Several elements of reproduction, including dystocia rates, calf mortality, and pregnancy success, are affected by nutritional management. Failure to become pregnant is one of the key reasons for culling a female from the herd, particularly for primiparous cows. An analysis for the cost of retaining non-pregnant heifers showed increasing costs with increasing percentage of non-pregnant heifers retained, thus it is not economically advantageous to do so (Bohling, 2011).

Management of body condition prior to calving, and providing adequate nutrition during the postpartum period to minimize BW loss are of the greatest benefit to increasing pregnancy rates in primiparous cows. It is suggested to calve younger females in a BCS of 6 (1 = emaciated to 9 = obese; Wagner et al., 1988) or greater (Banta et al., 2005). Research by Hess et al. (2005) underscores the importance of prepartum nutrition in PPI length. Body condition at breeding does influence PPI; however, it is too late to correct for any nutritional disadvantages at this point in time. There is a positive correlation between BCS at calving and BCS at breeding, so condition at calving should be used to determine nutritional strategies to increase pregnancy rates. It should be noted cows calving at a BCS of 5 experienced a negative energy balance in late gestation (Hess et al., 2005); however, this decrease in energy may yield more efficient usage of nutrients by the cow as she goes into lactation (Hawkins et al., 2000; Hunter, 1991). In a separate study examining the effect of cows calving in a thin (BCS < 5) vs. moderate (BCS ≥ 5) BCS, pregnancy rate to AI were similar; however, PPI was decreased 30 d in moderate condition cows (Lents et al., 2008). In contrast, Mulliniks et al. (2012) utilized 2- and 3-yr old cows calving in a BCS of 4, 5 or 6 to demonstrate a lack of significance of BCS at calving on pregnancy rate and PPI. Similar serum glucose concentrations and NEFA levels were observed in cows managed in an extensive grazing system, and had no effect on reproductive response (Mulliniks et al., 2012). The lack of significance in serum metabolites indicates cows could meet their nutritional needs solely through grazed forage, and were not utilizing body stores to make up for a deficit. It is possible cows can be metabolically adapted to maintain performance at lower BCS (Mulliniks et al., 2016).

Forage Quality

In the Nebraska Sandhills, two distinct forage types are available for grazing. Sub-irrigated meadow, lying between dunes, is dominated by cool season grasses and is generally higher in CP during the summer (Lardy et al., 1997). Predominant species include reed canarygrass (*phalaris arundinacea*), Kentucky bluegrass (*poa pratensis*), bluejoint reedgrass (*calamagrostis Canadensis*) and northern reedgrass (*calamagrostis inexpansa*; Shelbourn, 1998). Upland range is dominated by warm season grasses, and thus more closely follows a linear decline of CP throughout the summer months (Lardy et al., 1997). Characteristic grass species for this area include sand bluestem (*andropogon hallii*), little bluestem (*schizachyrium scoparium*), prairie sandreed (*calamovilfa longifolia*), needleandthread (*hesperostipa* comata), and blue grama (*bouteloua gracilis*); Shelbourn, 1998). Forage quality of upland range peaks early in the growing season and begins to decline throughout late summer. An increase in plant maturity corresponds with a decrease in forage quality, indicating forage quality is greatest for upland range in the spring (Lardy et al., 1997; Randel, 1990). Despite this decline during the breeding season, research by Adams et al. (1996), indicates nutrient requirements of early-summer calving herds grazing upland range can be met entirely through grazed forages.

As forage matures into late summer in the Nebraska Sandhills, forage CP declines and cell wall constituents (NDF) increases (Lardy et al., 1997). Waterman et al. (2007) demonstrated reduced CP and *in situ* organic matter digestibility in May vs. August forages. These qualities contribute to a lower metabolizable energy (ME) and metabolizable protein (MP) value available to the cow. As NDF increases, voluntary intake is decreased (Van Soest, 1964).

The protein in both warm and cool season grasses is high in RDP, so supplementation of RUP may be beneficial to meet the increased demands of lactation. Triplett et al. (1995), suggests moderate supplementation of RUP improves first-service conception rates and has a tendency to improve overall pregnancy rates. Lardy et al. (1997) demonstrated RDP and RUP levels were greatest in June range forage samples (10.2 and 2.3%, RDP and RUP) at Gudmundsen Sandhills Laboratory. This was followed by a marked decline throughout late summer, and reached their lowest in November (5.7 and 0.9%, RDP and RUP). These data points correlate with a declining *in vitro* dry matter disappearance (IVDMD; 68.2 vs. 48.9%, June vs. November).

MAY-CALVING IN THE NEBRASKA SANDHILLS

Introduction

Conventionally, a calving date set earlier in the year has been preferred to allow marketing of heavier calves at weaning in the fall; however, research suggests the increasing nutritional demands of early lactation can be met and exceeded solely through grazed forage, allowing for a lower cost management system (Adams et al., 1996). Thus, producers have adjusted their calving date to better match the physiological state of the cow to forage production, such as the May-calving system in the Nebraska Sandhills. This system not only mitigates the risk of imminent weather during the calving season, but better matches the cow's peak lactation period to increasing forage quality.

The premise behind calving in May for the Nebraska Sandhills has 2 main objectives: match forage green-up, and increasing quality, with peak cow nutrient demands and to lower harvested feed input. In addition, cows graze dormant, low-quality forage during the dry period, resulting in less overwinter supplementation to meet

gestational demands. Better pairing of forage quality to the nutrient demands of the cow has the potential to extend the grazing season and decrease the amount of harvested feed needed per year (Adams et al., 1996).

Stockton et al. (2007) demonstrated cows calving in April required less harvested feed input than those in a February calving system (758 kg/yr vs. 1486 kg/yr). Cows calving in three different systems (May, June and August) had similar pregnancy rates; however, June-calving dams weaned the heaviest calves (Griffin et al., 2012). June-born calves may also take advantage of an alternate marketing time point, and generally will receive a higher price because of decreased market supply. Additionally, calves weaned in June brought a higher net return than March when both calves entered a calf-fed feedlot system ($253.08 vs. $191.88, June vs. March; Stockton et al., 2007). In this scenario, reduced feed inputs and alternate marketing time indicate calving later in the year may be advantageous to the Sandhills producer.

Clark et al. (1997) performed an economic analysis of June vs. March calving in the Nebraska Sandhills. Calves born in June conservatively cost $45 less per calf than March-born. The difference in cost is mostly due to a reduction in harvested feed for early summer calving herds. Opportunity cost of labor, and personal time harvesting forage was not considered, but would be expected to further increase profits.

Another benefit of calving in late-spring is the lower likelihood of severe weather events affecting calf mortality and growth. Alternately, heat stress plays a considerable role in conception. High temperatures and heat stress delayed onset of puberty in heifers, depressed estrus activity, and increased perinatal mortality (Vincent, 1972). For early summer-calving herds, minimum temperature in the first 21 d of the breeding season is

shown to have the greatest detriment to pregnancy rates. It was determined optimal minimum temperature during the breeding season be equivalent to 12.6° C, with an inflection point of 10.0 ° C (Amundson et al., 2006). The inflection point is considered the point at which the pregnancy rate change grows increasingly negative. Late Summer minimum temperatures in the Nebraska Sandhills exceed both the inflection point and optimal temperature. Despite this, multiparous cows calving in June had similar pregnancy rates to those calving in March (92 vs. 95%, June vs. March; Adams et al., 2001).

Heifers and Primiparous Cows

Despite an increasing plane of nutrition immediately postpartum, lower pregnancy rates (70 vs. 87%) were observed for May vs. March-calving heifers in the Nebraska Sandhills (Springman et al., 2017). Though the May-calving system corresponds with a higher ambient temperature during the breeding season, it has not been shown to affect pregnancy rate in multiparous cows (Griffin et al., 2012), and thus is unlikely to be the cause of declining pregnancy rates in younger females. It is more likely that ability of the younger female to physically consume enough lower quality forage to meet the demands of maintenance, lactation and growth (Funston et al., 2016).

Postpartum DMI as a percentage of BW (DMI%BW) increased through postpartum wk 7 for lactating primiparous cows. This increase in DMI%BW did not correspond to increasing BW. In fact, both lactating and non-lactating heifers underwent BW loss (Linden et al., 2014). These data indicate May-calving primiparous cows may be unable to meet nutrient demands when grazing low quality forage. It is unclear whether RDP, and consequent MP, requirements were met in this study.

There is an abundance of scientific literature indicating protein is often the limiting nutrient in range forage (Adams et al., 1996; Krysl et al., 1987). When adapted for a May-calving herd grazing range in the Nebraska Sandhills, research by Lardy et al. (1997) indicated a negative MP balance of -1 g and -148 g for the months of August and September, respectively. This negative balance is due to a deficiency in RDP availability in Sandhills range (-55 g and -567 g, August and September), not in RUP. When RDP is deficient, rumen bacteria are limited in their ability to synthesize MCP (Hackmann, 2014). It should be noted, these values are based on the nutrient requirements of a mature cow, and not those of a heifer or primiparous cow, whose protein requirements would be expected to be even greater.

Heifers managed on a decreasing plane of nutrition post-insemination showed decreased conception rate and increased embryonic mortality (Arias et al., 2012; Kruse et al., 2017). Reduction of nutrient intake resulted in smaller dominant follicle size and a greater rate of follicle turnover (Murphy et al., 1991). This reduction in follicular size may be a causation of embryonic death (Perry et al., 2005). In contrast, primiparous cows maintained on a higher plane of nutrition had a larger dominant follicle size and higher levels of glucose and insulin in blood serum. Higher serum glucose levels indicate adequate energy intake, while increased insulin levels provide for appropriate uptake of glucose into the cell. These data also correspond with a shorter PPI and increased pregnancy rates in the high gain group (Ciccioli et al., 2003).

Supplementation of varying levels of RUP to sheep fed low-quality hay (6% CP) showed no difference in ovulation rate or serum LH concentration (Meza-Herrera et al., 2007) suggesting RDP may be the limiting factor when ruminants are fed a low-quality

forage. This idea is supported by the lack of significance in percent females calving in the first 21 d of the calving season, a measure of early embryonic mortality, amongst May-calving heifers and primiparous cows either not supplemented or supplemented with RUP throughout the breeding season (Lansford et al., 2017). During the breeding season of a March-calving herd, there is a positive RDP and MP balance, suggesting these females are not limited by microbial efficiency and are meeting their nutrient requirements (Lardy et al., 1997).

Another potential cause of reduced pregnancy rates in younger beef females is limited glucose availability. Between May and August 2-,3-, and 4-yr old April-calving cows grazing forage similar to Sandhills upland range, experienced a decline in serum glucose and an increase in serum insulin. Additionally, blood urea nitrogen levels decreased from May to August, indicative of declining protein availability within forages (Waterman et al., 2007). This research suggests a metabolic imbalance in the summer months for May-calving cows. Cows in the previous study experienced an increase in BW and BCS throughout the summer months, similar to that reported by Lansford et al. (2017) in 2-yr old cows grazing Sandhills upland range. It is possible decreased microbial efficiency and production of VFA's, due to an RDP deficiency, is the root cause of decreased energy availability and consequent depressed pregnancy rates.

Serum levels of BHB have the potential to be utilized as a tool to indicate a metabolic imbalance of glucose availability. As mentioned previously, BHB levels are a secondary indicator of serum glucose concentrations, with higher BHB levels when serum glucose in low, and vice versa. In a 2-yr study utilizing 3- to 9-yr old Angus-based cows, serum BHB concentrations were significantly lower in females becoming pregnant to timed AI

(Hobbs et al., 2017). This data underscores the importance of glucose to the ability of the cow to conceive earlier in the calving season. Cows who conceive earlier in the breeding season should calve earlier, which has been shown to increase cow longevity within the herd (Cushman et al., 2013), calf BW at weaning (Marshall et al., 1990), and carcass value of steer progeny (Funston et al., 2012).

CONCLUSIONS

Conscious reproductive and nutritional decisions have far-reaching impacts on the beef herd. Use of estrus synchronization leads to tighter calving windows, and greater growth potential of progeny. If heifers are kept in the herd, those born in the first portion of the calving season are likely to remain in the herd longer than those born later in the calving season. Additionally, using AI in conjunction with estrus synchronization allows access to better genetics and will accelerate the rate of genetic change within the herd for the desired trait.

Adequate nutrition before, during, and after the breeding period is critical to maximizing conception rates in beef females. Alterations in the rate of gain during these periods can affect pregnancy outcome. Even prior to conception, diet has the ability to alter oocyte quality and competency. Imbalances in maternal nutrition during the gestational period also lead to alterations in fetal growth, which last long after parturition. The timing and level of insult determines the embryonic, placental and fetal outcome. Early gestation restriction, such as that experienced during the breeding season, can hamper conceptus implantation and growth, while mid-gestation differences can affect placental growth and vascularization. If the placenta is insufficient to keep up with the late gestation nutrient demands of the rapidly growing fetus, fetal stress in incurred and

may lead to IUGR. Alternately, difference in the maternal environment during late gestation alone can reduce fetal nutrient availability and alter postnatal health and growth trajectory.

OBJECTIVES

- Determine the efficacy of a subcutaneous injection of prostaglandin $F_{2\alpha}$ in estrus synchronization and pregnancy success of beef heifers
- Determine the effect of RUP supplementation during the breeding season on reproductive performance of May-calving heifers and primiparous cows
- Determine the effect of differing forage source during the breeding season and diet differences on reproductive outcomes of a May-calving herd
- Assess differences in prepartum nutrition on subsequent cow pregnancy success
- Determine the impacts of differing levels of late gestation nutrition on steer progeny postnatal growth, feedlot performance, and carcass characteristics
- Determine the impacts of differing levels of late gestation nutrition on heifer progeny postnatal growth, reproductive performance, and first calf growth

LITERATURE CITED

Adams, D. C., D. Clark, R. Sandberg, G. Carriker, T. J. Klopfenstein, and T. Milton. 2001. June versus March Calving for the Nebraska Sandhills: Production Traits. In: 2001 Nebraska Beef Cattle Report. Rep. No. MP 76-A. Univ. of Nebraska, Lincoln. p. 8-9.

Adams, D. C., R. T. Clark, T. J. Klopfenstien, and J. D. Volesky. 1996. Matching the cow with forage resources. Rangelands 18: 57-62.

Adams, G. 1999. Comparative patterns of follicle development and selection in ruminants. Journal of reproduction and fertility. Supplement 54: 17-32.

Adams, G. P., R. L. Matteri, J. P. Kastelic, J. C. Ko, and O. J. Ginther. 1992. Association between surges of follicle-stimulating hormones and emergence of follicular waves in heifer. J. Reprod. Fertil. 94: 177-188.

Aerts, L., and F. A. Assche. 1977. Rat foetal endocrine pancreas in experimental diabetes. J. Endocrinol. 73: 339-346.

Aerts, L., K. Holemans, and F. A. V. Assche. 1990. Maternal diabetes during pregnancy: Consequences for the offspring. Diab. Metab. Rev. 6: 147-167.

Aldoretta, P. W., and W. W. Hay. 1995. Metabolic substrates for fetal energy metabolism and growth. Clin. Perinatol. 22: 15-36.

Alejandro, B., R. Perex, G. Pedrana, J. T. Milton, A. Lopez, M. A. Blackberry, G. Duncombe, H. Rodriguez-Martinez, and G. B. Martin. 2002. Low maternal nutrition during pregnancy reduced the number of sertoli cells in the newborn lamb. Reprod Fertil Dev 14: 333-337.

Amundson, J. L., T. L. Mader, R. J. Rasby, and Q. S. Hu. 2006. Environmental effects on pregnancy rate in beef cattle. J. Anim. Sci. 84: 3415-3420. doi:10.2527/jas.2005-611.

Andreasyan, K., A. L. Ponsonby, T. Dwyer, R. Morley, M. Riley, K. Dear, and J. Cochrane. 2007. Higher maternal dietary protein intake in late pregnancy is associated with a lower infant ponderal index at birth. Euro J Clin Nutr 61: 498-508. doi:10.1038/sj.ejcn.1602552.

Arias, R. P., P. J. Gunn, R. P. Lemenager, and S. L. Lake. 2012. Effects of post-AI nutrition on growth performance and fertility of yearling beef heifers. J. Anim. Sci. 63: 117-121.

Armstrong, D., and W. Hansel. 1959. Alteration of the Bovine Estrous Cycle with Oxytocin1. Journal of Dairy Science 42: 533-542.

Bach, A. 2011. Ruminant Nutrtion Symposium: Optimizing performance of the offspring: Nourishing and managing dam and postnatal calf for optimal lactation, reproduction, and immunity. J Anim Sci 90: 1835-1845.

Banta, J. P., D. L. Lalman, and R. P. Wettemann. 2005. Symposium Paper: Post-calving nutrition and management programs for two-year-old beef cows. The Professional Animal Scientist 21: 151-158. doi:10.15232/S1080-7446(15)31196-7.

Barker, D.J.P., and C. Osmond. 1986. Infant mortality, childhood nutrition and ischaemic heart disease in England and Wales. Lancet I: 1077-1081.

Barker D.J.P., P.D. Winter, C. Osmond, B. Margetts, and S.J. Simmonds. 1989. Weight in infancy and death from ishaemic disease. Lancet II: 577-580.

Barker, D.J.P., A.R. Bull, C. Osmond and S.J. Simmonds. 1990. Fetal and placental size and risk of hypertension in adult life. Br Med J 30: 259-262.

Barker, D.J.P. 1991. The intrauterine origins of cardiovascular and obstructive lung disease in adult life. The Marc Danials Lecture 1990. J. Roy Coll Phys Lond. 25: 129-132.

Bazer, F., T. Spencer, and W. Thatcher. 2012. Growth and development of the ovine conceptus. Journal of animal science 90: 159-170.

Bazer, F. W., G. Wu, G. A. Johnson, J. Kim, and G. Song. 2011. Uterine histotroph and conceptus development: Select nutritients and exreted phosphoprotein 1 affect mechanistic target of rapamycin cell signaling in ewes. Biol. Reprod. 85: 1094-1107. doi:10.1095/biolreprod.111.094722.

Beam, T., T. Jenkins, P. Moate, R. Kohn, and D. Palmquist. 2000. Effects of Amount and Source of Fat on the Rates of Lipolysis and Biohydrogenation of Fatty Acids in Ruminal Contents1. Journal of Dairy Science 83: 2564-2573.

Bell, A. W., and D. E. Bauman. 1997. Adaptations of glucose metabolism during pregnancy and lactation. J. Mammary Gland Biol. 2: 265-278.

Bergman, E. N. 1990. Energy contributions of volatile fatty acids from the gastrointestinal tract in various species. Physiol. Rev. 70: 567-590.

Bird, I. M., L. Zhang, and R. R. Magness. 2003. Possible mechanisms underlying pregnancy-induced changes in uterine artery endothelial function. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 284: R245-R258.

Bloss, R., J. Northam, L. Smith, and R. Zimbelman. 1966. Effects of oral melengestrol acetate on the performance of feedlot cattle. Journal of Animal Science 25: 1048-1053.

Boddicker, R. L., J. T. Siebert, J. S. Johnson, S. C. Pearce, J. T. Selsby, N. K. Gabler, M. C. Lucy, T. J. Safranski, R. P. Rhoads, L. H. Baumgard, and J. W. Ross. 2014. Gestational heat stress alters postnatal offspring body composition indices and metabolic parameters in pigs. PLoS One 9: e110859. doi:10.1371/journal.pone.0110859.

Bohling, T. T. 2011. Replacement alternative for beef cow herds: An analysis of retaining non-pregnant cows, Univ. of Nebraska, Lincoln, Lincon, Nebraska.

Castro, L. C., and R. L. Avina. 2002. Maternal obesity and pregnancy outcomes. Curr. Opin. Obstet. Gynecol. 14: 601-606.

Cetin, I., and B. Koletzko. 2008. Long-chain ω-3 fatty acid supply in pregnancy and lactation. Current Opinion in Clinical Nutrition & Metabolic Care 11: 297-302.

Ciccioli, N. H., R. P. Wettemann, L. J. Spicer, C. A. Lents, F. J. White, and D. H. Keisler. 2003. Influence of body condition at calving and postpartum nutritition on endocrine function and reproductive performance of primiparous beef cows. J. Anim. Sci. 81: 3107-3120.

Clark, R. T., D. C. Adams, G. P. Lardy, and T. J. Klopfenstein. 1997. Matching calving date with forage nutrients: Production and economic impacts. In: Range Beef Cow Symp, Rapid City, SD. p 223-232.

Collier, R. J., L. H. Baumgard, A. L. Lock, and D. E. Bauman. 2005. Physiological limitations, nutrient partitioning. Yield of farmed species. Constraints and

opportunities in the 21st Century (ed. R Sylvester-Bradley and J Wiseman): 351-377.

Coppock, C., and D. Wilks. 1991. Supplemental fat in high-energy rations for lactating cows: effects on intake, digestion, milk yield, and composition. Journal of Animal Science 69: 3826-3837.

Crawford, M., W. Doyle, A. Leaf, M. Leighfield, K. Ghebremeskel, and A. Phylactos. 1993. Nutrition and neurodevelopmental disorders. Nutrition and health 9: 81-97.

Cronje, P. B., J. V. Nolan, and R. A. Leng. 1991. Acetate clearance rate as a potential index of availability of glucogenic precursors in ruminant fed on roughage-based diets. British Journal of Nutrition 66: 301-312. doi:10.1079/BJN19910033.

Crouse, M. S., K. J. McLean, N. P. Greseth, M. R. Crosswhite, N. N. Pereira, A. K. Ward, L. P. Reynolds, C. R. Dahlen, R. P. Borowicz, and J. S. Caton. 2017. Effects of maternal nutritional status on nutrient transporter expression and nutrient concentrations in bovine utero-placental tissues and fluids on days 16 to 50 of gestation. In: Western Section, American Society of Animal Science, Fargo, ND. p 6-14.

Crowe, M., V. Padmanabhan, M. Mihm, I. Beitins, and J. Roche. 1998. Resumption of follicular waves in beef cows is not associated with periparturient changes in follicle-stimulating hormone heterogeneity despite major changes in steroid and luteinizing hormone concentrations. Biology of Reproduction 58: 1445-1450.

Cushman, R. A., L. K. Kill, R. N. Funston, E. M. Mousel, and G. A. Perry. 2013. Heifer calving date positively influences calf weaning weights through six parturitions. J. Anim. Sci. 91: 4486-4491. doi:10.2527/jas.2013-6465.

Cushman, R. A., S. C. Tenley, E. M. Soares, and A. K. McNeel. 2017. Improving calving day to improve lifetime productivity. In: XLV Uruguayan Buiatric Congress, Paysandu, Uruguay. p 61-67.

Da-Silva, P., R. P. Aitken, S. M. Shing, P. A. Racey, and J. M. Wallace. 2002. Impact of maternal overnutrition during pregnancy on pituitary gonadotropin gene expression and ovarian development in growth-restricted and normally grown late gestation fetuses. Reproduction 123: 769-777.

Dalinghaus, M., C. D. Rudolph, and A. M. Rudolph. 1991. Effects of maternal fasting on hepatic glucoenogenesis and glucose metabolism in fetal lambs. J. Develop. Physiol. 16: 267-275.

Dorniak, P., T. H. Welsh, F. W. Bazer, and T. E. Spencer. 2012. Endometrial HSD11B1 and Cortisol regeneration in the ovine uterus: Effects of pregnancy, Interferon Tau, and Prostaglandins. Biol. Reprod. 86: 1-10. doi:10.1095/biolreprod.111.097063.

Dresner, A., D. Laurent, M. Marcucci, M. E. Griffin, S. Dufour, G. W. Cline, L. A. Slezak, D. K. Anderson, R. S. Hundal, D. L. Rothman, K. F. Peterson, and G. I. Shulman. 1999. Effects of free fatty acids on glucose transport and IRS-1-associated phosphatidylinositol 3-kinase activity. J. Clin. Invest. 103: 253-259.

Du, M., J. X. Zhao, X. Yan, Y. Huang, L. V. Nicodemus, W. Yue, R. J. McCormick, and M. J. Zhu. 2011. Fetal muscle development, mesenchymal multipotent cell differentiation and associated signaling pathways. J. Anim. Sci. 89: 583-590.

Dunlap, K. A., J. D. Brown, A. B. Keith, and M. C. Satterfield. 2015. Factors controlling nutrient availability to the developing fetus in ruminants. Journal of animal science and biotechnology 6: 16.

Dutta-Roy, A. K. 2000. Transport mechanisms for long-chain polyunsaturated fatty acids in the human placenta. The American journal of clinical nutrition 71: 315s-322s.

Fan, A. M., C. C. Willhite, and S. A. Book. 1987. Evaluation of the nitrate drinking water standard with reference to infant methemoglobinemia and potential reproductive toxicity. Regul. Toxicol. Pharmacol. 7: 135-148. doi:10.1016/0273-2300(87)90024-9.

Fazzari, M. J., and J. M. Greally. 2009. Introduction to Epigenomics and Epigenome-Wide Analysis. Statistical Methods of Molecular Biology 620: 243-265.

Fields, M., and P. Fields. 1996. Morphological characteristics of the bovine corpus luteum during the estrous cycle and pregnancy. Theriogenology 45: 1295-1325.

Flynn, N., C. Meininger, T. Haynes, and G. Wu. 2002. The metabolic basis of arginine nutrition and pharmacotherapy. Biomedicine & Pharmacotherapy 56: 427-438.

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.

Forde, N., M. Beltman, P. Lonergan, M. Diskin, J. Roche, and M. Crowe. 2011. Oestrous cycles in Bos taurus cattle. Animal reproduction science 124: 163-169.

Fowden, A. L. 1995. Endocrine regulation of fetal growth. Reprod. Fertil. Dev. 7: 351-363.

Fowden, A. L., and D. J. Hill. 2001. Intra-uterine programming of the endocrine pancreas. Br. Med. Bull. 60: 123-142.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2008. Partitioning of energy in pregnant beef cows during nutritionally induced body weight fluctuation. J. Anim. Sci. 86: 3703-3777.

Funston, R. N. 2004. Fat supplementation and reproduction in beef females. Journal of Animal Science 82: E154-E161.

Funston, R. N., E. E. Grings, A. J. Roberts, and B. T. Tibbitts. 2016. Invited Review: Choosing a calving date. The Professional Animal Scientist 32: 145-153. doi:10.15232/pas.2015-01463.

Funston, R. N., D. M. Larson, and K. A. Vonnahme. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: implication for beef cattle production. J Anim Sci 88: 205-215.

Funston, R. N., J. A. Musgrave, T. L. Meyer, and D. M. Larson. 2012. Effect of calving period on ADG, reproduction, and first calf characteristics of heifer progeny. J. Anim. Sci. 90: 5118-51121. doi:10.2527/jas.2012-5263.

Funston, R. N., and A. F. Summers. 2013. Effect of prenatal programming on heifer development. Vet Clin N Am-Food A 3: 517-536.

Geisert, B. G. 2007. Development of a set of forage standard to estimate *in vivo* digestibility of forages and prediction of forage quality of diets consumed by cattle grazing Nebraska Sandhills range pastures, Univ. of Nebraska, Lincoln.

Ginther, O., D. Bergfelt, L. Kulick, and K. Kot. 2000. Selection of the dominant follicle in cattle: role of estradiol. Biology of reproduction 63: 383-389.

Ginther, O. J., K. Kot, L. Kulick, S. Martin, and M. Wiltbank. 1996. Relationships between FSH and ovarian follicular waves during the last six months of pregnancy in cattle. Journal of reproduction and fertility 108: 271-279.

Gluckman, P. D., and M. A. Hanson. 2004. Living with the past: evolution, development, and patterns of disease. Science 305: 1733-1736.

Gluckman, P. D., and G. C. Liggins. 1984. Regulation of fetal growth. Fetal Physiology and Medicine 2: 511-557.

Goland, R. S., S. Jozak, W. B. Warren, I. M. Conwell, R. I. Stark, and P. J. Tropper. 1993. Elevated levels of umbilical cord plasma corticotropin-releasing hormone in growth-retarded fetuses. J. Clin. Endocrinol. Metab. 77: 1174-1179.

Goldenburg, R. L., J. C. Hauth, and W. W. Andrews. 2000. Intrauterine infection and preterm delivery. N. Engl. J. Med. 342: 1500-1507.

Gonzalez-Recio, O. 2011. Epigenetics: A New Challenge in the Post-Genomic Era of Livestock. Frontiers in Genetics 2.

Goodman, R. L., and F. J. Karsch. 1980. Pulsatile secretion of luteinizing hormone: Differential suppression by ovarian steroids. Endocrinology 107: 1286-1290. doi:https://doi.org/10.1210/endo-107-5-1286.

Grazul-Bilska, A. T., J. S. Caton, W. Arndt, K. Burchill, C. Thorson, E. Borowczyk, J. J. Bilski, D. A. Redmer, L. P. Reynolds, and K. A. Vonnahme. 2009. Cellular proliferation and vascularization in ovine fetal ovaries: Effects of undernutrition and selenium in maternal diet. Reproduction 137: 699-707.

Griffin, W. A., L. A. Stalker, D. C. Adams, R. N. Funston, and T. J. Klopfenstein. 2012. Calving date and wintering system effects on cow and calf performance I: A

systems approach to beef production in the Nebraska Sandhills. The Professional Animal Scientist 28: 249-259. doi:10.15232/S1080-7446(15)30355-7.

Gruener, N., H. I. Shuval, K. Behroozi, S. Cohen, and H. Schechter. 1973. Methemoglobinemia induced by transplantal passage of nitrate in rats. Bull. Environ. Contam. Toxicol. 9: 44-48. doi:10.1007/BF01856770.

Hackmann, T. J. 2014. Strategies to improve rumen microbial efficiency. In: 25th Annual Florida Ruminant Nutrition Symposium, Gainesville, FL

Hall, M. B., and M. L. Eastridge. 2014. Invited Reveiw: Carbohydrate and fat: Considerations for energy and more. The Professional Animal Scientist 30: 140-149.

Hales, C.N., and D.J.P. Barker. 1992. Type 2 (non-insulin dependent) diabetes mellitus: the thrifty phenotype hypothesis. Diabetologia 35:595-601.

Hansel, W., and E. M. Convey. 1983. Physiology of the estrous cycle. Journal of Animal Science 57: 404-424.

Hansel, W., P. Malven, and D. Black. 1961. Estrous cycle regulation in the bovine. Journal of Animal Science 20: 621-625.

Hawkins, D. E., M. K. Peterson, M. G. Thomas, J. E. Sawyer, and R. C. Waterman. 2000. Can beef heifers and young postpartum cows by physiologically and nutritionally manipulated to optimize reproductive efficiency? J. Anim. Sci. 77 (E. Suppl.). doi:10.2527/jas2000.00218812007700ES0045x.

Hay, W. W. 1991. Energy and substrate requirements of the placenta and fetus. Proceedings of the Nutrition Society 50: 321-336.

Heijmans, B. T., E. L. Tobi, A. D. Stein, H. Putter, G. J. Blauw, E. S. Susser, P. E. Slagbloom, and L. H. Lumeye. 2008. Persistent epigenetic differences associated with prenatal exposure to famine in humans. Proc. Natl. Acad. Sci. 105: 17046-17049.

Hess, B. W., S. L. Lake, E. J. Scholljegerdes, T. R. Weston, V. Nayigihugu, J. D. C. Molle, and G. E. Moss. 2005. Nutritional controls of beef cow reproduction. J. Anim. Sci. 83 (E. Suppl.): E90-E106.

Hirshfield, A. N. 1994. Relationship between the supply of primordial follicles and the onset of follicular growth in rats. Biol Rerpod 50: 421-428.

Hobbs, J. D., S. R. Edwards, E. R. Cope, Z. D. McFarlane, K. G. Pohler, and J. T. Mulliniks. 2017. Circulating beta-hydroxybutyrate concentration may be a predictive measurement for young cows that have a greater probability to conceive at a fixed-time artificial insemination. J. Anim. Sci. 95: 1545-1552. doi:10:2527/jas2016.1247.

Hohenboken, W. D. 1988. Bovine nirvana-from the perspective of an experimentalist. Journal of Animal Science 66: 1885-1891.

Hunter, R. A. 1991. Strategic supplementation for survival, reproduction and growth of cattle. In: Proc. 2nd Grazing Livest. Nutr. Conf., Oklahoma Agric. Exp. Sta. MP-133, Stillwater, OK. p 32-47.

Inskeep, E. K. 2004. Preovulatory, postovulatory, and postmaternal recognition effects of concentrations of progesterone on embyronic survival in the cow. J. Anim. Sci. 82: E24-E39.

Ishigami, K., and K. Inoue. 1976. Metabolism of nitrate and methemoglobinemia in ruminants. Research Bulleting of Obihiro University 10: 45-55.

Jirtle, R., and M. Skinner. 2007. Environmental epigenomics and disease susceptibility. Nat Rev Genet 8: 253-262.

Johnson, S. K., and R. Jones. 2004. Costs and Comparisons of Estrous Synchronization Systems. In: Applied Reproductive Strategies in Beef Cattle, North Platte, Neb. p 103-115.

Jones, G. A. 1972. Dissimilatory metabolism of nitrate by the rumen microbiota. Can. J. Microbiol. 18: 1783-1787.

Jones, H., T. Powell, and T. Jansson. 2007. Regulation of placental nutrient transport–a review. Placenta 28: 763-774.

Karsdorp, V., J. Van Vugt, H. Van Geijn, P. Kostense, D. Arduim, N. Montenegro, and T. Todros. 1994. Clinical significance of absent or reversed end diastolic velocity waveforms in umbilical artery. The Lancet 344: 1664-1668.

Kim, J., G. Song, G. Wu, and F. W. Bazer. 2012. Functional roles of fructose. PNAS 109: E1619-E1628. doi:10.1073/pnas.12042910.

Klopfenstein, T. J. 1996. Need for escape protein by grazing cattle. Theriogenology 60: 191-199.

Krehbiel, C. R. 2014. Invited Review: Applied nutrition of ruminants: Fermentation and digestive physiology. The Professional Animal Scientist 30: 129-139.

Krehbiel, C. R., R. A. Britton, D. L. Harmon, T. J. Wester, and R. A. Stock. 1995. The effects of ruminal acidosis on volatile fatty acid absorption and plasma activites of pancreatic enzymes in lambs. J. Anim. Sci. 73: 3111-3121.

Kruse, S. G., G. A. Bridges, B. J. Funnell, S. L. Bird, S. L. Lake, R. P. Arias, O. L. Amundson, E. L. Larimore, D. H. Keisler, and G. A. Perry. 2017. Influence of post-insemination nutrition on embryonic development in beef heifers. Theriogenology 90: 185-190. doi:10.1016/j.theriogenology.2016.11.021.

Krysl, L. J., M. L. Galyean, J. D. Wallace, F. T. McCollum, M. B. Judkins, M. E. Branine, and J. S. Caton. 1987. Cattle nutrition on blue grama rangeland in New Mexico. N.M. Agric. Exp. Stn. Bull 727: 1-35.

Kwon, H., T. E. Spencer, F. W. Bazer, and G. Wu. 2003. Developmental changes of amino acids in ovine fetal fluids. Biology of reproduction 68: 1813-1820.

Lamb, G. C., C. R. Dahlen, J. E. Larson, G. Marquezine, and J. S. Stevenson. 2009. Control of the estrous cycle to improve fertility for fixed-time artificial insemination in beef cattle: A Review. J Anim Sci 88: 181-192.

Lansford, A. C., J. Musgrave, and R. N. Funston. 2017. Effect of supplementation during the breeding season on a May-calving herd in the Nebraska Sandhills. In: Western Section - American Society of Animal Science, Fargo, ND

Lardy, G., D. C. Adams, T. J. Klopfenstein, D. Clark, and J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills Native Range and subirrigated meadow diets and application of a metabolizable protein system. In: 1997 Nebraska Beef Cattle Report. Rep. No. MP 67-A. Univ. of Nebraska, Lincoln

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. 85: 841-847.

Lauderdale, J. 2001. Use of prostaglandin F2α (PGF2α) in cattle breeding. Factors Affecting Calf Crop: Biotechnology of Reproduction: 23.

Lauderdale, J. 2009. ASAS Centennial Paper: Contributions in the to the development of protocols for breeding management of cattle through synchronization of estrus and ovulation. Journal of animal science 87: 801-812.

Lauderdale, J., E. Moody, and C. Kasson. 1977. Dose effect of PGF2α on return to estrus and pregnancy in cattle. J. Anim. Sci.(Suppl. 1) 45: 9.

Lea, R. G., L. P. Andrade, M. T. Rae, L. T. Hannah, C. E. Kyle, J. F. Murray, S. M. Rhind, and D. W. Miller. 2006. Effects of maternal undernutrition during early pregnancy on apoptosis regulators in the ovine fetal ovary. Reproduction 131: 113-124.

Lee, C., and K. A. Beauchemin. 2014. A review of feeding supplementary nitrate to ruminant animals: nitrate toxicity, methane emissions, and production performance. Can J Anim Sci 94: 557-570. doi:10.1139/CJAS-2014-069.

Lemons, J. 1979. Fetal-placental nitrogen metabolism. In: Seminars in perinatology. p 177-190.

Leng, R. A. 2008. The potential of feeding nitrate to reduce enteric methane production in ruminants. In: Report to Department of Climate Change, Commonwealth Government of Australia. Rep. No.

Lents, C. A., F. J. White, N. H. Ciccioli, R. P. Wetteman, L. J. Spicer, and D. L. Lalman. 2008. Effects of body condition score at parturition and postpartum supplementation on estrous behavior and size of dominant follice in beef cows. J. Anim. Sci. 86: 2549-2556. doi:10.2527/jas.2008-1114.

Lesage, J., B. Blondeau, M. Grino, B. Breant, and J. P. Dupouy. 2001. Maternal undernutrition during late gestation induces fetal overexposure to glucocorticoids and intrauterine growth retardation, and disturbs the hypothalmo-pituitary adrenal axis in the newborn rat. Endocrinology 142: 1692-1702. doi:10.1210/endo.142.5.8139.

Leury, B. J., A. R. Bird, K. C. Chandler, and A. W. Bell. 1990. Glucose partitioning in the pregnant ewe: effects of undernutrition and excercise. Brit. J. Nutr. 64: 449-462.

Lindegaard, M. L., G. Olivecrona, C. Christoffersen, D. Kratky, J. Hannibal, B. L. Petersen, R. Zechner, P. Damm, and L. B. Nielsen. 2005. Endothelial and lipoprotein lipases in human and mouse placenta. Journal of lipid research 46: 2339-2346.

Linden, D. R., E. C. Titgemeyer, K. C. Olson, and D. E. Anderson. 2014. Effects of gestation and lactation on forage intake, digestion, and passage rates of primiparous beef heifers and multiparous beef cows. J. Anim. Sci. 92: 2141-2151. doi:10.2527/jas2013-6813.

Long, N. M., M. J. Nijland, P. W. Nathanielsz, and S. P. Ford. 2010. The effect of early to mid-gestational nutrient restriction on female offspring fertility and hypothalamic-pituitary-adrenal axis response to stress. Anim Reprod Sci 72: 63-71.

Long, N. M., C. B. Tousley, K. R. Underwood, S. I. Paisley, W. J. Means, B. W. Hess, M. Du, and S. P. Ford. 2012. Effects of early- to mid-gestational undernutrition with or without protein supplementation on offspring growth, carcass

charecteristics, and adipocyte size in beef cattle. J. Anim. Sci. 90: 197-206. doi:10.2527/jas.2011-4237.

Long, N. M., N. Tuersunjiang, L. A. George, C. O. Lemley, Y. Ma, W. J. Murdoch, P. W. Nathanielsz, and S. P. Ford. 2013. Maternal nutrient restriction in the ewe from early to midgestation programs reduced steroidogenic enzyme expression and tended to reduce progesterone content of copora lutea, as well as circulating progesterone in nonpregnant aged female offspring. Reprod Biol Endocrinol 11: 34.

Lorenzo, M., S. Fernandez-Veledo, R. Vila-Bedmar, L. Garcie-Guerra, C. D. Alvaro, and I. Nieto-Vazquez. 2008. Insulin resistance induced by tumor necrosis factor-alpha in myocytes and brown adipocytes. J. Anim. Sci. 86: E94-E104.

Lucas, A. 1991. Programming by early nutrition in Man. In: G.R. Bock, J. Whelan (ed) The childhood environment and adult diseas. Ciba Found. Symp. John Wiley & Sons, Chichester, England, pp 38-50.

Lucy, M., H. Billings, W. Butler, L. Ehnis, M. Fields, D. Kesler, J. Kinder, R. Mattos, R. Short, and W. Thatcher. 2001. Efficacy of an intravaginal progesterone insert and an injection of PGF2alpha for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers, and dairy heifers. Journal of animal science 79: 982-995.

Lumeng, C. N., and A. R. Saltiel. 2011. Inflammatory links between obesity and metabolic disease. J. Clin. Invest. 121: 2111-2117.

Lundberg, J. O., E. Weitzberg, and M. T. Gladwin. 2008. The nitrate-nirite-nitric oxide pathway in physiology and therapeutics. Nat. Rev. Drug Discov. 7: 156-157.

Lyimo, Z., M. Nielen, W. Ouweltjes, T. A. Kruip, and F. Van Eerdenburg. 2000. Relationship among estradiol, cortisol and intensity of estrous behavior in dairy cattle. Theriogenology 53: 1783-1795.

Malek, A., R. Sager, E. Aegerter, and H. Schneider. 1993. Metabolism of glutamic acid studied in the dually in vitro perfused human placental cotyledon. Placenta 14: 87-102.

Marette, A., Y. Liu, and G. Sweeney. 2014. Skeletal muscle glucose metabolism and inflammation in the development of metabolic syndrome. Rev. Endocr. Metab. Disrod. 15: 299-305.

Marshall, D. M., W. Minqiang, and B. A. Freking. 1990. Relative calving date of first-calf heifers as related to production efficiency and subsequent reproductive performance. J. Anim. Sci. 68. doi:10.2527/1990.68771812x.

Martin, A. O., J. L. Simpson, C. Ober, and N. Freinkel. 1985. Frequency of diabetes mellitus in mothers of probands with gestational diabetes: Possible maternal influence on the predisposition to gestational diabetes. Am. J. Obstet. Gynecol. 151: 471-475.

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.

McNanley, T., and J. Woods. 2008. Placental physiology. Global library of women's. Paula and David Bloomer, Medicine.

McPherson, N. O., V. G. Bell, D. L. Zander-Fox, T. Fullston, L. L. Wu, R. L. Robker, and M. Lane. 2015. When two obese parents are worse than one! Impacts on

embryo and fetal development. Am. J. Physiol. Endocrinol. Metab. 309: E568-E581. doi:10.1152/ajpendo.00230.2015.

Meza-Herrera, C. A., T. Ross, D. Hallford, D. Hawkins, and A. Gonzalez-Bulnes. 2007. Effects of body condition and protein supplementation on LH secretion and luteal function in sheep. Reprod Domest Anim 42: 461-465. doi:10.1111/j.1439-0531.2006.00807.

Molina-Font, J. A. 1998. Nutrition and Fetal Growth. Early Human Development 53: S51-S60.

Momoko, I., A. Iwase, and K. Sugimoto. 2015. Control of plant cell differentiation by histone modification and DNA methylation. Current Opinion in Plant Biology 28: 60-67.

Moody, E., J. McAllister, and J. Lauderdale. 1978. Effect of PGF2α and MGA on control of the estrous cycle in cattle. J. Anim. Sci 47: 36.

Moriel, P., R. F. Cooke, D. W. Bohnert, J. M. B. Vendramini, and J. D. Arthington. 2012. Effects of energy supplementation frequency and forage quality on performance, reproductive, and physiological responses of replacement beef heifers. J. Anim. Sci. 90: 2371-2380. doi:10.2527/jas2011-4958.

Moriel, P., M. B. Piccolo, L. F. A. Artioli, R. S. Marques, M. H. Poore, and R. F. Cooke. 2016. Short-term energy restriction during late gestation of beef cows decreases postweaning calf humoral immune response to vaccination. J. Anim. Sci. 94. doi:10.2527/jas2016-0426.

Mott, J. 1982. Control of the foetal circulation. Journal of Experimental Biology 100: 129-146.

Mulliniks, J., E. Cope, Z. McFarlane, J. Hobbs, and R. Waterman. 2016. Drivers of grazing livestock efficiency: how physiology, metabolism, experience and adaptability influence productivity. Journal of Animal Science 94: 111-119.

Mulliniks, J. T., S. H. Cox, M. E. Kemp, R. L. Endecott, R. C. Waterman, D. M. VanLeeuwen, and M. K. Peterson. 2012. Relationship between body condition score at calving and reproductive performance in young postpartum cows grazing native range. J. Anim. Sci. 90: 2811-2817.

Murdoch, W. J., E. A. V. Kirk, K. A. Vonnahme, and S. P. Ford. 2003. Ovarian response to undernutrition in pregnant ewes. Reprod. Biol. Endocrinol. 1: 6.

Murphy, B. E. P., S. J. Clark, I. R. Donald, M. Pinksy, and D. L. Vedady. 1974. Conversion of maternal cortisol to cortisone during placental transfer to the human fetus. Am. J. Obstet. Gynecol. 118: 538-541.

Murphy, M., M. Ackerland, and K. Holtenius. 2000. Rumen fermentation in lactating dairy cows selected for milk fat content fed two forage to concentrate ratios with hay or silage. J. Dairy Sci. 83: 756-764.

Murphy, M. G., W. J. Enright, M. A. Crowe, K. McConnell, L. J. Spicer, M. P. Boland, and J. F. Roche. 1991. Effect of dietary intake on pattern of growth of dominant follicles during the oestrus cycle in bef heifers. J. Reprod. Fertil 92: 333-338.

Nellor, J. E., and H. Cole. 1956. The hormonal control of estrus and ovulation in the beef heifer. Journal of Animal Science 15: 650-661.

Newell, L. C. 1968. Chemical composition of Two Warm-season Prairie Grasses in Three Environments. Crop Science 8: 325-329.

Nilsson, E. E., and M. K. Skinner. 2009. Progesteron regulation of primoridal follicle assembly in bovine fetal ovaris. Mol Cell Endocrinol 313: 9-16.

Nolan, J. V. 1975. Quantitative models of nitrogen metabolism in sheep. In: I. W. MacDonald and A. C. I. Warner (eds.) Digestion and Metabolism in the Ruminant. Univ. of New England Publishing Unit, Armidale, Australia.

Norman, A. W., and H. L. Henry. 2015. Pancreatic Hormones: Insulin and Glucagon Hormones. Elsevier Inc.

NRC. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. The National Academies Press, Washington, DC.

Osgerby, J. C., D. C. Wathes, D. Howard, and T. S. Gadd. 2002. The effect of maternal undernutrition on ovine fetal growth. J. Endocrinol. 173: 131-141. doi:0022-0795/02/0173-131.

Pacheco, D., and G. C. Waghorn. 2008. Dietary nitrogen - definitions, digestion, excretion and consequences of excess for grazing ruminants. In: Proceedings of the New Zealand Grassland Association. p 107-116.

Painter, R. C., T. J. Roseboom, and O. P. Bleker. 2005. Prenatal exposure to the Dutch famine and disease in later life: an overview. Reprod Toxicol 20: 345-352.

Patterson, H. H., D. C. Adams, T. J. Klopfenstein, and G. P. Lardy. 2006. Applications of the 1996 NRC to protein and energy nutrition of range cattle The Professional Animal Scientist 22: 307-317.

Perry, G. 2004. Fertility of Natural vs. Synchronized Estrus. In: Applied Reproductive Strategies in Beef Cattle, North Platte, Neb. p 86-98.

Perry, G. A., M. F. Smith, M. C. Lucy, J. A. Green, T. E. Parks, M. D. MacNeil, A. J. Roberts, and T. W. Geary. 2005. Relationship between follicle size at insemination and pregnancy success. P. Natl. Acad. Sci. USA 102: 5268-5273. doi:10.1073/pnas.0501700102.

Randel, R. D. 1990. Nutrition and postpartum rebreeding in cattle. J. Anim. Sci. 68: 853-862.

Reynolds, L., C. Ferrell, D. A. Robertson, and S. Ford. 1986. Metabolism of the gravid uterus, foetus and utero-placenta at several stages of gestation in cows. The Journal of Agricultural Science 106: 437-444.

Reynolds, L. P., J. S. Caton, D. A. Redmer, A. T. Grazul-Bilska, K. A. Vonnahme, P. P. Borowicz, J. S. Luther, J. M. Wallace, G. Wu, and T. E. Spencer. 2006. Evidence for altered placental blood flow and vascularity in compromised pregnancies. The Journal of physiology 572: 51-58.

Rhind, S. M., W. A. C. McKelvey, S. R. McMillen, R. G. Gunn, and D. A. Elston. 1989. Effect of restricted food intake, before and/or after mating, on the reproductive performance of Greyface ewes. Anim Prod 48: 149-155.

Rhind, S. M., M. T. Rae, and A. N. Brooks. 2001. Effects of nutrition and evnironmental factors on the fetal programming of the reproductive axis. Reproduction 122: 205-214.

Robinson, J. J., I. McDonald, C. Fraser, and R. M. J. Crofts. 1977. Studies on reproduction in prolific ewes. I. Growth of the products of conception. J Agri Sci 88.

Roche, J. 1976. Calving rate of cows following insemination after a 12-day treatment with silastic coils impregnated with progesterone. Journal of animal science 43: 164-169.

Roche, J. F. 1996. Control and regulation of folliculogenesis - a symposium in perspective. Rev. Reprod. 1: 19-27.

Rogers, T. A., and M. Kleiber. 1957. Milk Fat Synthesis from Acetate in Mammary Gland of the Cow. Exp. Biol. Med. 94: 705-708. doi:10.3181/00379727-94-23059.

Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. V. Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal Fermentation. J. Anim. Sci. 70: 3551-3561.

Senger, P. L. 2005. Pathways to pregnancy and parturition - 3rd Edition. Current Conception, Inc., Redmond, OR.

Shelbourn, M. 1998. The Sand Hills at a Glance. Rangelands 20: 10-12.

Silverman, B. L., B. E. Metzger, N. H. Cho, and C. A. Loeb. 1995. Impaired glucose tolerance in adolescent offspring of diabetic mothers. Relationship to fetal hyperinsulinism. Diabetes Care 18: 611-617.

Simmons, M., F. Battaglia, and G. Meschia. 1979. Placental transfer of glucose. Journal of developmental physiology 1: 227-243.

Springman, S. A., H. R. Nielson, J. A. Musgrave, J. Nollette, A. Applegarth, and R. N. Funston. 2017. Impact of heifer development system in two different breeding seasons. In: 2017 Nebraska Beef Cattle Report. Rep. No. MP104. Univ. of Nebraska, Lincoln. p. 8-10.

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.

Stockton, M. C., D. C. Adams, R. K. Wilson, T. J. Klopfenstein, R. T. Clark, and G. L. Carriker. 2007. Production and economic comparisons of two calving dates for beef cows in the Nebraska Sandhills. The Professional Animal Scientist 23: 500-508. doi:10.1532/S1080-7446(15)31011-1.

Sullivan, T. M., G. C. Micke, R. M. Greer, H. F. Irving-Rodgers, R. J. Rodgers, and V. E. Perry. 2009. Dietary manipulation of *Bos indicus* x heifers during gestation affects the reproductive development of their heifer calves. Reprod Fertil Dev 21.

Summers, A. F., A. D. Blair, and R. N. Funston. 2015a. Impact of supplemental protein source offered to primiparous heifers during gestation on II. Progeny performance and carcass charecteristics. J. Anim. Sci. 93: 1871-1880. doi:10.2527/jas2014-8297.

Summers, A. F., T. L. Meyer, and R. N. Funston. 2015b. Impact of supplemental protein source offered to primiparous heifers during gestation on I. Average daily gain, feed intake, calf birth body weight, and rebreeding in pregnant beef heifers. J. Anim. Sci. 93: 1865-1870. doi:10.2527/jas2014-8296.

Summers, A. F., K. H. Ramsay, and R. N. Funston. 2011. Case Study: The effects of maternal nutrition on steer progeny performance. The Professional Animal Scientist 27: 251-256.

Tardiff, A., N. Julien, A. Pelletier, G. Thibault, A. K. Srivastava, J. L. Chiasson, and L. Coderre. 2001. Chronic expose to B-hydroxybutyrate impairs insulin action in primary cultures of adult cardiomyocytes. Am. J. Physiol. Endocrinol. Metab. 281: E1205-E1212.

Tibbitts, B. T., T. L. Meyer, D. J. Kelly, and R. N. Funston. 2017. Timed Insemination vs. Modified Estrus Detection in Beef Heifers. In: Nebraska Beef Cattle Report. Rep. No. MP 104. Univ. of Nebraska, Lincoln. p. 11-12.

Triplett, B. L., D. A. Neuendorff, and R. D. Randel. 1995. Influence of undegraded intake protein supplementation on milk production, weight gain, and reproductive performance in postpartum Brahman cows. J. Anim. Sci. 73: 3223-3229.

Ulberg, L., R. Christian, and L. Casida. 1951. Ovarian response in heifers to progesterone injections. Journal of Animal Science 10: 752-759.

Umbreit, J. 2007. Methemoglobin - It's not just blue: A concise review. Am. J. Hematol. 82: 134-144. doi:10.1002/ajh.20738.

Van Soest, P. J. 1964. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility North Atlantic Section, ASAS, Cornell University, Ithaca, NY.

Vanzant, E. S., and R. C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low-quality, tallgrass-prairie forage. J. Anim. Sci. 72: 1059-1067.

Vassena, R., R. J. Mapletoft, S. Allodi, J. Singh, and G. P. Adams. 2003. Morphology and developmental competence of bovine oocytes relative to follicular status. Theriogenology 60: 923-932.

Vaughn, P. R., C. Lobo, F. C. Battaglia, P. V. Fennessey, R. B. Wilkening, and G. Meschia. 1995. Glutamine-glutamate exchange between placenta and fetal liver. American Journal of Physiology-Endocrinology And Metabolism 268: E705-E711.

Vincent, C. K. 1972. Effects of season and high environmental temperature on fertility in cattle: A Review. J. Am. Vet. Med. Assoc. 161: 1333-1338.

Vishwanath, R. 2003. Aritifical Insemination: the state of the art. Theriogenology 59: 571-584.

Vonnahme, K. A., M. J. Zhu, P. P. Borowicz, T. W. Geary, B. W. Hess, L. P. Reynolds, J. S. Caton, W. J. Means, and S. P. Ford. 2007. Effect of early gestational undernutrition and angiogenics factor expression and vascularity in the bovine placentome. J. Anim. Sci. 85: 2464-2472.

Vraspir, R. A., A. F. Summers, D. O'Hare, L. D. Rowden, and R. N. Funston. 2014. Comparison of long-term progestin-based synchronization protocols on Fixed-time AI pregnancy rate in beef heifers. In: Nebraska Beef Cattle Report. Rep. No. MP 101. Univ. of Nebraska, Lincoln. p. 8-10.

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 requirment during winter. J. Anim. Sci 66: 603-612.

Wallace, J. M., D. A. Bourke, R. P. Aitken, J. S. Milne, and W. W. Hay. 2003. Placental glucose transport in growth-restricted pregnancies induced by overnourished adolescent sheep. J. Physiol. 133: S1732-S1736.

Waterman, R. C., and W. R. Butler. 2010. Metabolic signals of the beef cow in negative energy balance. In: 4th Grazing Livestock Nutrition Conference, Champaign, IL. p 93-101.

Waterman, R. C., E. E. Grings, T. W. Geary, A. J. Roberts, L. J. Alexander, and M. D. MacNeil. 2007. Influence of seasonal forage quality on glucose kinetics of young beef cows. J. Anim. Sci. 85: 2582-2595. doi:10.2527/jas.2007-0023.

Wathes, D., M. Fenwick, Z. Cheng, N. Bourne, S. Llewellyn, D. Morris, D. Kenny, J. Murphy, and R. Fitzpatrick. 2007. Influence of negative energy balance on cyclicity and fertility in the high producing dairy cow. Theriogenology 68: S232-S241.

Wiltbank, J., and L. Casida. 1956. Alteration of ovarian activity by hysterectomy. Journal of Animal Science 15: 134-140.

Wiltbank, J., W. ROWDEN, and J. Ingalls. 1961. EFFECTS OF VARIOUS FORMS AND LEVELS OF ESTROGENS ALONE OR IN COMBINATIONS WITH GONADOTROPHINS ON ESTROUS CYCLE OF BEEF HEIFERS. Journal of Animal Science 20: 341-&.

Wiltbank, J., D. Zimmerman, J. Ingalls, and W. Rowden. 1965. Use of progestational compounds alone or in combination with estrogen for synchronization of estrus. Journal of Animal Science 24: 990-994.

Wu, G., F. W. Bazer, T. A. Cudd, C. J. Meininger, and T. E. Spencer. 2004. Maternal nutrition and fetal development. J. Nutr. 134: 2169-2172.

Wu, G., F. W. Bazer, J. M. Wallace, and T. E. Spencer. 2014. Board Invited Review: Intrauterine growth retardation: Implications for the animal sciences. J Anim Sci 84: 2316-2337.

Wu, Q., A. M. Ortegon, B. Tsang, H. Doege, K. R. Feingold, and A. Stahl. 2006. FATP1 is an insulin-sensitive fatty acid transporter involved in diet-induced obesity. Mol. Cell. Biol. 26: 3455-3467.

Zambrano, E., C. J. Bautista, M. Deas, P. M. Martinez-Samayoa, M. Gonzalez-Zamorano, H. Ledesma, J. Morales, F. Larrea, and P. W. Nathanielsz. 2006. A low maternal protein diet during pregnancy and lactation has sex- and window of exposure-specific effects on offspring growth and food intake, glucose metabolism and serum leptin in the rat. The Journal of Physiology 571: 221-230. doi:10.1113/jphysiol.2005.100313.

Zeisel, S. H. 2009. Epigentic mechanisms for nutrition determinants of later health outcomes. Am J Clin Nutr 89: 4188-4193.

Zhang, S., T. R. H. Regnault, P. L. Barker, K. J. Botting, I. C. McMillen, C. M. McMillan, C. T. Roberts, and J. L. Morrison. 2015. Placental adaptation in growth restriction. Nutrition 7: 360-369. doi:10.3990/nu7010360.

Zhu, M. J., S. P. Ford, W. J. Means, B. W. Hess, P. W. Nathanielsz, and M. Du. 2006. Maternal nutrient restriction affects properties of skeletal muscle in offspring. J Physiol 575: 241-250.

Zimbelman, R. 1963. Determination of the minimal effective dose of 6-methyl-17-acetoxyprogesterone for control of the estrual cycle of cattle. Journal of Animal Science 22: 1051-1058.

Zimbelman, R., and L. Smith. 1966. Control of ovulation in cattle with melengestrol acetate. Journal of reproduction and fertility 11: 193-201.

CHAPTER II

Comparison of two alternate PGF2α products in two estrus synchronization protocols in beef heifers[1]

N. Oosthuizen*, A. C. Lansford‡, L. B. Canal*, P. L. P. Fontes*, C. D. Sanford*, C. R. Dahlen†, N. DiLorenzo*, R. N Funston‡, and G. C. Lamb§[2]

** North Florida Research and Education Center, Marianna, FL 32446*

† Department of Animal Sciences, North Dakota State University, Fargo, ND 58108

‡ University of Nebraska West Central Research and Extension Center, North Platte, NE 69101

§ Department of Animal Science, Texas A&M University, College Station, TX 77843-2471

[1] The authors thank Zoetis Animal Health (Parsippany, NJ) for their donation of PGF2α (Lutalyse and Lutalyse *HighCon*). The authors also thank ABS Global (DeForest, WI) for their semen donation, and the ABS Global representatives, K. Porter, J. Knock, and M. Sandbulte for their assistance in conducting this experiment.

[2] Corresponding author: gclamb@tamu.edu

ABSTRACT: Two experiments were conducted to evaluate the effects of a high concentrate, s.c. PGF2α compared with a conventionally concentrated, i.m. PGF2α in estrus synchronization protocols for heifers. In Exp. 1, 869 Angus-based beef heifers were enrolled at 8 locations. All heifers were exposed to the 7-d CO-Synch + controlled internal drug release (CIDR) estrus synchronization protocol. On d -7 of the protocol heifers received 100 µg of GnRH i.m., and a CIDR insert for 7 d. On d 0, at CIDR removal, estrus detection patches were applied to heifers and, within location, heifers randomly received 1 of 2 PGF2α treatments: 5 mL of Lutalyse i.m. (CONTROL; n = 434) or a 2 mL of Lutalyse *HighCon* s.c. (HiCON; n = 435). A second GnRH injection was administered at 54 ± 2 h and heifers were fixed-time AI (TAI). Heifers were evaluated for estrus activity at TAI by determining the activation of estrus detection patches. Pregnancy rates to AI (PR/AI) were diagnosed by transrectal ultrasonography between 35 and 55 d after TAI. The percentage of heifers exhibiting estrus between d 0 and TAI did not differ ($P = 0.68$) between CONTROL and HiCON treatments (47 vs. 46 ± 4%, respectively). Additionally, PR/AI were similar ($P = 0.65$) between CONTROL and HiCON treatments (46 vs. 45 ± 3%). In Exp. 2, 190 Angus-based beef heifers were enrolled at 2 locations. Heifers were exposed to the melengestrol acetate (MGA) - PGF2α protocol where they were offered 0.5 mg MGA/d from d 1 to 14. On d 33, heifers were randomly assigned to receive CONTROL (n = 95) or HiCON (n = 95) treatment, and estrus detection aids were applied. Heifers were exposed to AI 12 h after detection of estrus. Heifers not detected in estrus at location 1 received a second PGF2α injection 6 d after the initial PGF2α injection, and were placed with fertile bulls. Heifers at location 2

that did not express estrus were administered 100 µg of GnRH i.m. and exposed to TAI 96 h post initial PGF2α injection. Transrectal ultrasonography was used to diagnose PR/AI between 51 and 57 d after the initial $PGF2_{\alpha}$ injection. The percentage of heifers exhibiting estrus during the estrus detection period was similar ($P = 0.40$) between CONTROL and HiCON treatments (82 vs. 87 ± 4%). Furthermore, PR/AI were similar ($P = 0.62$) between CONTROL and HiCON treatments (60 vs. 65 ± 5%). In summary, the 2 concentrations and corresponding routes of administration of PGF2α were similar in efficacy at synchronizing estrus in beef heifers.

Keywords: beef heifer, estrus synchronization, prostaglandin $F_{2\alpha}$

INTRODUCTION

Exogenous hormones and their analogues are used to manipulate the bovine estrous cycle to reduce the amount of labor and time expended on estrus detection. Prostaglandin $F_{2\alpha}$ is a fatty acid hormone commonly administered to cows and heifers as part of estrus synchronization protocols. Administration of PGF2α results in regression of a functional corpus luteum between d 5 and 16 of the estrous cycle (Rowson et al., 1972), and estrus within approximately 3 d (Tervit et al., 1973). Numerous studies have evaluated the effectiveness of various PGF2α products. No differences were reported between the ability of different PGF2α products to decrease progesterone concentrations (Schams and Karg, 1982; Guay et al., 1988) or induce an estrus response (Plata et al., 1990; Martineau, 2003), and have shown no differences in pregnancy rates (Salverson et al., 2002; Hiers et al., 2003; Stevenson & Phatak, 2010).

A high concentrate PGF2α product, Lutalyse *HighCon* (12.5 mg of dinoprost tromethamine/mL**;** Zoetis Animal Health), was recently been approved for use by the

United States Food and Drug Administration. According to label directions, Lutalyse *HighCon* may be administered by i.m. or s.c. injection in bovine females. Subcutaneous administration may reduce the occurrence of blemishes on beef carcasses (Powell, 2013), improve tenderness (Griffin et al., 1998), and reduce the income lost per head at slaughter (Hilton, 2004). To date, no research has been conducted to determine the effectiveness of this product in estrus synchronization protocols for beef heifers.

Therefore, this study was performed to evaluate the efficacy of the high concentrate PGF2α product, Lutalyse *HighCon*, by determining its effectiveness in estrus response and pregnancy rates in beef heifers. We hypothesized that a s.c. injection of a high concentrate PGF2α would not alter estrus response or pregnancy rates when compared with the administration of a conventional concentrate PGF2α in estrus synchronization protocols for beef heifers.

MATERIALS AND METHODS

All heifers were handled in accordance with procedures approved by each collaborating university's Animal Care and Use Committee.

Experiment 1

Angus-based crossbred, yearling heifers (n = 869; 406 ± 2 kg BW) were enrolled at 8 locations in 2 states (South Dakota and North Dakota). Herd size ranged from 50 to 220 heifers. Within location, heifers were exposed to the 7-d CO-Synch + controlled internal drug release (CIDR) protocol. On d -7, heifers received a 2-mL i.m. injection of GnRH (Factrel; 100 μg gonadorelin hydrochloride; Zoetis Animal Health, Parsippany, NJ) and a CIDR (EAZI-BREED CIDR; 1.38 g progesterone; Zoetis Animal Health) insert. Heifer BW was recorded at 5 of the 8 locations (SD-1, SD-3, SD-4, SD-7, and

ND). On d 0, at CIDR removal, estrus detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were applied, and heifers were randomly assigned to receive 1 of 2 PGF2α treatments (Fig. 1). Heifers assigned to the **CONTROL** treatment (n = 434) received a 5-mL i.m. injection of Lutalyse (5 mg of dinoprost tromethamine/mL; Zoetis Animal Health), whereas those assigned to the **HiCON** treatment (n = 435) received a 2-mL s.c. injection of Lutalyse *HighCon*. All heifers received a 100-μg injection of GnRH and were inseminated 54 ± 2 h after CIDR removal.

Estrus detection patches were utilized for estrus detection between CIDR removal and TAI. Heifers were considered to be in estrus when at least 50% of the rub-off coating was removed from the patch, or when the patch was absent at TAI. No less than 10 d after TAI, heifers were exposed to bulls for the remainder of the breeding season at 6 locations (SD-1, SD-2, SD-3, SD-4, SD-7, and ND).

Transrectal ultrasonography (Aloka 500V, Vancouver, BC, Canada; or Ibex Pro, E.I. Medical Imaging, Loveland, CO) was performed between d 35 and 55 after TAI to determine pregnancy rates to AI **(PR/AI)**. Final pregnancy rates were determined by transrectal ultrasonography at least 35 d after the end of the breeding season.

Experiment 2

Yearling, Angus-based crossbred heifers (n = 190) were managed at 2 locations. Heifers at location 1 (n = 100; 340 ± 3 kg BW; **L1**) were managed at the West Central Research and Extension Center near North Platte, NE. Each heifer was offered a ration consisting of 6.4 kg grass hay, 3.6 kg wet corn gluten feed, and 0.45 kg of 1 of 2 mineral supplements.

Heifers were synchronized using a melengestrol acetate (**MGA**) - PGF2α protocol

(Fig. 2). Heifers were offered 0.5 mg of MGA (Zoetis Animal Health, Parsippany, NJ) pellets in their diet per d from d 1 to 14. On d 33, heifers were blocked by previous development treatments (Springman et al., 2017) and assigned to either CONTROL (n = 50) or HiCON (n = 50) treatment. An estrus detection patch was applied concurrently with the PGF2α injection.

All heifers were managed together and continuously observed for estrus from d 33 to 39. Heifers were considered to be expressing estrus when at least 50% of the rub-off coating was removed from the patch or when the patch was absent. Heifers were AI 12 h after estrus was detected. Heifers not detected in estrus between d 33 and 39 (n = 16) were given an injection of Lutalyse *HighCon* and placed with 2 bulls for natural service exposure. Heifers exposed to AI were placed in a separate pasture for 10 d before being placed with those not detected in estrus. Heifers remained with bulls for a 60 d breeding season at a ratio of 1:50. Pregnancy rates to AI and final pregnancy rates were diagnosed via transrectal ultrasonography (Aloka, Hitachi Aloka Medical America Inc., Wallingford, CT) 51 and 127 d after the initial PGF2α injection, respectively.

A second group of yearling, Angus-based crossbred heifers were managed at the Kelly Ranch near Sutherland, NE (n = 90; 326 ± 4 kg BW; location 2, **L2**), and were offered a ration containing 0.6 kg wet distillers grains, 2.4 kg grass hay, 3.2 kg corn silage, and 0.2 kg balancer pellets. Heifers were synchronized with the MGA-PGF2α protocol as previously described for L1 and assigned randomly to receive CONTROL (n = 45) or HiCON (n = 45) treatment.

Heifers were observed for estrus continuously from d 33 to 36. Heifers detected in estrus were AI approximately 12 h later. Heifers not expressing estrus by 96 h (n = 14)

were administered 2 ml of GnRH, and TAI. Ten d following AI, 2 bulls were placed with heifers at a ratio of 1:45 during a 40 d breeding season. Pregnancy rates to AI were diagnosed via transrectal ultrasonography 57 d after the initial PGF2α injection, and BW was concurrently recorded. A final pregnancy diagnosis was performed 50 d after the initial pregnancy diagnosis on heifers not diagnosed pregnant to AI, and BW was simultaneously recorded.

Statistical Analysis

The GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C) was used for all statistical analyses. For Exp. 1, the model included the fixed effects of treatment, location, and the treatment × location interaction. The response variables analyzed were estrus expression, PR/AI, and final pregnancy rates. For Exp. 2, the model included the fixed effects of treatment, location, and the treatment × location interaction. The response variables analyzed were estrus detection time points, ADG, PR/AI, and final pregnancy rates. Artificial insemination sire and AI technician were distributed evenly among treatments; therefore, these variables were not included in the model. Individual heifer was considered the experimental unit. Means were declared significant for both experiments at $P \leq 0.05$, with $0.05 < P < 0.10$ considered a tendency.

RESULTS AND DISCUSSION

Experiment 1

Initial BW differed ($P < 0.01$) among locations, but did not differ ($P = 0.49$) between treatments (406 ± 2 kg). Body weight ranged from 380.6 ± 4.0 kg at location SD-4 to 432.4 ± 2.2 kg at location SD-7. Estrus response rates for all heifers at all locations are summarized in Table 1. Estrus expression between d 0 and TAI did not

differ between CONTROL and HiCON treatments ($P = 0.68$); however, estrus expression differed among locations ($P < 0.01$), with the greatest estrus response at location SD-6 (65 ± 5%) and poorest at location SD-5 (36 ± 4%). No treatment × location interaction was detected ($P = 0.37$). The lack of difference between estrus response of CONTROL and HiCON treatment groups indicates both treatments were equally effective at inducing regression of the corpus luteum when administered in the 7-d CO-Synch + CIDR protocol.

Pregnancy rates to TAI for all heifers at all locations are summarized in Table 2. Pregnancy rate to TAI did not differ between CONTROL and HiCON treatments ($P = 0.65$); however, there was an effect of location ($P < 0.01$) on PR/AI, which was greatest at location SD-4 (61 ± 6%), and poorest at location SD-5 (38 ± 4%). No treatment × location interaction was detected ($P = 0.18$). At the conclusion of the breeding season, final pregnancy rates did not differ between CONTROL and HiCON treatments ($P = 0.95$). Final pregnancy rates differed ($P < 0.01$) among location, and ranged from 78 to 98% (Table 3).

Each location was unique in its management practices, and thus location impacted the estrus synchrony and fertility in this study. Each location was producer-owned and differed in nutrition, facilities, animal handling practices, and individual production goals. Varying management practices among locations may have contributed to the reported differences in estrus response, PR/AI, and final pregnancy rates observed.

Experiment 2

Initial BW was similar ($P = 0.36$) between treatments (333 ± 4 kg); however, BW differed ($P = 0.01$) between locations (340 vs. 326 ± 3 kg, L1 vs. L2). Additionally, BW

at first pregnancy diagnosis was similar ($P = 0.26$) between treatments (392 ± 4 kg) but also differed ($P = 0.04$) by location (386 vs. 397 ± 4 kg, L1 vs. L2). Heifers at L2 had a greater ADG ($P < 0.01$) between d 33 and AI pregnancy diagnosis compared with heifers at L1 (0.90 vs. 1.3 ± 0.03 kg/d). At final pregnancy diagnosis, heifer BW was similar ($P = 0.71$) between locations (424 ± 14 kg), and treatment groups ($P = 0.85$; 425 ± 11 kg). The discrepancy in BW and ADG between locations could be a result of different nutritional management strategies. Heifers at L2 initiated the study at a lower BW, yet due to a higher energy ration fed through the treatment period, may have compensated to reach a similar final BW.

The percentage of heifers detected in estrus is summarized in Table 4, and was similar between CONTROL and HiCON treatments at ≤ 60 h ($P = 0.15$), ≤ 72 h ($P = 0.51$), and at 72 h ($P = 0.27$). These data indicated both treatments were similar in their timing of estrus. There was a tendency ($P < 0.08$) for a location effect at ≤ 60 h and ≤ 72 h. The tendency for a location effect on estrus response times was likely a result of differing management practices. The total percentage of heifers observed in estrus throughout the detection period was also similar between treatment groups ($P = 0.40$), which was comparable to those of a 5-mL Lutalyse i.m. injection reported in a previous study (Salverson et al., 2002). Heifers received the same amount of dinoprost tromethamine (25 mg/dose), regardless of administration route. Thus, similar estrus response and timing should be expected.

The following year, in 2017, additional yearling Angus-based heifers located at WCREC (n = 98) were exposed to an MGA-PG protocol. Heifers were managed the same as L1, except all heifers received 2 mL s.c. Lutalyse *HighCon* on d 33. Heifers were

observed for estrus activity for 4 d after PG injection and AI 12 h after detection. Those not detected (n = 13) were given a second injection of Lutalyse *HighCon* and placed with fertile bulls for a 45 d breeding season. Heifers that were exposed to AI were placed in a separate pasture for 10 d, then placed with those who did not express estrus. Percentage of heifers exhibiting estrus at ≤ 60 h (52 ± 5%), ≤ 72 h (77 ± 4%), 72 h (24 ± 4%) and total response (87 ± 3%). Percent of heifers confirmed pregnant to AI was 70 ± 5% and overall pregnancy success was 93 ± 3%.

Heifer pregnancy rates are summarized in Table 5. A treatment × location interaction ($P = 0.03$) was detected for PR/AI between L1 (44 vs. 64 ± 7%, CONTROL vs. HiCON) and L2 (73 vs. 62 ± 7%, CONTROL vs. HiCON). The PR/AI achieved were similar to those reported in previous studies (Springman et al., 2017; Tibbitts et al., 2017). Final pregnancy rates were similar between treatments ($P = 0.11$) and did not differ ($P = 0.96$) by location. We realize the limitations of this experiment based on a low number of heifers enrolled in the study, but feel the non-significant *P* – values are adequate in supporting our conclusions.

In both experiments, heifers in the HiCON treatment had similar rates of estrus expression when compared to the CONTROL heifers. Furthermore, AI and final pregnancy rates were similar between treatments.

IMPLICATIONS

The beef industry regularly incurs economic losses due to carcass lesions resulting from improper injection technique (Pratt, 2004). Intramuscular injections cause muscle trauma which results in an increase in connective tissue around the site during wound healing; therefore, this tissue damage negatively impacts beef tenderness

(Boleman et al., 1998) and consumer acceptability of beef (Fajt et al., 2011). Additionally, needle movement which can occur during administration of an i.m. injection, may result in a portion of the exogenous product being administered subcutaneously (Powell, 2013). The Beef Quality Assurance program advises producers to use a s.c. route of administration when possible to improve tenderness. Subcutaneous injections may result in a reduced amount of carcass damage and less trimming at slaughter, and are thus more favored in the beef industry. Lutalyse *HighCon* is a high concentrate PGF2α product that may be administered either i.m. or s.c. Lutalyse *HighCon* is a novel, high concentrate PGF2α product on the pharmaceutical market that is a suitable alternative to conventionally concentrated PGF2α products, such as Lutalyse, in estrus synchronization protocols for beef heifers.

LITERATURE CITED

Boleman, S. L., S. J. Boleman, W. W. Morgan, D. S. Hale, D. B. Griffin, J. W. Savell, R. P. Ames, M. T. Smith, J. D. Tatum, T. G. Field, G. C. Smith, B. A. Gardner, J. B. Morgan, S. L. Northcutt, H. G. Dolezal, D. R. Gill, and F. K. Ray. 1998. National beef quality audit-1995: Survey of producer-related defects and carcass quality and quantity attributes. J. Anim. Sci. 76:96–103.

Fajt, V. R., S. A. Wagner, L. L. Pederson, and B. Norby. 2011. The effect of intramuscular injection of dinoprost or gonadotropinreleasing hormone in dairy cows on beef quality. J. Anim. Sci. 89:1939–1943. doi:10.2527/jas.2010-2923.

Griffin, D. D., D. R. Smith, and D. M. Grotelueschen. 1998. Proper injection procedures for cattle. In: 1998 Nebraska Extension Publication. Pub. No. G98-1351-A. Univ. of Nebraska–Lincoln. p 1–4.

Guay, P., D. Rieger, and S. Roberge. 1988. Superovulatory and endocrine responses in Holstein heifers treated with either prostaglandin $F_{2\alpha}$, cloprostenol or fenprostalene. Theriogenology. 29:1193–1199.

Hiers, E. A., C. R. Barthle, M. V. Dahms, G. E. Portillo, G. A. Bridges, D. O. Rae, W. W. Thatcher, and J. V. Yelich. 2003. Synchronization of *Bos indicus* x *Bos taurus* cows for timed artificial insemination using gonadotropin-releasing hormone plus prostaglandin $F_{2\alpha}$ in combination with melengestrol acetate. J. Anim. Sci. 81:830–835.

Hilton, W. M. 2004. Beef quality assurance injection sites and techniques. In: 2004 Purdue Extension Publication. Pub. No. VY-60-W. Purdue Univ. p. 1–3.

Martineau, R. 2003. Dinoprost versus cloprostenol : Does route of injection modulate

their efficacy in dairy cattle? Bov. Pract. 37:10–19.

Plata, N., J. Spitzer, C. Thompson, D. M. Henricks, M. P. Reid, and T. J. Newby. 1990. Synchronization of estrus after treatment with luprostlol in beef cows and in beef and dairy heifers. Theriogenology. 33:943–952.

Powell, J. 2013. Injection site management. In: 2013 Univ. of Arkansas Division of Agriculture Research and Extension Publication. Pub. No. FSA3109. Univ. of Arkansas. p. 1–4.

Pratt, J. H. 2004. Injection damage. In: A. H. Andrews, editor, Bovine Medicine: Diseases and husbandry of cattle. Blackwell Publishing, Ames, IA. p. 1078–1080.

Rowson, L., H. R. Tervit, and A. Brand. 1972. The use of prostaglandins for synchronization of oestrus in cattle. J. Reprod. Fertil. 29:145. (Abstr.).

Salverson, R. R., J. M. DeJarnette, C. E. Marshall, and R. A. Wallace. 2002. Synchronization of estrus in virgin beef heifers using melengestrol acetate and PGF2α: an efficacy comparison of cloprostenol and dinoprost tromethamine. Theriogenology. 57:853–858.

Schams, D., and H. Karg. 1982. Hormonal responses following treatment with different prostaglandin analogues for estrous cycle regulation in cattle. Theriogenology. 17:499–513.

Springman, S. A., H. R. Nielson, T. L. Meyer, M. Kirby, J. Teichert, and R. N. Funston. 2017. Effect of heifer development system on reproduction and subsequent gain as a pregnant heifer. In: 2017 Nebraska Beef Cattle Report. Pub. No. MP104. Univ. of Nebraksa–Lincoln. p. 5–7.

Stevenson, J. S., and A. P. Phatak. 2010. Rates of luteolysis and pregnancy in dairy cows

after treatment with cloprostenol or dinoprost. Theriogenology. 73:1127–1138.

Tervit, H. R., L. E. A. Rowson, and A. Brand. 1973. Synchronization of oestrus in cattle using a prostaglandin $F_{2\alpha}$ analogue. J. Reprod. Fertil. 179–181.

Tibbitts, B. T., T. L. Kelly, D. J. Meyer, and R. N. Funston. 2017. Comparison of timed insemination vs. modified estrus detection protocol in beef heifers. Prof. Anim. Sci. 33:97–100.

Table 1. Estrus response at the time of fixed-time AI in heifers after receiving conventional or high concentrate PGF2α (Exp. 1)

	Treatment[1]				
Item	CONTROL	HiCON	Overall	SEM	*P*-value
	---------- n/n (%) ----------				
Location					
SD-1	11/25 (44.0)	16/25 (64.0)	27/50 (54.0)^{wxy}	13.9	0.15
SD-2	15/29 (51.7)	17/27 (63.0)	32/56 (57.1)^{wx}	13.1	0.39
SD-3	33/70 (47.1)	30/70 (42.9)	63/140 (45.0)^{xyz}	8.3	0.61
SD-4	13/31 (41.9)	10/29 (34.5)	23/60 (38.3)^{yz}	12.7	0.56
SD-5	27/63 (42.9)	18/64 (28.1)	45/127 (35.4)^{z}	8.7	0.09
SD-6	25/40 (62.5)	29/43 (67.4)	54/83 (65.1)^{w}	10.8	0.65
SD-7	43/110 (39.1)	38/110 (34.6)	81/220 (36.8)^{z}	6.6	0.49
ND	35/65 (53.9)	41/67 (61.2)	76/132 (57.6)^{w}	8.5	0.39
Overall	202/433 (46.7)	199/435 (45.7)		3.8	0.68

[1] All heifers were estrus synchronized using the 7-d CO-Synch + controlled internal drug release (CIDR) protocol. On d -7, heifers received a 100-µg injection of GnRH (Factrel; Zoetis Animal Health, Parsippany, NJ) and a CIDR (EAZI-BREED CIDR; Zoetis Animal Health) insert. On d 0, at CIDR removal, estrus detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were applied and heifers were randomly assigned to receive 1 of 2 PGF2α treatments. Heifers assigned to the CONTROL treatment (n = 417) received a 5-mL i.m. injection of Lutalyse (5 mg of dinoprost tromethamine/mL; Zoetis Animal Health), whereas those assigned to the HiCON treatment (n = 424) received a 2-mL s.c. injection of Lutalyse *HighCon* (12.5 mg of dinoprost tromethamine/mL**;** Zoetis Animal Health). All heifers received a 100-µg injection of GnRH and were exposed to fixed-time AI (TAI) 54 ± 2 h after CIDR removal. Estrus detection patches were concurrently observed for activation. Heifers were considered to be in estrus when at least 50% of the rub-off coating was removed from the patch, or when the patch was absent.

[w - z] Percentages within column for location differ ($P \leq 0.05$).

Table 2. Pregnancy rates to fixed-time AI in heifers after receiving conventional or high concentrate PGF2α (Exp. 1)

	Treatment[1]				
Item	CONTROL	HiCON	Overall	SEM	*P*-value
	---------- n/n (%) ----------				
Location					
SD-1	12/25 (48.0)	9/25 (36.0)	21/50 (42.0)^{yz}	13.9	0.39
SD-2	9/29 (31.0)	16/27 (59.3)	25/56 (44.6)^{xyz}	13.2	0.03
SD-3	34/70 (48.6)	29/70 (41.4)	63/140 (45.0)^{yz}	8.3	0.39
SD-4	22/31 (71.0)	15/29 (51.7)	37/60 (61.7)^{x}	12.7	0.13
SD-5	27/63 (42.9)	21/64 (32.8)	48/127 (37.8)^{z}	8.7	0.25
SD-6	19/40 (47.5)	25/43 (58.1)	44/83 (53.0)^{xy}	10.8	0.33
SD-7	44/110 (40.0)	40/110 (36.4)	84/220 (38.2)^{z}	6.6	0.58
ND	28/66 (42.4)	28/67 (41.8)	56/133 (42.1)^{yz}	8.7	0.94
Overall	195/434 (44.9)	183/435 (42.1)		3.8	0.65

[1] All heifers were estrus synchronized using the 7-d CO-Synch + controlled internal drug release (CIDR) protocol. On d -7, heifers received a 100-µg injection of GnRH (Factrel; Zoetis Animal Health, Parsippany, NJ) and a CIDR (EAZI-BREED CIDR; Zoetis Animal Health) insert. On d 0, at CIDR removal, estrus detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were applied and heifers were randomly assigned to receive 1 of 2 PGF2α treatments. Heifers assigned to the CONTROL treatment (n = 417) received a 5-mL i.m. injection of Lutalyse (5 mg of dinoprost tromethamine/mL; Zoetis Animal Health), whereas those assigned to the HiCON treatment (n = 424) received a 2-mL s.c. injection of Lutalyse *HighCon* (12.5 mg of dinoprost tromethamine/mL**;** Zoetis Animal Health). All heifers received a 100-µg injection of GnRH and were exposed to fixed-time AI (TAI) 54 ± 2 h after CIDR removal. Pregnancy rate to TAI was recorded between d 35 and 55 after TAI.

[x - z] Percentages within column for location differ ($P \leq 0.05$).

Table 3. Final pregnancy rates in heifers after receiving conventional or high concentrate PGF2α (Exp. 1)

	Treatment[1]				
Item	CONTROL	HiCON	Overall	SEM	*P*-value
	---------- n/n (%) ----------				
Location					
SD-1	14/16 (87.5)	13/17 (76.5)	27/33 (81.8)^{yz}	8.8	0.21
SD-2	28/29 (96.6)	26/27 (96.3)	54/56 (96.4)^{x}	6.8	0.97
SD-3	69/70 (98.6)	68/70 (97.1)	137/140 (97.9)^{x}	4.3	0.74
SD-4	26/31 (83.9)	21/29 (72.4)	47/60 (78.3)^{z}	6.5	0.08
SD-5[2]	-	-	-	-	-
SD-6[2]	-	-	-	-	-
SD-7	105/110 (95.5)	103/110 (93.6)	208/220 (94.6)^{x}	3.4	0.59
ND	18/21 (85.7)	34/36 (94.4)	52/57 (91.2)^{xy}	6.9	0.21
Overall	260/277 (93.9)	265/289 (91.7)		2.6	0.95

[1] All heifers were estrus synchronized using the 7-d CO-Synch + controlled internal drug release (CIDR) protocol. On d -7, heifers received a 100-µg injection of GnRH (Factrel; Zoetis Animal Health, Parsippany, NJ) and a CIDR (EAZI-BREED CIDR; Zoetis Animal Health) insert. On d 0, at CIDR removal, estrus detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were applied and heifers were randomly assigned to receive 1 of 2 PGF2α treatments. Heifers assigned to the CONTROL treatment (n = 417) received a 5-mL i.m. injection of Lutalyse (5 mg of dinoprost tromethamine/mL; Zoetis Animal Health), whereas those assigned to the HiCON treatment (n = 424) received a 2-mL s.c. injection of Lutalyse *HighCon* (12.5 mg of dinoprost tromethamine/mL**;** Zoetis Animal Health). All heifers received a 100-µg injection of GnRH and were exposed to fixed-time AI (TAI) 54 ± 2 h after CIDR removal. Final pregnancy diagnosis was performed at least d 35 after the end of the breeding season.

[2] Heifers at SD-5 and SD-6 were not exposed to clean-up bulls after TAI; therefore, they were not included in overall pregnancy diagnosis analyses.

[x - z] Percentages within column for location differ ($P \leq 0.05$).

Table 4. Time of estrus for yearling beef heifers given 2 alternate PGF2α injections (Exp. 2)

	Treatment[1]			*P*- value[2]		
	CONTROL	HiCON	SEM	TRT	Location	T × L
Estrus response, %						
≤ 60 h	48	59	5.2	0.15	0.07	0.81
72 h	22	16	4.3	0.27	0.69	0.72
≤ 72 h	71	75	4.7	0.51	0.08	0.96
Total Response	82	87	3.9	0.40	0.85	0.40

[1] Heifers were administered 1 of 2 alternate PGF2α products on d 33 as part of a MGA-PGF2α protocol. CONTROL: 5 mL of Lutalyse (Zoetis Animal Health, Parsippany, NJ; n = 95) i.m. or HiCON: 2 mL of Lutalyse *HighCon* (Zoetis Animal Health; n =95) s.c.
[2] TRT: $PGF_{2\alpha}$ injection treatment main effect; Location: location main effect; T × L: $PGF_{2\alpha}$ injection treatment × location interaction.

Table 5. Pregnancy rates of yearling beef heifers given 1 of 2 alternate PGF2α injections (Exp. 2)

	Treatment[1]			*P*- value[2]		
	CONTROL	HiCON	SEM	TRT	Location	T × L
AI Pregnancy[3], %	63	60	5.3	0.62	0.06	0.03
Overall Pregnancy[4], %	98	93	2.7	0.11	0.96	0.85

[1] Heifers were administered 1 of 2 alternate PGF2α products on d 33 as part of a MGA-PGF2α protocol. CONTROL: 5 mL of Lutalyse (Zoetis Animal Health, Parsippany, NJ; n = 95) i.m. or HiCON: 2 mL of Lutalyse *HighCon* (Zoetis Animal Health; n = 95) s.c.
[2] TRT: *P*-value represents the main effects of treatment; Location: *P*-value represents main effects of location; T × L: *P*-value represents the treatment × location interaction.
[3] Pregnancy was diagnosed via transrectal ultrasonography a minimum of 51 d after PGF2α treatment.
[4] Final pregnancy diagnosis was conducted via transrectal ultrasonography a minimum of 107 d after PGF2α treatment.

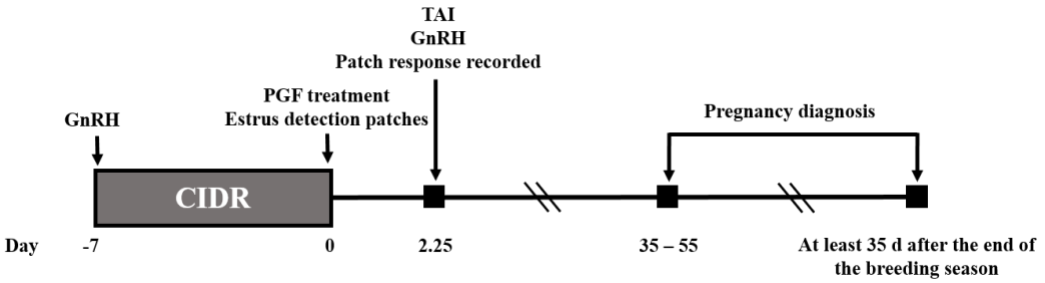

Figure 1. Schematic of treatments. All heifers were exposed to the 7-d CO-Synch + CIDR protocol. On d -7, heifers received a 2-mL i.m. injection of GnRH (100 μg gonadorelin hydrochloride; Zoetis Animal Health, Parsippany, NJ) and a controlled internal drug releasing (EAZI-BREED CIDR; 1.38 g progesterone; Zoetis Animal Health) insert. On d 0, at CIDR removal, estrus detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were applied and heifers were randomly assigned to receive 1 of 2 PGF2α treatments. Heifers assigned to the CONTROL treatment (n = 417) received a 5-mL i.m. injection of Lutalyse (5 mg of dinoprost tromethamine/mL; Zoetis Animal Health), whereas those assigned to the HiCON treatment (n = 424) received a 2-mL s.c. injection of Lutalyse *HighCon* (12.5 mg of dinoprost tromethamine/mL**;** Zoetis Animal Health). All heifers received a 100-μg injection of GnRH and were exposed to fixed-time AI (TAI) 54 ± 2 h after CIDR removal. Pregnancy diagnosis was performed via transrectal ultrasonography between d 35 and 55 after TAI. Final pregnancy diagnosis was performed at least 35 d after the end of the breeding season (Exp. 1).

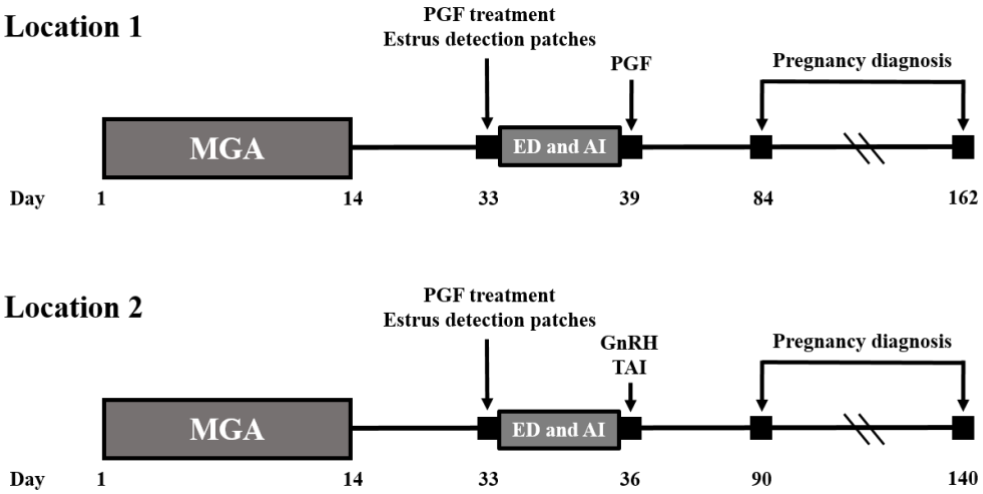

Figure 2. MGA-PGF2α protocol. Melengesterol acetate (MGA; Zoetis Animal Health, Parsippany, NJ) was offered to heifers at a rate of 0.5 mg/d for 14 d. On d 33, heifers were administered either 5 mL of Lutalyse (CONTROL; n = 95; Zoetis Animal Health) i.m. or 2 mL of Lutalyse *HighCon* (HiCON; n = 95; Zoetis Animal Health) s.c. Estrus detection (ED) was conducted for 6 d following PGF2α treatment at location 1. Heifers not detected in estrus were given a second PGF2α injection and were placed with bulls. Heifers at location 2 that did not express estrus by 96 h after PGF2α treatment were administered 2 ml of GnRH (Factrel; Zoetis Animal Health), and exposed to fixed-time AI (TAI). Pregnancy was diagnosed via transrectal ultrasonography between 51 and 57 d after initial PGF2α injection. Final pregnancy diagnosis was conducted via transrectal ultrasonography 129 and 107 d after PGF2α treatment, for location 1 and 2, respectively (Exp. 2).

CHAPTER III

Effect of supplementation during the breeding season on a May-calving herd in the Nebraska Sandhills

A.C. Lansford, J.A. Musgrave, and R.N. Funston[1]

University of Nebraska, West Central Research and Extension Center, North Platte 69101

ABSTRACT

A 4-yr study at the Gudmundsen Sandhills Laboratory, Whitman, NE, evaluated the effects of supplementation during the breeding season on May-calving heifers and primiparous cows. Beginning mid-July, and throughout a 45 d breeding season, heifers and primiparous cows grazed upland range and received either: (1) no supplement (NSP; n = 128 heifers, 67 primiparous cows) or (2) heifers and primiparous cows received 0.45 kg/animal per d or 0.91 kg/animal per day; respectively, of a 32% CP (DM) supplement (SUP, n = 129 heifers and 68 primiparous cows). Cows and heifers were synchronized using a single PGF2α injection 5 d after bull placement (1:20 bull to cow ratio). Pregnancy was diagnosed via transrectal ultrasonography in mid-October or November for heifers and primiparous cows, respectively. Weaning occurred at pregnancy diagnosis. Body weight and BCS were taken at several time points throughout the year. Heifer BW and BCS following supplementation were unaffected by treatment ($P \geq 0.10$). Primiparous cow BW and BCS were greater in SUP cows at the time of pregnancy diagnosis ($P < 0.01$). Pregnancy rate was similar ($P \geq 0.41$) between treatments for both age groups. Treatment did not affect calf BW at birth or dystocia rates for primiparous cows ($P \geq 0.17$). Calf BW at weaning was greater ($P < 0.01$) for SUP primiparous dams.

Supplementation during the breeding season did not affect pregnancy rates in young beef females, despite BW and BCS changes in primiparous cows.

Key Words: beef heifer, May-calving, reproduction, supplementation

INTRODUCTION

In the northern Great Plains, calving in early summer better matches high forage quality to the increased nutrient demand of lactation. Early lactation occurs when forage CP and DE are greatest, thus providing abundant energy and requiring fewer harvested feed inputs (Stockton et al., 2007). Griffin et al. (2012) demonstrated similar pregnancy rates among multiparous cows in 3 different calving systems (May, June, and August); however, younger females exhibit a decrease in pregnancy rate in a May- vs March-calving system (70 vs. 87%, respectively; Springman et al., 2017). Forage seasonality (warm vs. cool season), precipitation levels, and ambient temperature affect the quality and quantity of forage available during the breeding season. As forage matures into late summer in the Nebraska Sandhills, forage CP declines and NDF increases (Lardy et al., 1997). As cell wall constituents increase, voluntary intake is decreased (Van Soest, 1964). This corresponds with declining forage quality during the breeding season of a May-calving herd. Therefore, the inability of younger females to physically consume enough energy from the low-quality range forages may be negatively impacting pregnancy rates (Funston et al., 2016). Inadequate CP or energy intake after calving and during the breeding season has been shown to lower pregnancy rates and extend the length of the postpartum interval **(PPI**; Stockton et al., 2007). Therefore, we hypothesized supplementing CP during the breeding season would help meet nutrient demands and improve pregnancy rates in May-calving heifers and primiparous cows. The

objective of this study was to determine the effects of supplementing May-calving heifers and primiparous beef cows during the breeding season on ADG and reproductive response.

MATERIALS AND METHODS

The University of Nebraska Animal Care and Use Committee approved the procedures and facilities used in this experiment.

Heifer Management

A 4-yr study was conducted at Gudmundsen Sandhills Laboratory, Whitman, NE to determine the effect of CP supplementation during the breeding season on subsequent growth and pregnancy rates in heifers and primiparous cows in a May-calving herd. Crossbred (5/8 Red Angus, 3/8 Simmental), yearling replacement heifers (n = 257) with an average initial BW of 304 ± 2 kg grazing Sandhills native range received either no supplement (**NSP**) or a 32% CP supplement at a rate of 0.45 kg/animal per day (**SUP**; Table 1) beginning 2 wk before and terminated at the end of the breeding season. Supplement was delivered 3 times/week on a pasture (35.6 ha) basis. No replications of pasture were conducted. Nutrient predictions of the breeding season diet are presented in Table 2.

Prior to this study, heifers were randomly assigned to 1 of 2 development treatments from January to May (Springman et al., 2017). Heifers were offered either meadow hay *ad libitum* and fed supplement at a rate of 1.8 kg/animal per day or allowed to graze dormant meadow and fed supplement at a rate of 0.45 kg/animal per day of supplement. Heifers were blocked by development treatment and randomly assigned to breeding treatment for the current study.

Blood samples (5 mL) were collected on d -10 and d 0 of the breeding season. A heifer with plasma progesterone concentration greater than 1 ng/ml at either collection time was considered pubertal (Roberts et al., 2017). Body weight was recorded at each blood collection, with initial BW was considered an average of the 2 time points.

Approximately July 15, fertile bulls were placed with heifers at a 1:20 bull to heifer ratio for a 45 d breeding season. Heifers were synchronized using a single PGF2α (Lutalyse, Zoetis Animal Health, Parsippany, NJ) injection 5 d after bulls were introduced. After the supplementation period, all heifers were managed as a single herd and grazed dormant winter range. Pregnancy was diagnosed via transrectal ultrasonography (Aloka, Hitachi Aloka Medical America Inc., Wallingford, CT) and BW and BCS measured in October, a minimum of 45 d following bull removal. Heifers were removed from the herd if they failed to become pregnant or were injured at pregnancy diagnosis.

In the subsequent year following supplementation, prepartum BW and BCS were recorded 14 d before an expected calving date of April 16. The first day 2 or more heifers calved was considered the start of the calving season and was used to calculate percent calved in the first 21 d. Calf birth BW, sex, birth date were recorded, and a calving ease (**CE**) score (1 = no assistance to 4 = caesarian section; Burfening et al., 1978) were assigned at parturition. A CE score of 2 or greater was considered dystocia. Following the birth of the first calf, heifers were then considered primiparous cows. Heifers were removed from the herd if calf death or injury occured after calving.

Primiparous Cow Management

In a continuation of the heifer phase, 2-yr-old primiparous cows not previously removed from the breeding herd (n = 135) were utilized to evaluate supplementation effects during their second breeding season. The average initial BW for primiparous cows was 387 ± 3 kg. Primiparous cows were blocked by heifer breeding season treatment and randomly assigned to either NSP (n = 67) or SUP (0.91 kg/animal per day, 32% CP, DM; Table 1; n = 68). Treatment began 2 wk before and terminated at the end of the breeding season. No replications of pasture were conducted. Breeding season diet nutrient predictions for NS and SUP primiparous cows are presented in Table 2. Estimated primiparous cow conception date and PPI were calculated by subtracting 285 d from the calving date of the second calf.

Bulls were placed with primiparous cows at a 1:20 bull to cow ratio for a 45 d breeding season beginning approximately July 21. Cows were synchronized with a single PGF2α injection 5 d after bull placement. Primiparous cows were managed as a single herd before and after the breeding season. Throughout the duration of the study, primiparous cows grazed upland Sandhills native range.

Pregnancy diagnosis of primiparous cows was conducted via transrectal ultrasonography at weaning in November, a minimum of 60 d following bull removal. Primiparous cows were removed from the herd at weaning for herd if they failed to become pregnant or were injured. Primiparous cow BW and BCS were measured on d 0 of the breeding season, at pregnancy diagnosis, and 14 d before an expected calving date of May 15. Percent of cows calving in the first 21 d was calculated similar to heifers, with the first day 2 or more cows calved considered the start of the calving season. At

parturition, calf sex, BW, and CE score were recorded. A CE score of 2 or greater was considered dystocia.

Calf Management

First calf BW was measured at birth, before the breeding season and at an average weaning date of November 2. Calf birth BW was analyzed based on heifer breeding season treatment. The remaining BW measurements were analyzed based on primiparous cow breeding season treatment, as calves were impacted by primiparous dam treatment.

Statistical Analysis

Supplement was provided on a pasture basis for heifers and primiparous heifers, so pasture within year was considered the experimental unit and breeding season supplementation the treatment. The PROC GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.) was used for all statistical analyses. The model statement included the fixed effect of breeding season supplementation as either a heifer or primiparous cow and all variables of interest. Development treatment and breeding season average CP were included as a covariate in the model statement. Measurements taken before the beginning of the second breeding season were analyzed based on treatment as a heifer. *P*-values $\leq$ 0.05 were considered significant and $0.05 < P \leq 0.10$ considered a tendency.

RESULTS AND DISCUSSION

Chronological BW and BCS measurements are presented in Table 3, while reproductive performance for heifers and primiparous cows is presented in Table 4. Calf BW and performance is presented in Table 5.

Heifers

At initiation of the current study and before the breeding season, heifer BW and percentage of pubertal heifers did not differ ($P \geq 0.87$) between treatments. Following the supplementation period, heifer BW and BCS did not differ ($P \geq 0.11$) between treatments. In contrast, SUP heifers tended ($P = 0.08$) to maintain a greater rate of BW gain during the breeding season. Heifer pregnancy rate was similar ($P = 0.55$) between treatments. Prepartum BW and BCS for heifers was similar ($P \geq 0.21$) despite CP supplementation during the previous breeding season. Likewise, overwinter ADG was similar ($P = 0.33$) between treatments.

At calving, previous breeding season treatment did not affect ($P \geq 0.21$) calf BW at birth or dystocia rates. Vonnahme et al. (2007) suggests early gestation nutritional deficiencies may negatively impact vascularity of the placenta; however, early gestation undernutrition may not have lasting effects on calf growth pre- or post-natally. Percentage of heifers calving in the first 21 d was similar ($P = 0.23$) between treatment groups. From prepartum BW as a heifer to prebreed BW as a primiparous cow, both treatment groups had a similar ($P = 0.63$) rate of BW gain. Similarly, calf ADG from birth to prebreed was not different ($P = 0.48$) based on dam's previous breeding season supplementation.

Primiparous Cows

Following reassignment of breeding season supplementation treatment, there were no differences ($P \geq 0.67$) in initial BW or BCS of the primiparous cow at prebreeding. Calf BW at prebreeding was similar ($P = 0.80$) between treatment groups. Estimated length of PPI was not different ($P = 0.39$; 92 ± 2 d) between treatments and was similar

in length to those reported by Ciccioli et al. (2003) despite a lower ADG (-0.01 kg/d) from prepartum to prebreeding for cattle in this study.

After the supplementation period, SUP primiparous cows weighed 22 kg more ($P = 0.01$), and had a greater BCS ($P < 0.01$) than their NSP counterparts at pregnancy diagnosis. In addition, SUP primiparous cow ADG during the breeding season was greater ($P < 0.01$) than for NSP primiparous cows. Linden et al. (2014) suggested this slower growth rate for the NSP primiparous cow is a byproduct of her physical inability to consume enough of a low-quality forage during early lactation to meet the demands of growth and lactation. Ruminal bacteria responsible for processing nonstructural carbohydrates improved yield by as much as 18.7% with the inclusion of protein in the diet (Russell et al., 1992). Furthermore, increased diet TDN values will increase bacterial efficiency (Patterson et al., 2006). Therefore, feeding additional CP and TDN during early lactation and breeding may have provided SUP cows with improved energy availability. Despite a decline in BW (-4 kg) for NSP primiparous cows during the breeding season, pregnancy rate did not differ ($P = 0.83$) from SUP primiparous cows.

For calves nursing SUP primiparous dams, calf BW at weaning and ADG during the supplementation period were greater ($P < 0.01$, Table 5) than calves nursing NSP dams. The increase in first calf weaning weight and ADG, without affecting dam BW or BCS, may be due to calves consuming supplement directly, rather than increased milk production by the dam. This agrees with Tedeschi and Fox (2009), who suggest an inverse relationship between milk consumption and feed intake. Additionally, Stalker et al. (2006a) reported greater calf BW at weaning, with no effect on dam BW or BCS, in

calves whose dams were provided higher quality forage (subirrigated meadow) in a March-calving herd.

Overwinter, NSP primiparous cows had a greater ($P = 0.01$) ADG, which led to a similar ($P = 0.39$) prepartum BW for NSP and SUP females. In contrast, previously supplemented primiparous cows did maintain a greater ($P = 0.01$) BCS overwinter.

Nutritional requirements of beef females depend on physiological state. According to the NRC (2000), growing heifer calves require 9% CP and 58% TDN (DM) and lactating primiparous cows require 13% CP and 66% TDN (DM). Despite an increase in total CP availability during the breeding season, pregnancy rates were not improved in heifers and primiparous cows by supplementation of a supplement high in bypass protein. Research conducted in the Nebraska Sandhills has indicated a deficiency in RDP for a May-calving herd (Lardy, 1997). This is supported by the predicted negative RDP balance during an August breeding season (NRC, 2000). It is possible supplementing to meet RDP requirements may positively influence pregnancy rates. Additionally, females were maintained at a BCS $\geq$ 5 throughout both years of the study, sufficient for successful conception (Short et al., 1990). Increasing nutrition postpartum improved reproductive performance for cows calving at a BCS of 4 or less; however, for those at a BCS of 5 or greater, no effect was shown (Richards et al., 1986; Stalker et al., 2006b). This could explain the lack of reproductive response, as NSP females were in adequate BCS. Overall, increasing amount of supplementation and/or protein degradability may be needed to elicit a reproductive response in May-calving cattle with adequate BCS in the Nebraska Sandhills.

IMPLICATIONS

Supplementation of low-quality forage with RUP throughout the breeding season did not improve reproductive performance in May-calving heifers or primiparous cows. Although heifer BW and BCS were not impacted by treatment, SUP primiparous cows had increased BW and BCS following the supplementation period. Calves nursing SUP primiparous dams had increased wean BW, which may be advantageous to the producer. It is possible supplementation with RDP may improve pregnancy rates in young beef females.

LITERATURE CITED

Burfening, P. J., D. D. Kress, R. L. Friedrich, and D. D. Vaniman. 1978. Phenotypic and genetic relationship between calving ease, gestation length, birth weight and preweaning growth. J. Anim. Sci. 47: 595-600. doi:10.2527/jas1978.473595x.

Ciccioli, N. H., R. P. Wettemann, L. J. Spicer, C. A. Lents, F. J. White, and D. H. Keisler. 2003. Influence of body condition at calving and postpartum nutrition on endocrine function and reproductive performance of primiparous beef cows. J. Anim. Sci. 81: 3107-3120. doi:10.2527/2003.81123107x.

Funston, R. N., E. E. Grings, A. J. Roberts, and B. T. Tibbitts. 2016. Invited Review: Choosing a calving date. Prof. Anim. Sci. 32: 145-153. doi:10.15232/pas.2015-01463.

Griffin, W. A., L. A. Stalker, D. C. Adams, R. N. Funston, and T. J. Klopfenstein. 2012. Calving date and wintering system effects on cow and calf performance I: A systems approach to beef production in the Nebraska Sandhills. Prof. Anim. Sci. 28: 249-259. doi:10.15232/S1080-7446(15)30355-7.

Lardy, G., D. C. Adams, T. J. Klopfenstein, D. Clark, and J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills Native Range and subirrigated meadow diets and application of a metabolizable protein system. In: 1997 Nebraska Beef Cattle Report. Rep. No. MP 67-A. Univ. of Nebraska, Lincoln

Linden, D. R., E. C. Titgemeyer, K. C. Olson, and D. E. Anderson. 2014. Effects of gestation and lactation on forage intake, digestion, and passage rates of primiparous beef heifers and multiparous beef cows. J. Anim. Sci. 92: 2141-2151. doi:10.2527/jas2013-6813.

NRC. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. The National Academies Press, Washington, DC.

Patterson, H. H., D. C. Adams, T. J. Klopfenstein, and G. P. Lardy. 2006. Applications of the 1996 NRC to protein and energy nutrition of range cattle. Prof. Anim. Sci. 22: 307-317. doi:10.15232/S1080-7446(15)31113-X.

Richards, M. W., J. C. Spitzer, and M. B. Warner. 1986. Effect of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. J. Anim. Sci. 62: 300-306. doi:10.2527/jas1986.622300x.

Roberts, A. J., A. G. da Silva, A. F. Summers, T. W. Geary, and R. N. Funston. 2017. Developmental and reproductive characteristics of beef heifers classified by pubertal status at time of first breeding. J. Anim. Sci. 95:5629-5636. doi:10.2527/jas2017.1873.

Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. V. Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal Fermentation. J. Anim. Sci. 70: 3551-3561. doi:10.2527/1993.7151298x.

Short, R. E., R. A. Bellows, R. B. Staigmiller, J. G. Berardinelli, and E. E. Custer. 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. J. Anim. Sci. 68: 799-816. doi:10.2527/1990.683799x.

Springman, S.A., H.R. Nielson, and R.N. Funston. 2017. Impact of heifer development system and winter supplemention of May calving cows on subsequent growth and reproduction in two different breeding seasons. Proc. West. Sec. Am. Soc. Anim. Sci. 68:119-123.

Stalker, L. A., D. C. Adams, T. J. Klopfenstein, D. M. Feuz, and R. N. Funston. 2006a. 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.

Stalker, L. A., K. W. Creighton, J. A. Musgrave, D. C. Adams, and T. J. Klopfenstein. 2006b. Effects of Supplementing Lactating, June-calving Cows on Second-calf Pregnancy Rates. In: Nebraska Beef Report. Rep. No. MP 88-A. Univ. of Nebraska, Lincoln. p. 5-6.

Stockton, M. C., D. C. Adams, R. K. Wilson, T. J. Klopfenstein, R. T. Clark, and G. L. Carriker. 2007. Production and economic comparisons of two calving dates for beef cows in the Nebraska Sandhills. Prof. Anim. Sci. 23: 500-508. doi:10.1532/S1080-7446(15)31011-1.

Tedeschi, L. O., and D. G. Fox. 2009. Predicting milk and forage intake of nursing calves. J. Anim. Sci. 87: 3380-3391. doi:10.2527/jas.2009-2014.

Van Soest, P. J. 1964. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. North Atlantic Section, ASAS, Cornell University, Ithaca, New York.

Vonnahme, K. A., M. J. Zhu, P. P. Borowicz, T. W. Geary, B. W. Hess, L. P. Reynolds, J. S. Caton, W. J. Means, and S. P. Ford. 2007. Effect of early gestational undernutrition and angiogenisis factor expression and vascularity in the bovine placentome. J. Anim. Sci. 85: 2464-2472. doi:10.2527/jas.2006-805.

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.

Table 1. Composition and nutrient analysis of supplement fed to May-calving heifers and primiparous cows during the breeding season

Item	
Ingredient, % of diet	
Dried distillers grains plus solubles	62.0
Wheat middlings	11.0
Cottonseed meal	9.0
Dried corn gluten feed	5.0
Molasses	5.0
Calcium carbonate	3.0
Trace minerals and vitamins[1]	3.0
Urea	2.0
Nutrient	
CP, % DM	31.6
RUP, % CP	41.0
TDN, % DM	89.4

[1]Formulated to provide 80 mg/0.45 kg of BW monensin (177 mg/kg).

Table 2. Predicted breeding season nutrient values of the diet (NRC, 2000) supplied to either heifers or primiparous cows in a May-calving herd[1]

	Heifer		Primiparous Cow	
	NSP	SUP	NSP	SUP
Predicted DMI, kg/d	7.5	7.5	9.0	9.3
Diet supplied CP, %	9.7	11.0	9.7	11.9
Diet supplied TDN, %	59.0	61.0	59.0	62.0
MP balance, g/d	118	149	62	193
RDP balance, g/d	-99	-145	-119	-216
NE balance, Mcal/d	4.1	4.7	-0.6	0.8

[1]Heifers and primiparous cow grazing upland range were offered either no supplement (NS) or a 32% CP (DM) supplement delivered 3 times/wk on a pasture basis. Heifers received 0.45 kg/animal per day supplement (SUP), and primiparous cows received 0.91 kg/animal per day SUP. Supplementation began 2 wk before and throughout a 45 d breeding season.

Table 3. Effects of breeding supplementation treatment[1] on May-calving female's chronological BW, BCS, and ADG

	Treatment			
	NSP	SUP	SEM	*P* – Value
Heifer BW				
Prebreed, kg	307	307	3	0.87
Breeding season ADG, kg/d[2]	0.42	0.49	0.03	0.08
Pregnancy diagnosis, kg	350	357	3	0.11
Overwinter ADG, kg/d[3]	0.22	0.19	0.02	0.33
Prepartum, kg	392	392	4	0.98
Early lactation ADG, kg/d[4]	0.0	-0.02	0.03	0.63
Primiparous cow BW, kg				
Prebreed, kg	382	385	4	0.67
Breeding season ADG, kg/d[2]	-0.05	0.10	0.02	< 0.01
Pregnancy diagnosis, kg	374	396	5	0.01
Overwinter ADG, kg/d[3]	0.40	0.29	0.03	0.01
Prepartum, kg	426	432	5	0.39
Heifer BCS[5]				
Pregnancy diagnosis	5.8	5.8	0.03	0.54
Prepartum	5.1	5.2	0.04	0.21
Primiparous cow BCS[5]				
Prebreed	5.3	5.3	0.05	0.87
Pregnancy diagnosis	5.1	5.3	0.06	< 0.01
Prepartum	4.9	5.1	0.07	0.01

[1]Heifers and primiparous cow grazing upland range were offered either no supplement (NS) or a 32% CP (DM) supplement delivered 3 times/wk on a pasture basis. Heifers received 0.45 kg/animal per day supplement (SUP), and primiparous cows received 0.91 kg/animal per day SUP. Supplementation began 2 wk before and throughout a 45 d breeding season.

[2]Calculated from prebreed BW in July to pregnancy diagnosis BW in mid-October.

[3]Calculated from pregnancy diagnosis BW in mid-October to prepartum BW in May.

[4]Calculated from heifer prepartum BW in May to primiparous cow prebreed BW in July.

[5]Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).

Table 4. Effects of breeding season treatment[1] on reproductive performance in heifers

	Treatment			
	NSP	SUP	SEM	*P*-Value
Heifers				
Pubertal[2], %	67	67	4	0.96
Pregnancy rate, %	68	71	4	0.55
Calved in first 21 d, %	71	79	5	0.23
Dystocia[3], %	18	13	4	0.34
Primiparous cows				
PPI, d[4]	94	92	2	0.39
Pregnancy rate, %	78	79	6	0.83
Calved in first 21 days, %	84	81	6	0.65
Dystocia[3], %	0	0	30	0.99

and primiparous cows in a May-calving herd

[1]Heifers and primiparous cow grazing upland range were offered either no supplement (NS) or a 32% CP (DM) supplement delivered 3 times/wk on a pasture basis. Heifers received 0.45 kg/animal per day supplement (SUP), and primiparous cows received 0.91 kg/animal per day SUP. Supplementation began 2 wk before and throughout a 45 d breeding season.

[2]Considered pubertal if blood serum progesterone concentration > 1 ng/ml.

[3]Percentage of females with a calving ease score of 2 or greater (1 = no assistance to 4 = caesarian section; Burfening et al., 1978).

[4]Length of postpartum interval from birth of first calf to conception of second calf calculated from subsequent calving date minus 285 d.

Table 5. Effects of breeding season treatment on calves born to May-calving primiparous cows

	Treatment[1]			
	NSP	SUP	SEM	*P*-Value
Birth BW, kg[1]	29	30	0.5	0.21
Early lactation ADG, kg/d[1,2]	0.86	0.87	0.01	0.48
2 mo BW, kg[3]	96	97	2	0.80
Breeding season ADG, kg/d[3,4]	0.42	0.50	0.01	< 0.01
Wean BW, kg[3]	168	181	3	< 0.01

[1]Calf birth BW and early lactation ADG were analyzed based on heifer treatment. Heifers grazing upland range were offered either no supplement (NS) or 0.45 kg/d 32% CP (DM) supplement (SUP) delivered 3 times/wk on a pasture basis. Supplementation began 2 wk before and throughout a 45 d breeding season.

[2]Calculated from parturition in May to 2 mo. BW in July.

[3]Calf 2 mo BW, wean BW, and consequent breeding season ADG were calculated based on primiparous cow treatment. Primiparous cows grazing upland range were offered either no supplement (NS) or 0.45 kg/d 32% CP(DM) supplement (SUP) delivered 3 times/wk on a pasture basis. Supplementation began 2 wk before and throughout a 45 d breeding season.

[4]Calculated from 2 mo BW in July to wean BW in early November.

CHAPTER IV

Effect of forage type during the breeding season on a May-calving herd in the Nebraska Sandhills

A.C. Lansford, J. Musgrave and R.N. Funston

University of Nebraska, West Central Research and Extension Center, North Platte 69101

ABSTRACT: An ongoing study at the Gudmundsen Sandhills Laboratory is examining the effects of 2 forage types on May-calving female performance. Females were stratified by age, then blocked by BW and allotted to 1 of 2 forage types: Sandhills upland range (**RN**) or sub-irrigated meadow (**MDW**). Treatment began 2 wk prior to the breeding season and continued for 91 d for heifers and primiparous cows, or a 138 d for multiparous cows. Calves were weaned from cows at pregnancy diagnosis. Meadow grazing increased ($P \leq 0.05$) pregnancy diagnosis BW throughout all age classes, though pregnancy rate was similar ($P \geq 0.39$). Calves belonging to either primiparous or multiparous cows also had increased ($P \leq 0.05$) BW at weaning. Although heifers had a similar ($P \geq 0.10$) BCS at pregnancy diagnosis, meadow grazing increased ($P \leq 0.05$) primiparous and multiparous cow pregnancy diagnosis BCS. All age classes of the RN treatment had a greater ($P < 0.01$) BW change overwinter than MDW females, which resulted in no difference ($P \geq 0.10$) in prepartum BW. Change in BCS overwinter was not affected ($P \geq 0.15$) by breeding season treatment for any age class. No differences ($P \geq 0.57$) were detected in calving date for heifers or primiparous cows, multiparous cows previously grazing range calved later ($P = 0.02$) than those allotted to the MDW treatment. No differences ($P \geq 0.21$) in dystocia rate or subsequent calf birth BW were

detected at parturition for any age class. Grazing a higher-quality forage throughout the breeding season resulted in differences in BW and BCS at pregnancy diagnosis, although preliminary data demonstrate no differences in pregnancy rates.

Key words: breeding season, forage-type May-calving

INTRODUCTION

Two distinct forage types are available for grazing in the Nebraska Sandhills. Upland range is largely composed of warm-season grasses, while sub-irrigated meadow is dominated by cool season grasses (Volesky et al., 2007; Volesky et al., 2004). These differences in forage seasonality create disparities in forage quality for grazing cattle, with sub-irrigated meadow offering a higher CP value throughout the late summer grazing months (Lardy et al., 1997). In scientific literature, there is an abundance of data indicating protein is the first limiting nutrient in extensive grazing systems (Adams et al., 1996; Krysl et al., 1987) and supplementation of protein can shorten the interval to conception (Vanzant and Cochran, 1994), increase DMI (Moriel et al., 2012), and improve cow BCS (Stalker et al., 2006). For lactating primiparous cows grazing low quality forage, DMI was increased postpartum despite a loss of BW (Linden et al., 2014). This agrees with the suggestion by Funston et al. (2016) that younger beef females are not able to physically consume enough low-quality forage to meet their nutrient demands. Research by Springman et al. (2017), demonstrates a declining pregnancy rate in May- vs. March-calving heifers (70 vs. 87%, May vs. March). For lactating primiparous May-calving cows in the Nebraska Sandhills, upland range does not meet MP or RDP requirements during the breeding season (Lardy et al., 1997; NRC, 2000). Heifers managed on a declining plane of nutrition, similar to summer upland range, exhibited

decreased conception rates and higher embryonic mortality (Arias et al., 2012; Kruse et al., 2017). We hypothesized young beef females grazing sub-irrigated meadow would more closely meet their MP and RDP requirements throughout the breeding season and consequently, resulting in greater pregnancy rates. Therefore, our objective was to analyze the effects of two forage types on reproductive and gain response of May-calving heifers, primiparous cows, and multiparous cows grazing upland range or sub-irrigated meadow throughout the breeding season.

MATERIALS AND METHODS

The University of Nebraska Animal Care and Use Committee approved the procedures and facilities used in this experiment.

Female Management

Two years of an ongoing study evaluating the effects of forage quality on reproductive response and ADG in a May-calving herd were conducted at the Gudmundsen Sandhills Laboratory (**GSL**) near Whitman, Neb. Crossbred (5/8 Red Angus, 3/8 Simmental, n = 126, 65, and 187, heifers, primiparous cows, and multiparous cows, respectively) females were blocked by age and randomly assigned to graze either upland range (**RN**) or sub-irrigated meadow (**MDW**) for 2 wk prior to the breeding season through pregnancy diagnosis. Upland range sites were stocked at a rate of 0.5 AUM, while sub-irrigated meadows were stocked at a rate of 4 AUM for the breeding season, where a 1 AUM was equivalent to a 454 kg heifer and a cow-calf pair was considered 1.5 AUM. Two months prior to the treatment period, sub-irrigated meadows were grazed for 30 d and approximately 2 AUM of forage removed. This allowed for a 30 d regrowth period prior to treatment initiation. Heifer and primiparous cow treatment

was approximately 91 d, while multiparous cow treatment was approximately 138 d. Pastures (n = 4) are as follows: Meadow – heifers and primiparous cows Range – heifers and primiparous cows, Meadow – multiparous cows, Range – multiparous cows. Females remained on the same breeding season treatment each year of the study. Females moved to subsequent age classification (primiparous cow, multiparous cow) at calf birth. Nutrient profiles and predicted nutrient balances for each forage type are presented in Tables 1 and 2.

Heifers were developed on 1 of 2 development systems from weaning to May 1. Heifers were offered either meadow hay ad libitum and 1.8 kg/d of supplement (32% CP, DM) or were allowed to graze sub-irrigated meadow and offered 0.45 kg/d of the same supplement (Springman et al., 2017). Following completion of development treatment to start of breeding season treatment, heifers grazed upland range.

Blood samples (5 mL) were collected from heifers on d -10 and 0 of the breeding season via coccygeal venipuncture to determine plasma progesterone concentrations. Plasma progesterone concentrations were determined using a direct solid phase RIA (Coat-A-Count; Diagnostics Products Corp., Los Angeles, CA). Heifers were considered pubertal if plasma progesterone concentrations were ≥ 1.0 ng/mL at one or both time points. Heifer BW was recorded at each blood collection and prebreed BW considered the average of these 2 time points. Primiparous and multiparous cow BW recorded and a body condition score (BCS; 1 = emaciated to 9 = obese; Wagner et al., 1988) was assigned on d 0 of the breeding season.

Beginning approximately July 20, all females were placed in their respective pastures, and fertile bulls were introduced with females at a 1:20 ratio for a 45 d breeding

season. Heifers and cows were synchronized using a single PGF2α injection (Lutalyse, Zoetis Animal Health, Parsippany, NJ) 5 d after bull placement.

Grazing treatments ended at pregnancy diagnosis. Pregnancy diagnosis was conducted via transrectal ultrasonography (Aloka, Hitachi Aloka Medical America Inc., Wallingford, CT) for heifers and primiparous cows approximately 91 d after bull introduction and 138 d for multiparous cows. Female BW and BCS were collected at pregnancy diagnosis. Calf BW was recorded and calves weaned from primiparous and multiparous cows at their respective pregnancy diagnosis. Females were removed from the herd at this time for reproductive failure or injury.

After pregnancy diagnosis, all females were managed as a single herd similarly for the remainder of the year. Two weeks prior to an expected calving date of May 5, BW and BCS were recorded on heifers and cows. At parturition, calf birth BW, sex, and birth date were recorded; and a calving ease (**CE**) was assigned (1 = no assistance, 2 = easy assist, 3 = difficult assist, 4 = caesarian section, and 5 = breech/abnormal presentation; Burfening et al., 1978). A CE score of 2 or greater was considered as dystocia. Females were removed for calf death or injury at the end of the calving season.

Forage Analysis

Forage analysis is presented in Table 1. Three times (approximately July 30, August 20, and September 15) throughout the breeding season, esophageally fistulated cows grazed for 30 minutes on each pasture (n = 4) before extrusa was collected. Each pasture was grazed by at least 3 fistulated cows. Each sample was ground to pass a 1-mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ). Samples were analyzed for DM and OM by AOAC (1990) standards.

In vitro digestibility

In vitro organic matter disappearance was measured using a modified Tilley and Terry (1963) method. The modifications are as follows. Inoculum was obtained by collecting whole rumen contents from 4 ruminally cannulated steers (2 steers/run) and strained through 4 layers of cheesecloth. Ruminal fluid from both steers was mixed to reduce variation. Strained ruminal fluid was mixed with McDougal's Buffer (1:1 ratio) and 1 g urea/L (Weiss, 1994). Forage samples of 0.5 g were weighed and deposited into a 100 mL tube and mixed with 50 mL of inoculum. Test tubes were capped and placed in a 39°C water bath for 48 h. This was followed by addition of HCL acid and pepsin before being placed back into the water bath for 24 h. Samples were removed after this period and immediately placed in a freezer. Tubes were removed from the freezer and allowed to thaw in a 39°C water bath for 10 minutes before filtering. Samples were rinsed from the tube with distilled water, filtered through a Whatman 541 paper filter, and then dried in a 100° C oven for 6 h (Van Soest and Robertson, 1977). This process was repeated twice, where run was considered experimental unit (n = 2). Samples were replicated 3 times for each run, and averaged across runs for digestibility estimates.

Five chopped hays with known in vivo digestibility values were used as standards to adjust forage sample IVOMD values (Geisert, 2007). The hays utilized were immature meadow hay, immature smooth bromegrass, mature smooth bromegrass, mature brome hay, and a mixture of warm and cool season grass species.

Crude Protein

Forage samples of 0.06 g were analyzed for nitrogen content using a combustion chamber (FlashSmart N/Protein Analyzer CE, Elantech, Inc., Lakewood, NJ; AOAC,

1999; method 990.03). Nitrogen content was multiplied by a standard 6.25 to determine protein content. Forage samples were run in duplicate. Samples with a CV above 5% were reran in duplicate and combined with previous results. Outliers within sample were removed from the data analysis, and were considered values ± 4 SD from the mean. Average protein percentage were corrected to a common standard.

Statistical Analysis

The PROC GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC, version 9.4) was used for all statistical analyses. Cow age classification within pasture was considered the experimental unit. The model statement contained the fixed effects of breeding season treatment. Treatment year and age were considered as covariates on all variables of interest. Development system was considered a covariate on heifer data and previous breeding season treatment a covariate on primiparous and multiparous cow data. Covariates were removed from the model statement if $P \geq 0.05$. Measurements repeated on the same subject were analyzed using a repeated measures technique, where month since initiation of treatment was considered the repeated measure. Heterogeneous compound symmetry was selected for covariance structures due to generating the lowest Akaike and Bayesian information criterion. When analyzing calf-at-side BW, calf's birth BW was included as a covariate. The Tukey-Kramer adjustment was used to obtain superscripts for all multiple comparisons of LS means. *P*-values ≤ 0.05 were considered significant, and those between $0.05 < P \leq 0.10$ were considered a tendency.

RESULTS AND DISCUSSION

Heifer Performance

Results for heifer BW, BCS, ADG, and reproductive performance are presented in Table 2. The percentage of heifers pubertal at start of the breeding season did not differ ($P = 0.78$) between treatment. Initial BW before the breeding season was also similar ($P \geq 0.10$) between treatments (325 ± 4 kg). There was a treatment × month interaction ($P = 0.02$) for heifer BW from trial initiation to prepartum BW measurement. Heifer BW was increased ($P < 0.01$) by meadow grazing, and as such, MDW heifers had a greater ($P \leq 0.05$) BW at pregnancy diagnosis. There was no effect of treatment ($P \geq 0.37$) on heifer BCS, so heifer BCS at pregnancy diagnosis was similar ($P \geq 0.10$). No differences ($P = 0.71$) in pregnancy rate were detected. Overwinter, change in heifer BCS was not influenced ($P = 0.71$) by breeding season treatment, and heifers had a similar ($P \geq 0.10$) prepartum BCS. Conversely, RN heifers gained 17 kg more ($P < 0.01$) BW overwinter to result in a similar ($P \geq 0.10$) prepartum BW between treatments, despite differences at pregnancy diagnosis. No differences ($P \geq 0.54$) were detected in calving date or percentage of heifers calving in the first 21 d of the season. Furthermore, calf birth BW and dystocia rates were similar ($P \geq 0.21$) between treatments.

Primiparous Cow Performance

Primiparous cow BW, BCS, ADG, and reproductive performance are presented in Table 3. Initial BW and BCS were similar ($P \geq 0.10$) for primiparous cows. A treatment × month interaction ($P = 0.03$) existed for primiparous cow BW, with MDW cows having a greater ($P \leq 0.05$) BW at pregnancy diagnosis. Furthermore, a treatment × month interaction ($P = 0.04$) existed for cow BCS, with MDW cows also have a greater ($P \leq 0.05$) BCS at pregnancy diagnosis. There was a tendency ($P = 0.10$) for MDW heifers to

have a greater BCS regardless of month, although differences were not detected ($P \geq 0.10$) for initial or prepartum BCS. Cows grazing meadow gained BW and BCS, while those grazing range lost BW and BCS over the breeding season ($P < 0.01$). Despite this, no differences ($P = 0.43$) in pregnancy rate were observed, which may be a result of a low number of cows enrolled in the study (n = 65). To date, there is a 7 percentage point greater pregnancy rate for primiparous cows grazing meadow compared with range. There was a treatment × month interaction ($P < 0.01$) for calf BW, with MDW calves tending to have a greater ($P \leq 0.10$) weaning BW. Calf ADG was increased ($P < 0.01$) by meadow grazing. Overwinter, RN cows gained more BW ($P = 0.03$), though there was no change in BCS ($P = 0.74$). This resulted in similar ($P \geq 0.10$) prepartum BW and BCS between treatments.

Similar to heifers, no differences ($P \geq 0.57$) in calving date or percentage of cows calving in the first 21 d of the season were detected. Calf birth BW and dystocia rates were also not impacted ($P \geq 0.48$) by breeding season treatment.

Multiparous Cow Performance

The results of multiparous cow BW, BCS, ADG, and reproductive performance are presented in Table 4. By design, initial BW and BCS were similar between treatments ($P \geq 0.10$). As with heifers and primiparous cows, a treatment × month interaction existed ($P < 0.01$) for cow BW, with MDW cows having a greater ($P \leq 0.05$) BW at pregnancy diagnosis. Furthermore, a tendency for a treatment × month interaction ($P = 0.07$) was detected for cow BCS, with MDW cows also having a greater ($P \leq 0.05$) BCS at pregnancy diagnosis. There was also a tendency ($P = 0.09$) for MDW cows to have a

greater BCS over time despite no difference ($P \geq 0.10$) detected in initial or prepartum BCS. During the treatment period, MDW cows lost less ($P < 0.01$) BCS than cows grazing range. Pregnancy rate was similar ($P = 0.39$) between treatments.

There was a treatment × month interaction ($P < 0.01$) for calf BW, with MDW calves having a greater ($P \leq 0.05$) BW at weaning. This agrees with MDW calves having a greater ($P < 0.01$) ADG over the treatment period.

Similar to the previous age classifications, RN cows gained more ($P < 0.01$) BW overwinter than MDW cows, with no differences ($P = 0.15$) in BCS change. Cow BW and BCS prepartum were similar ($P \geq 0.10$) between treatments. Cows grazing range during the breeding season had a later ($P = 0.02$) calving date than those who grazed meadow, which may suggest RN cows conceived later in the season. In contrast, no difference ($P = 0.31$) in percentage of cows calving in the first 21 d of the season was observed. Neither calf birth BW nor dystocia rates were impacted ($P \geq 0.98$) by breeding season treatment.

Nutrient requirements of beef females differ by physiological state and are influenced by growth and lactation. The first 90 d after calving demand the greatest nutrient inputs in both primiparous and multiparous cows, due to early lactation milk production. Primiparous cows have even greater CP and TDN requirements throughout the breeding season due to the combined demands of continued growth and lactation (NRC, 2000). Sub-irrigated meadow forages are higher in CP throughout the breeding season; however, IVDMD and IVOMD values are similar (Table 1; Lardy et al., 1997). Increased dietary CP increases rumen microbial efficiency and production (Russell et al., 1992). All age classes experienced an increase in BW by grazing MDW forage. When

cattle experience moderate nutrient restriction, protein accretion continues, but fat accretion is limited (Hornick et al., 2000). This is supported by decreased BCS in primiparous and multiparous cows grazing range in this study. Furthermore, increasing dam's dietary CP increased milk yield, fat, and protein (Colmenero and Broderick, 2006). This, coupled with increased dietary quality, may have resulted in increased calf-at-side BW when dams grazed meadow. Meadow forage may more closely meet the nutrient requirements of May-calving females during the breeding season, and as a result, BW and BCS may be increased.

Despite these factors, pregnancy rates were not impacted by breeding season forage type. Pregnancy rates for heifers and primiparous cows in this study are much greater than those previously reported (Lansford et al., 2017). This may be a result of altered precipitations levels and consequent grass growth, or adaptability to the environment on the female's behalf. Overwinter, females previously grazing range had greater BW gain so that prepartum BW was similar between treatments within age classification. Lansford et al. (2017) reported a similar effect for heifers and primiparous cows who experienced moderate nutrient restriction during the breeding season. After the breeding season, all females were placed on upland range. This may have placed females who grazed meadow forage at a disadvantage due to a sudden change in diet composition and quality. Dietary CP of range forage in November is lower than meadow forage (Lardy et al., 1997) and a sudden change in diet may have altered grazing behavior and metabolism of MDW females.

At parturition, MDW multiparous cows began calving earlier in the season than RN cows; however, this was not observed for heifers or primiparous cows. Jordan and

Swanson (1979) found multiparous cows fed increased dietary CP had increased serum LH concentrations and decreased circulating progesterone in the early postpartum period. It is possible multiparous cows allotted to meadow grazing had a shortened anestrous period due to increased forage CP, although percentage of females calving in the first 21 d of the season was not significantly different.

IMPLICATIONS

Allotting heifers, primiparous, and multiparous May-calving cows to a higher CP forage during the breeding season had no impact on pregnancy rates. Grazing sub-irrigated meadow increased BW in all age classifications over the treatment period, and primiparous and multiparous cows weaned heavier calves. Previous research indicated lower pregnancy rates in May-calving heifers and primiparous cows. The May-calving herd at GSL was developed from a March-calving herd several years prior to this study, so it is possible these younger females have become adapted to differences in breeding season forage quality.

LITERATURE CITED

Adams, D. C., R. T. Clark, T. J. Klopfenstien, and J. D. Volesky. 1996. Matching the cow with forage resources. Rangelands 18: 57-62.

AOAC. 1990. Official Methods of Analysis. 14th ed. ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Arias, R. P., P. J. Gunn, R. P. Lemenager, and S. L. Lake. 2012. Effects of post-AI nutrition on growth performance and fertility of yearling beef heifers. J. Anim. Sci. 63: 117-121.

Burfening, P. J., D. D. Kress, R. L. Friedrich, and D. D. Vaniman. 1978. Phenotypic and genetic relationship between calving ease, gestation length, birth weight and preweaning growth. J. Anim. Sci. 47: 595-600.

Colmenero, J. O., and G. Broderick. 2006. Effect of Dietary Crude Protein Concentration on Milk Production and Nitrogen Utilization in Lactating Dairy Cows1. Journal of Dairy Science 89: 1704-1712.

Funston, R. N., E. E. Grings, A. J. Roberts, and B. T. Tibbitts. 2016. Invited Review: Choosing a calving date. The Professional Animal Scientist 32: 145-153. doi:10.15232/pas.2015-01463.

Geisert, B. G. 2007. Development of a set of forage standard to estimate *in vivo* digestibility of forages and prediction of forage quality of diets consumed by cattle grazing Nebraska Sandhills range pastures, Univ. of Nebraska, Lincoln.

Hornick, J.-L., C. Van Eenaeme, O. Gerard, I. Dufrasne, and L. Istasse. 2000. Mechanisms of reduced and compensatory growth. Domestic animal endocrinology 19: 121-132.

Jordan, E., and L. Swanson. 1979. Serum progesterone and luteinizing hormone in dairy cattle fed varying levels of crude protein. Journal of Animal Science 48: 1154-1158.

Kruse, S. G., G. A. Bridges, B. J. Funnell, S. L. Bird, S. L. Lake, R. P. Arias, O. L. Amundson, E. L. Larimore, D. H. Keisler, and G. A. Perry. 2017. Influence of post-insemination nutrition on embryonic development in beef heifers. Theriogenology 90: 185-190. doi:10.1016/j.theriogenology.2016.11.021.

Krysl, L. J., M. L. Galyean, J. D. Wallace, F. T. McCollum, M. B. Judkins, M. E. Branine, and J. S. Caton. 1987. Cattle nutrition on blue grama rangeland in New Mexico. N.M. Agric. Exp. Stn. Bull 727: 1-35.

Lansford, A. C., J. Musgrave, and R. N. Funston. 2017. Effect of supplementation during the breeding season on a May-calving herd in the Nebraska Sandhills. In: Western Section - American Society of Animal Science, Fargo, ND

Lardy, G., D. C. Adams, T. J. Klopfenstein, D. Clark, and J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills Native Range and subirrigated meadow diets and application of a metabolizable protein system. In: 1997 Nebraska Beef Cattle Report. Rep. No. MP 67-A. Univ. of Nebraska, Lincoln

Linden, D. R., E. C. Titgemeyer, K. C. Olson, and D. E. Anderson. 2014. Effects of gestation and lactation on forage intake, digestion, and passage rates of primiparous beef heifers and multiparous beef cows. J. Anim. Sci. 92: 2141-2151. doi:10.2527/jas2013-6813.

Moriel, P., R. F. Cooke, D. W. Bohnert, J. M. B. Vendramini, and J. D. Arthington. 2012. Effects of energy supplementation frequency and forage quality on performance,

reproductive, and physiological responses of replacement beef heifers. J. Anim. Sci. 90: 2371-2380. doi:10.2527/jas2011-4958.

NRC. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. The National Academies Press, Washington, DC.

Russell, J. B., J. D. O'Connor, D. G. Fox, P. J. V. Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal Fermentation. J. Anim. Sci. 70: 3551-3561.

Springman, S. A., H. R. Nielson, J. A. Musgrave, J. Nollette, A. Applegarth, and R. N. Funston. 2017. Impact of heifer development system in two different breeding seasons. In: 2017 Nebraska Beef Cattle Report. Rep. No. MP104. Univ. of Nebraska, Lincoln. p. 8-10.

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.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forages. J. Br. Grassl. Soc. 18: 104-111.

Van Soest, P. J., and J. B. Robertson. 1977. What is fibre and fibre in food? Nutr. Rev. 35.

Vanzant, E. S., and R. C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low-quality, tallgrass-prairie forage. J. Anim. Sci. 72: 1059-1067. doi:10.2527/1994.7241059x.

Volesky, J. D., W. H. Schacht, P. E. Reece, and T. J. Vaughn. 2007. Diet composition of cattle grazing Sandhills range during spring. Rangeland Ecol. Manag. 60: 65-70. doi:10.2111/05-232R2.1.

Volesky, J. D., W. H. Schacht, and D. M. Richardson. 2004. Stocking rate and grazing frequency effects on Nebraska Sandhills meadows. J. Range Manag. 57: 553-560.

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 requirment during winter. J. Anim. Sci 66: 603-612.

Weiss, W. P. 1994. Estimation of digestibility of forages by laboratory methods In: G.C. Fahey Jr., M. Collins, D.R. Mertens, and L.E. Moser (ed.) Forage Quality, Evaluation, and Utilization. p 644-681. Am. Soc. of Agron., Crop Sci. Soc. of Am., Soil Sci. Soc. of Am., Madison, WI.

Table 1. Nutrient analysis[1] of two forages grazed by a May-calving herd during 2016 breeding season

	Meadow			Range		
	Jul.	Aug.	Sept.	Jul.	Aug.	Sept.
Heifers & Primiparous cows						
CP, % DM	9.0	7.3	7.8	6.1	4.8	5.4
IVOMD, %	68.3	57.2	56.2	68.5	61.3	55.7
TDN[2], %	59.8	50.1	48.3	59.8	53.4	49.3
Multiparous cows						
CP, % DM	10.6	7.3	10.2	6.2	5.2	4.1
IVOMD, %	70.2	60.6	51.4	68.1	58.6	51.4
TDN[2], %	60.1	51.4	41.7	59.1	52.0	45.3

[1]Samples collected from esophogeally fistulated cows (n = 3). Samples then analyzed for CP (FlashSmart N/Protein Analyzer CE, Elantech, Inc., Lakewood, NJ; AOAC, 1999; method 990.03). IVOMD analysis was conducted using a modified Tilley and Terry (1963) method with modifications described above.

[2]TDN = IVOMD × OM

Table 2. Effects of breeding season forage type[1] on heifer BW, BCS, and reproductive response

	Treatment			*P* – Value[2]		
	MDW	RN	SEM	TRT	T × M	M
BW, kg						
Prebreed	325	325	4	0.58	0.02	< 0.01
Pregnancy diagnosis	377[a]	350[b]	4			
Prepartum	406	394	6			
BW change, kg						
Treatment[3]	52	26	2	< 0.01		
Winter[4]	29	46	4	< 0.01		
BCS[5]						
Pregnancy diagnosis	5.98	5.93	0.04	0.37	0.71	< 0.01
Prepartum	5.30	5.29	0.06			
BCS Change						
Winter[3]	-0.70	-0.65	0.08	0.71		
Pubertal, %[6]	89	87	4	0.78		
Pregnancy rate, %	92	90	4	0.71		
Calving date, Julian d	131	132	2	0.85		
Calved in first 21 d, %[7]	86	80	8	0.54		
Dystocia[8], %[8]	32	17	9	0.21		
Calf birth BW[9], kg	29	29	1	0.59		

[a,b]Means within a row lacking a common superscript differ ($P \leq 0.05$).
[1]Heifers grazed either sub-irrigated meadow (MDW) or upland range (RN) beginning at start of the breeding season and continuing for approximately 91 d.
[2]TRT = effect due to breeding season treatment, T × M = interaction between breeding season treatment and month, M = month, where month was considered as the month since trial began.
[3]Considered the time from prebreed in July to pregnancy diagnosis in October.
[4]Considered the time from pregnancy diagnosis in October to prepartum in May.
[5]Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).
[6]Considered pubertal if blood serum progesterone concentration > 1 ng/ml.
[7]The first day 2 or more cows calved was considered the start of the calving season.
[8]At parturition a calving ease (CE) score was assigned (1 = no assistance to 4 = caesarian section; Burfening et al., 1978). A score of 2 or greater was considered as dystocia.
[9]Calf born to heifer following breeding season treatment. Analyzed using breeding season treatment that occurred prior to birth of calf.

Table 3. Effects of breeding season forage type[1] on primiparous cow BW, BCS, and reproductive response

	Treatment			*P* – Value[2]		
	MDW	RN	SEM	TRT	T × M	M
BW, kg						
Prebreed	411	407	8	0.38	0.03	< 0.01
Pregnancy diagnosis	434[a]	385[b]	8			
Prepartum	448	445	14			
BW change, kg						
Treatment[3]	23	-22	3	< 0.01		
Winter[4]	22	49	8	0.03		
BCS[5]						
Prebreed	5.38	5.32	0.08	0.10	0.04	0.74
Pregnancy diagnosis	5.56[a]	5.09[b]	0.08			
Prepartum	5.55	5.41	0.15			
BCS Change						
Treatment[3]	0.19	-0.23	0.08	< 0.01		
Winter[4]	-0.31	-0.27	0.17	0.74		
Pregnancy rate, %	91	84	6	0.43		
Calving date, Julian d	141	138	4	0.57		
Calved in first 21 d, %[6]	86	86	13	1.0		
Dystocia[7], %	0	0	0	1.0		
Calf BW, kg						
Prebreed (2 mo)	82	85	3	0.34	< 0.01	< 0.01
Wean	158[x]	148[y]	3			
Treatment ADG, kg/d	0.81	0.68	0.02	< 0.01		
Calf born BW[8], kg						
Birth	35	33	1	0.48		

[a,b]Means within a row lacking a common superscript differ ($P \leq 0.05$).

[x,y]Means within a row lacking a common superscript tend to differ ($P \leq 0.10$).

[1]Primiparous cows grazed either sub-irrigated meadow (MDW) or upland range (RN) beginning at start of the breeding season and continuing for approximately 91 d.

[2]TRT = effect due to breeding season treatment, T × M = interaction between breeding season treatment and month, M = month, where month was considered as the month since trial began.

[3]Considered the time from prebreed in July to pregnancy diagnosis in October.

[4]Considered the time from pregnancy diagnosis in October to prepartum in May.

[5]Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).

[6]The first day 2 or more cows calved was considered the start of the calving season.

[7]At parturition a calving ease (CE) score was assigned (1 = no assistance to 4 = caesarian section; Burfening et al., 1978). A score of 2 or greater was considered as dystocia.

[8]Calf born to primiparous cow following breeding season treatment. Analyzed using breeding season treatment that occurred prior to birth of calf.

Table 4. Effects of breeding season forage type[1] on multiparous cow BW, BCS, and reproductive response

	Treatment			*P* – Value[2]		
	MDW	RN	SEM	TRT	T × M	M
BW, kg						
Prebreed	513	511	6	0.19	< 0.01	< 0.01
Pregnancy diagnosis	499[a]	458[b]	6			
Prepartum	517	505	10			
BW change, kg						
Treatment[3]	-13	-54	5	< 0.01		
Winter[4]	24	48	6	< 0.01		
BCS[5]						
Prebreed	6.02	5.95	0.05	0.09	0.07	< 0.01
Pregnancy diagnosis	5.26[a]	5.00[b]	0.05			
Prepartum	5.52	5.48	0.08			
BCS Change						
Treatment[3]	-0.76	-1.01	0.07	< 0.01		
Winter[4]	0.32	0.56	0.12	0.15		
Pregnancy rate, %	91	95	3	0.39		
Calving date, Julian d	140	146	2	0.02		
Calved in first 21 d, %[6]	89	79	7	0.31		
Dystocia[7], %	3	0	3	0.98		
Calf BW, kg						
Prebreed (2 mo)	103	101	2	0.91	< 0.01	< 0.01
Wean	226[a]	214[b]	2			
Treatment ADG, kg/d	0.89	0.82	0.01	< 0.01		
Calf born BW[8], kg						
Birth	36	36	0.7	1.0		

[a,b]Means within a row lacking a common superscript differ ($P \leq 0.05$).

[1]Multiparous grazed either sub-irrigated meadow (MDW) or upland range (RN) beginning at start of the breeding season and continuing for approximately 137 d.

[2]TRT = effect due to breeding season treatment, T × M = interaction between breeding season treatment and month, M = month, where month was considered as the month since trial began.

[3]Considered the time from prebreed in July to pregnancy diagnosis in October.

[4]Considered the time from pregnancy diagnosis in October to prepartum in May.

[5]Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).

[6]The first day 2 or more cows calved was considered the start of the calving season.

[7]At parturition a calving ease (CE) score was assigned (1 = no assistance to 4 = caesarian section; Burfening et al., 1978). A score of 2 or greater was considered as dystocia.

[8]Calf born to multiparous cow following breeding season treatment. Analyzed using breeding season treatment that occurred prior to birth of calf.

CHAPTER V

EFFECTS OF MATERNAL LATE GESTATION NUTRITION ON DAM AND SUBSEQUENT PROGENY GROWTH AND PERFORMANCE

A.C. Lansford, J.A. Musgrave, B.T. Tibbitts, J.D. Harms, and R.N. Funston

University of Nebraska, West Central Research and Extension Center, North Platte 69101

ABSTRACT: Multiparous, May-calving cows (n = 652) were managed at Gudmundsen Sandhills Laboratory near Whitman, NE over 6 production cycles to examine the effects of late gestation nutrition on steer and heifer progeny growth and performance. Dams were arranged in a 2 × 2 factorial on approximately gestational d 160 and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 ± 2 d, and then 1 of 2 supplementation groups: no supplement (**NS**) 0.45 kg/d of 33% CP (DM) supplement (**S**) for 85 ± 2 d. Sub-irrigated meadow forage is cool-season species dominant, while upland range is warm-season dominant, which creates differences in forage growth. Over the treatment period, BW gain was greatest for MS cows, intermediate for MNS cows, followed by RS and then RNS cows (P = 0.02). Treatment period BCS gain was increased ($P < 0.01$) in S cows (0.00 vs. 0.17 ± 0.03, NS vs. S). Subsequent dam rebreed pregnancy rate tended ($P = 0.09$) to increase for M cows (89 vs. 85 ± 2%, M vs. R). Sex-specific differences in postnatal progeny BW through development were detected ($P \leq 0.05$). Post-development heifer progeny BW tended ($P = 0.08$) to be increased by meadow grazing, with increased ($P = 0.01$) percent mature BW at breeding (60 vs. 59 ± 0.4%, M vs. R). Although heifer pregnancy rate was not impacted ($P \geq 0.29$), rebreed pregnancy rate as a primiparous cow was increased ($P = 0.02$) by maternal meadow grazing (91 vs. 76 ± 5%, M vs. R). Heifer progeny's first calf BW was increased ($P = 0.04$) by dam supplementation. Risk of dystocia was also increased ($P = 0.04$) by dam supplementation (9 vs. 20 ± 5%, NS vs. S).

Throughout the feedlot period steer progeny ADFI tended ($P \leq 0.10$) to be increased by maternal meadow grazing for steers in 2 feedlot systems. There was a tendency ($P \leq 0.09$) for increased marbling score in both feedlot systems for maternal meadow grazing. This translated to a tendency ($P \leq 0.09$) for meadow grazing to increase % of steers grading USDA low Choice or greater in both systems. These data suggest differences in maternal late gestation diet composition due to differences in supplementation and forage specie type and growth, result in altered postnatal phenotypes of both female and male progeny. Furthermore, prepartum grazing of forages that differ in specie composition has the potential to increase dam rebreed pregnancy rate.

Keywords: beef cattle, carcass quality, developmental programming, prepartum nutrition, reproductive performance

INTRODUCTION

Two distinct forage types exist in the Nebraska Sandhills: sub-irrigated meadow and upland range. Sub-irrigated meadow is largely cool-season dominant, while upland range is warm-season dominant. Despite increasing dietary CP and TDN for March-calving cows in late gestation, requirements still exceeded diets, although, dam rebreed pregnancy rates were not impacted (Larson et al., 2009; Stalker et al., 2006). During the treatment period in these experiments (Dec. 1 – Feb. 28) forage is dormant and CP and IVDMD are relatively constant (Lardy et al., 1997). Conversely, the time that a May-calving herd is in late gestation occurs during the initial growth phase of grasses, which allows forage CP to meet or exceed dam requirements (Lardy et al., 1997; NRC, 2000).

Rapid growth of the fetus occurs in late gestation, and is particularly sensitive to differences in maternal nutrition. The effects of maternal over- or under-consumption of energy

on progeny development are well-documented (Du et al., 2010a; Du et al., 2010b; Wu et al., 2004b); however, data examining the effect of overconsumption of protein on progeny postnatal development is limited. Previous research on fetal impacts of increased maternal dietary protein has varied greatly and been largely inconclusive (Andreasyan et al., 2007; Rehfeldt et al., 2011; Stalker et al., 2007; Summers et al., 2015a). This is likely due to differences in level of protein fed, total dietary protein intake, and specie differences.

There is potential then, for differences in forage specie and consequent protein level to affect maternal productivity, as well as progeny postnatal growth and performance. The objective of this study was to evaluate the effect of forage type and supplementation level on dam and subsequent progeny growth, steer progeny carcass characteristics, and heifer progeny reproductive performance.

MATERIALS AND METHODS

The University of Nebraska Animal Care and Use Committee approved the procedures and facilities used in this experiment.

A study was performed to examine the effects of late gestation nutrition on dam performance, and subsequent progeny growth and performance. The trial was conducted over 6 production cycles at the Gudmundsen Sandhills Laboratory (**GSL**), Whitman, NE and the West Central Research and Extension Center (**WCREC**), North Platte, NE.

Dam Management

Multiparous, May-calving cows (n = 652; 421 ± 2 kg) were blocked by BW and arranged in a 2 × 2 factorial treatment design on approximately d 160 of gestation. Dams were assigned to graze either upland range (**R**) or sub-irrigated meadow (**M**), and then randomly assigned to receive either no supplement (**NS**) or 0.45 kg/d (**S**) of a dried distiller's grains with solubles

(DDGS) – based supplement (Table 1). Pasture treatment continued for approximately 116 ± 2 d (mean ± SD) while supplementation treatment continued for approximately 85 ± 2 d (mean ± SD). Upland range sites are largely predominated by warm-season grasses such as prairie sandreed (*Calamovilfa longifolia*), sand bluestem (*Andropogon hallii*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and *Bouteloua* spp. (Volesky et al., 2007). Sub-irrigated meadow is composed largely of cool-season species, including smooth brome (*Bromus inermis*), slender wheatgrass (*Elymus trachycaulus*), reed canary grass (*Phalaris arundinacea*), red-top bent (*Agrostis gigantea*), and sedges (*Carex* spp.; Volesky et al., 2004). Range sites were stocked at a rate of 0.6 AUM, whereas sub-irrigated meadow was stocked at a rate of 3 AUM. One AUM was considered the equivalent of a 454 kg cow. Supplement was delivered Monday, Wednesday, and Friday on a pasture basis (35.6 ha). Dam BW and body condition score (BCS; 1 = emaciated to 9 = obese; Wagner et al., 1988) were recorded at initiation of the trial and at conclusion of pasture treatment. After the conclusion of the treatment period, dams were managed as a single herd grazing upland range for the remainder of the year. At parturition, calf birth BW, sex, and birth date were recorded. Dams were assigned a calving ease (**CE**) score (1 = no assistance, 2 = easy assist, 3 = difficult assist, and 4 = caesarian section; Burfening et al., 1978) at parturition. Dystocia was considered as a CE score of 2 or greater. Percentage of dams calving in the first 21 d was calculated by considering the first day 2 or more dams calved to be the start of the calving season.

In late July each year, dams and calves were weighed and dams were assigned a BCS. Dams were then placed with fertile bulls at a ratio of 1:20 for a 45 d breeding season. Five d after bull placement, dams were synchronized with a single PGF2α injection (25 mg i.m., Lutalyse; Zoetis Animal Health, Parsippany, NJ). Dams were diagnosed for pregnancy in early January,

approximately 4 mo after bull removal via rectal palpation or transrectal ultrasonography (Aloka, Hitachi Aloka Medical America Inc., Wallingford, CT). Dams remained in their gestational treatment group for the duration of the study unless removed for reproductive failure, calf death, or injury.

Progeny Management through Development

In July, at approximately 2 mo. of age, all calves were vaccinated against infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine respiratory syncytial virus and bovine viral diarrhea type I and II (BoviShield 5; Zoetis Animal Health). Calves were also weighed, branded, and bulls castrated. At weaning in early January, calves were weighed, given an injection of BoviShield 5 (Zoetis Animal Health). Calves were also vaccinated against bovine rotavirus-coronavirus, clostridium perfringens type C and D, and *E. Coli* bacteria-toxoid (Guardian; Intervet, Millsboro, DE); and a topical insecticide applied (Ivermectin; Aspen Veterinary, Liberty, MO).

Steer and heifer progeny were weaned at an average date of January 5. A 205-d adjusted weaning weight was calculated according to the Beef Improvement Federation (BIF, 2016). Calves were then blocked by BW and assigned to 1 of 2 backgrounding treatments for 123 d. Calves were either offered meadow hay ad libitum and 1.81 kg/d of a 33% CP supplement (DM, Table 1) or allowed to graze sub-irrigated meadow with 0.45 kg/d of the same supplement.

Post-yearling Heifer Management

After backgrounding, heifers were managed as a single herd until breeding in mid-July (Springman et al., 2017). Prior to the breeding season, blood samples (5 mL) were collected from heifers on d -10 and 0 of the breeding season via coccygeal venipuncture to determine plasma progesterone concentrations. Plasma progesterone concentrations were determined using a direct

solid phase RIA (Coat-A-Count; Diagnostics Products Corp., Los Angeles, CA). Heifers were considered pubertal if plasma progesterone concentrations were ≥ 1.0 ng/mL at one or both time points. Heifer BW was recorded at blood collection and 14 mo. prebreed BW was considered the average of these 2 time points. Heifers were placed with fertile bulls at a ratio of 1:20 (bull: heifer ratio) for a 45 d breeding season and allotted to yearly breeding season treatments. Heifers were synchronized using a single PGF2α (25 mg i.m., Lutalyse) 5 d after bull placement.

Pregnancy was diagnosed in mid-October via transrectal ultrasonography (Aloka) and breeding season treatment concluded. Heifer BW and BCS were recorded at pregnancy diagnosis. Two weeks prior to calving, heifer BW and BCS was recorded. At parturition, calf birth BW, sex, and birth date were recorded. Additionally, a CE score was assigned to heifers, with a score ≥ 2 considered dystocia.

At the start of the subsequent breeding season, BW was recorded on heifers and their calves, and heifers were assigned a BCS. Calves were vaccinated against infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine respiratory syncytial virus and bovine viral diarrhea type I and II (BoviShield 5). Calves were also weighed, branded, and bulls castrated. Breeding season management was similar to that described above. Pregnancy was diagnosed in November via transrectal ultrasonography (Aloka), and heifer BW and BCS recorded. Calf BW was recorded, and calves were weaned from heifers at pregnancy diagnosis. Heifers were removed from the study for reproductive failure, calf death, or injury.

Post-yearling Steer Management

At conclusion of the backgrounding treatment in May, one-half of the steers from each treatment were transported (162 km) to the WCREC feedlot (**S-YRL**) and implanted with 100 mg trenbolone acetate and 14 mg estradiol benzoate (Synovex Choice; Ft. Dodge Animal Health,

Overland, KS). The steers remaining at GSL (**L-YRL**) were implanted with 40 mg trenbolone acetate and 8 mg estradiol benzoate (Revalor G; Merck Animal Health, Summit, NJ) and grazed upland range. Approximately Sept. 14, L-YRL steers were transported to WCREC to enter the feedlot and were implanted with 36 mg zeranol (Ralgro; Merck Animal Health). Electronic identification tags were applied in both groups of steers at feedlot entry.

Upon feedlot entry, both groups of steers were limit fed 5 d at 2.0% of BW, and weighed 3 consecutive d. Feedlot entry BW was considered the average of these three time points. Steers were transitioned over 21 d to a common diet containing 39% dry rolled corn, 52% wet corn gluten feed, 6% prairie hay, and 3% supplement (DM). The supplement contained a mix of trace minerals, Rumensin (Elanco Animal Health, Greenfield, IN), and Tylan 40 (Elanco Animal Health). Approximately 110 d after feedlot entry for S-YRL steers and 70 d for L-YRL steers, steers were weighed and re-implanted with 200 mg trenbolone acetate and 28 mg estradiol benzoate (Synovex Plus; Ft. Dodge Animal Health). Reimplant BW was shrunk 4% for analyses. Hot carcass weight was recorded at slaughter and carcass data was collected following a 24-h carcass chill. Final BW was calculated by adjusting HCW to a common dressing percentage of 63.0%. Empty body fat (EBF) was calculated using the prediction equation proposed by Guiroy et al. (2001) where: EBF = 17.76107 + (11.8908 × 12^{th} rib fat depth) + (0.0088 × HCW+ [0.81855 × ((marbling score/100) + 1)] – (0.4356 × LM area).

GrowSafe Feeding System

Steers were placed in a GrowSafe feeding system (GrowSafe Systems Ltd., Airdrie, AB, Canada) upon feedlot entry. No intake data was recorded over the initial 2-wk adaptation period to the system or on the day of shipping. Steers remained in the GrowSafe feeding system for 190 or 142 d for S-YRL or L-YRL steers, respectively. Recorded intakes from the GrowSafe system

were used to calculate ADFI, G:F, and residual feed intake (**RFI**). Residual feed intake was considered as the actual ADFI minus predicted ADFI. Predicted ADFI was calculated using the following equation: Group avg. ADFI + [b_m × (Indiv. midBW$^{0.75}$ – Group avg. midBW$^{0.75}$)] + [b_g × (Indiv. ADG – Group avg. ADG)] where midBW$^{0.75}$ = mid-test metabolic BW and was predicted using the equation: Feedlot entry BW + [ADG × (Total no. of days in feedlot ÷ 2)]. Any daily DMI values above or below 4 standard deviations from the group mean for system within yr were considered outliers and excluded from the data. The first year of calculated RFI values was removed from the data set due to low R^2 values when ADFI was regressed to midBW$^{0.75}$ and ADG for both feedlot systems (0.36 and 0.12, S-YRL and L-YRL, respectively). For yr 2 to 5, R^2 values for the S-YRL system were 0.56, 0.64, 0.73, and 0.46, respectively, and for the L-YRL system were 0.66, 0.74, 0.69, and 0.81, respectively.

Statistical Analysis

All data were analyzed using the PROC GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC, version 9.4) with denominator degrees of freedom determined using the Kenward-Roger approximation. The experimental unit for dams was treatment × yr, for steer progeny BW and carcass characteristics was feedlot system × treatment × yr, and for heifer progeny and their calves was treatment × yr, where treatment was considered as dam's pasture × supplement assignment. All models included the fixed effects of dam's pasture and supplement assignment, and resulting interactions. Year was included as a covariate in all analyses. In all pre- and postpartum dam measurements, progeny gender and dam age were included as covariates. For heifer progeny data, development treatment, breeding season treatments, and calf sex were considered covariates. Analysis of steer progeny data included backgrounding treatment and feedlot system as covariates. Covariates were removed from the model when $P \geq 0.05$.

Percentage of bull calves was analyzed at parturition for both dam and heifer progeny, and was not found to be different by dam treatment ($P \geq 0.14$). Feedlot system significantly impacted steer BW ($P < 0.01$), so feedlot BW analyses were run separately for each system.

When analyzing steer feedlot ADG, the experimental unit for analyses was considered as period × treatment × feedlot system × yr where initial period was feedlot entry to reimplant, reimplant period was reimplant to slaughter, and total feedlot period was feedlot entry to slaughter. Conversely, the experimental unit for steer feedlot ADFI, G:F, and RFI values was considered as treatment × feedlot system × yr. Coefficients necessary for RFI calculation were obtained using the PROC GLM procedure (SAS). The model statement included ADG, $midBW^{0.75}$, year, and EBF. The slope coefficient, b_m, was considered as the residual estimate for $midBW^{0.75}$, and for b_g was considered the residual estimate for total feedlot ADG when total feedlot ADFI was regressed against those variables.

All BW and BCS measurements on dam and progeny were analyzed using repeated measures. The model included the fixed effects of dam pasture, dam supplement and the resulting interaction. Month was the repeated variable and was considered the month since initiation of the study for dam performance analysis, whereas month since birth was used for progeny performance analysis. Covariates included calf gender, dam age, and treatment year. Covariates were removed from the model when $P \geq 0.05$. Heterogeneous compound symmetry covariance structure was used for dam BW and BCS, and all heifer and steer progeny BW. Ante-dependent covariance structure was used for heifer progeny BCS. These covariance structures were chosen because they generated the lowest Akaike's and Bayesian information criterion values.

Tests for normality of data and homogenous variance were applied to all variables of interest using the PROC GLM procedure of SAS using Levene's test. The Tukey-Kramer adjustment was used for all comparisons of LS means. Data were considered significant at $P \leq 0.05$ and a tendency if $P \leq 0.10$ and $P > 0.05$. Data are presented as mean ± SEM, unless otherwise denoted.

RESULTS

Dam Performance

Dam results are presented in Table 3. Initial dam BW was similar ($P \geq 0.82$; 421 ± 2 kg) prior to gestational treatment. Over the duration of the study, dam BW tended ($P = 0.08$) to be greater for M dams. Additionally, supplemented dams had increased ($P = 0.05$) BW over the study; however, there was also a tendency ($P = 0.07$) for a supplementation × month interaction, which is apparent at prepartum BW. Dam prepartum BW was least for RNS dams (446 ± 4 kg), while no difference ($P \leq 0.10$) was detected between remaining treatments. There was a pasture × supplement interaction ($P = 0.02$) for dam BW change over the treatment period. Dams allotted to the MS treatment had the greatest BW gain, MNS dams were intermediate, followed by RS dams, and RNS dams.

At subsequent time points throughout the study, dam BW was not impacted by gestational treatment; however, differences in BW change still existed. From precalve to prebreed, there was a tendency for a pasture × supplement interaction ($P = 0.07$) in BW change. Dams allotted to the RNS had the greatest change in BW during the period of early lactation, followed by RS dams, while MNS dams were intermediate, and MS dams gained the least. All

treatments lost BW from prebreed in July to wean in January the following year; however, previously supplemented groups had a greater ($P < 0.01$) loss (-48 vs. -57 ± 2 kg).

There was no difference ($P = 0.92$) in dam BCS over time, and is likely due to increased variation between treatments over time ($\sigma^2 = 0.5$). Dam BCS was similar ($P \geq 0.41$) between treatments at all time points despite differences in dam BW; however, supplemented dams gained ($P < 0.01$) BCS over the treatment period while NS dams maintained condition (0.0 vs. 0.17 ± 0.03, NS vs. S). From precalve to prebreeding, dam BCS change was not impacted ($P \geq 0.29$) by gestational treatment. From initiation of the breeding season until pregnancy diagnosis in January, S dams lost more condition ($P < 0.01$) than NS dams (-0.98 vs. -1.12 ± 0.03, NS vs. S) although supplementation had no impact ($P = 0.50$) on rebreed pregnancy rates. Conversely, prepartum meadow grazing had a tendency ($P = 0.09$) to increase pregnancy rates (89 vs. 85 ± 2%, M vs. R) in the subsequent breeding season. A multiple regression analysis of pregnancy rate against treatment and early lactation BW and BCS change, respectively, was ran with no discernible relationship ($R^2 = 0.04$).

At parturition, dystocia rate was not impacted ($P \geq 0.14$) by treatment. Percentage of dams calving in the first 21 d of the calving season was also not impacted ($P \geq 0.12$) by prepartum treatment. There was a tendency ($P = 0.07$) for differences in calving date, although differences were not apparent after using a Tukey-Kramer adjustment.

Calf Performance through Development

Calf BW through development is presented in Table 4 and is separated by calf sex due to differences in response to dam treatment. From birth to completion of development, steer progeny BW was not impacted by dam's pasture or supplement assignment ($P \geq 0.19$).

Furthermore, 205-d adjusted weaning BW was similar ($P \geq 0.39$) for steers in each of the treatments. Conversely, there was a pasture × month interaction ($P = 0.01$) for heifer BW. Heifer 205-d adjusted weaning BW was increased ($P < 0.01$) by meadow grazing (194 vs. 189 ± 2 kg, M vs. R) and by supplementation (188 vs. 194 ± 2 kg, NS vs S).

Post-Development Heifer Performance

Post-development heifer progeny BW, BCS, and reproductive performance are presented in Table 5. After development, a tendency ($P = 0.10$) for a pasture × supplement × month interaction was detected for heifer BW. Similarly, a pasture × supplement × month interaction ($P = 0.02$) existed for heifer BCS. Although there were no differences ($P \geq 0.10$) in BW at prebreed, heifer BW as expressed as a percentage of mature BW was increased ($P = 0.01$) by meadow grazing (60 vs. 59 ± 0.4%; M vs. R) and tended to increase ($P = 0.06$) with dam supplementation (59 vs. 60 ± 0.4%; NS vs. S). Furthermore, a tendency ($P = 0.10$) for a pasture × supplement interaction was detected for percentage of heifers who attained puberty by of the breeding season, although differences were not apparent using a Tukey-Kramer adjustment for LS means.

At pregnancy diagnosis, there were no differences ($P \geq 0.10$) in heifer BW or BCS. Heifer pregnancy rate was also not different ($P \geq 0.29$) between gestational treatments. Before calving, MNS heifers had the lowest ($P \leq 0.05$) BW, but greatest BCS ($P \leq 0.05$). Following the same trend, RS heifers had the greatest ($P \leq 0.05$) precalve BW, but lowest BCS ($P \leq 0.05$). Heifers in the MS and RNS groups were intermediate for both variables. At parturition, a similar ($P \geq 0.33$) percentage of heifers calved in the first 21 d of the calving season between treatments. Rate of dystocia was increased ($P = 0.04$) by supplementation (9 vs. 20 ± 5%, NS vs. S), while pasture assignment had no effect ($P = 0.51$).

At beginning of the following breeding season as a primiparous cow, BW was not different ($P \geq 0.10$) between treatments; however, BCS was greatest ($P \leq 0.05$) for MS, intermediate for MNS and RNS, and least for RS primiparous cows. Postpartum interval was decreased ($P = 0.03$) by meadow grazing (89 vs. 95 ± 2 d, M vs. R), while supplementation had no effect ($P = 0.99$). Additionally, percentage of primiparous cows diagnosed pregnant was increased ($P = 0.02$) by meadow grazing (91 vs. 76 ± 5%, M vs. R). Dam supplementation did not affect ($P = 0.34$) primiparous cow pregnancy rates.

First calf BW is also presented in Table 4. Supplementation of the grand-dam during late gestation tended to increase ($P = 0.06$) calf BW from birth through weaning. Despite this, 205 d adjusted wean BW was not affected ($P \geq 0.30$) by grand-dam treatment.

S-YRL Steer Feedlot Performance and Carcass Characteristics

Feedlot phase BW, ADG, performance, and carcass characteristics for S-YRL steers is presented in Table 6. Steer BW in the feedlot was not affected ($P \geq 0.42$) by dam treatment.

Initial ADG was not affected ($P \geq 0.24$) by dam treatment; however, reimplant ADG had a tendency ($P = 0.06$) to be increased by meadow grazing (1.63 vs. 1.41 ± 0.08 kg/d, M vs. R). There were no differences ($P = 0.22$) in reimplant ADG between dam supplementation treatments. Total ADG over the feedlot period was not affected ($P \geq 0.13$) by dam treatment. Feedlot ADFI tended ($P = 0.10$) to increase with meadow grazing (11.95 vs. 11.61 ± 0.15 kg/d, M vs. R), but no differences were detected ($P = 0.41$) between dam supplementation. Based on no differences in total ADG or ADFI, there were no differences ($P \geq 0.44$) in G:F ratios. Furthermore, there were no differences in unadjusted or EBF adjusted RFI values ($P \geq 0.15$).

No differences were detected in HCW at slaughter ($P \geq 0.26$), due to lack of difference ($P \geq 0.10$) in final BW. Percentage EBF was increased ($P = 0.04$) by meadow grazing (34.6 vs. 33.6 ± 0.3%, M vs. R). This corresponded with increased ($P = 0.04$) marbling scores in steers whose dams grazed meadow (464 vs. 436 ± 10, M vs. R). Furthermore, percentage of steers grading USDA low Choice or greater tended ($P = 0.06$) to increase for meadow grazing (85 vs. 69 ± 8%, M vs. R). There were no differences ($P \geq 0.29$) in percentage of steers grading USDA average Choice or greater. No differences ($P \geq 0.11$) in 12th rib fat based on dam treatments were detected. There was a tendency ($P = 0.08$) for a pasture × supplement interaction on LM area, although differences were not apparent using a Tukey-Kramer adjustment for LS means. Despite this tendency, there were no differences ($P \geq 0.14$) in yield grade.

L-YRL Steer Feedlot Performance and Carcass Characteristics

Feedlot phase BW, ADG, performance, and carcass characteristics for L-YRL steers is presented in Table 7. Feedlot BW was not affected ($P \geq 0.24$) by dam treatments. Similar to S-YRL steers, initial feedlot ADG was similar ($P \geq 0.11$) between dam treatments. There was a pasture × supplement interaction ($P = 0.10$) for reimplant ADG, but no difference ($P \geq 0.26$) in total feedlot ADG. Feedlot ADFI was increased ($P = 0.01$) by meadow grazing (13.35 vs. 12.70 ± 0.19 kg/d, M vs. R). There were no differences ($P = 0.79$) in feedlot ADFI to dam supplementation. Conversely, there were no differences ($P \geq 0.19$) in G:F ratios between dam treatments, despite differences in feedlot ADFI. Furthermore, no differences ($P \geq 0.12$) were detected in unadjusted or EBF-adjusted RFI values.

There was a tendency ($P = 0.10$) for meadow grazing to increase HCW (433 vs. 422 ± 5 kg, M vs. R). Unlike S-YRL steers, there were no differences ($P \geq 0.57$) in EBF detected.

Marbling score had a tendency ($P = 0.09$) to be decreased by dam supplementation (506 vs. 480 ± 11, M vs. R), but no difference ($P = 0.39$) due to dam pasture assignment. Despite no difference in marbling scores based on pasture assignment, meadow grazing tended ($P = 0.09$) to increase percentage of steers grading USDA low Choice or greater (82 vs. 72 ± 4%, M vs. R). There was no difference ($P \geq 0.16$) in percentage of steers grading USDA average Choice or greater. Neither 12th rib fat thickness nor LM area were different ($P \geq 0.18$) between treatments. Yield grade was similar ($P \geq 0.56$) between treatments.

DISCUSSION

The primary factor limiting production in forage-based systems is energy, followed by protein. Furthermore, differences in intake account for 60 to 90% of the differences in nutritive value of a forage (Crampton et al., 1960). Protein supplementation to cows grazing low-quality forage increased DMI and improved forage utilization in both warm and cool season grasses (Bohnert et al., 2011). Similarly, Summers et al. (2015b) reported increased total DMI for prepartum protein-supplemented dams, which correlated with an increased rate of gain over the treatment period.

For cows grazing forage, acetate is the principal VFA produced, thus a high acetate to propionate ratio is often experienced (Bell and Bauman, 1997), which may limit dam gluconeogenesis. If maternal glucose requirements are not being met, the dam may compete with the fetus for nutrients (Wu et al., 2004a). Although inclusion of dried distillers grains increased DMI in heifers, Walter et al. (2012) demonstrated decreased rumen fluid propionate abundance, which may limit maternal hepatic glucose production. Although energy does not appear to be limited in this study, an imbalanced acetate to propionate ratio could have implications for fetal glucose availability.

Microbial yields are directly related to carbohydrate availability within the rumen (Nocek and Russell, 1988). Although NEm was limited in meadow forages in February, increased forage CP may have been utilized as an energy source for MNS and MS dams to maintain BCS (Table 1). When protein degradation in the rumen is extensive, or RUP is used as an energy source, concentrations of ammonia and urea increase in the cow (Tamminga, 2006). Similarly, steers offered a high-protein, low-energy diet had increased ruminal ammonia N (DelCurto et al., 1990). While circulating ammonia negatively impacts fertility through limiting embryonic development (Sinclair et al., 2000), increased urea concentrations result in decreased uterine pH, which may impact fetal development (Butler, 1998). Increased ruminal ammonia concentrations due to increased urea inclusion in the diet appears to negatively impact microbial production (Boucher et al., 2007). Limited microbial production results in decreased VFA production, which may further contribute to the nutritional imbalance. Several dietary factors and their interactions within this study which may have implications on dam and progeny performance.

Dam Performance

Change in BCS over the prepartum period is a better predictor of pregnancy success than BW change over the same period (Selk et al., 1988). Supplemented dams in this study gained more BCS over the treatment period, and had a greater BW before calving. Inclusion of monensin in the diet has been reported to increase ruminal propionate concentration, decrease ruminal acetate concentration, increase forage DMI, and decrease ruminal passage rate (reviewed in Schelling, 1984). All of these factors may have increased forage utilization, improved bacterial production and efficiency, altered maternal metabolism, and ultimately, improved fetal nutritional state. In agreement, previous research has indicated prepartum dam BW and BCS were increased in prepartum-supplemented primiparous and multiparous cows (Rolfe et al.,

2012; Stalker et al., 2007; Summers et al., 2015b). There were no differences in dystocia rates, similar to Summers et al. (2015b) and Corah et al. (1975).

Spring-calving dams fed to lose condition overwinter and then either gain or maintain BCS for the last 1 to 2 mo of gestation had similar pregnancy rates in the subsequent breeding season (Selk et al., 1988). Although supplemented dams gained BCS in the prepartum period, NS dams maintained condition. Consequently, no difference in pregnancy rate was detected due to prepartum supplementation. Alternately, dams grazing meadow in this study tended to have increased pregnancy rates for the subsequent breeding season. Change in BCS was similar throughout all time points for range and meadow treatments. In fact, dams grazing meadow in the prepartum period had decreased BW gain prior to the breeding season. As such, pregnancy rate in this study does not appear to be a function of BW, BCS, or change in those variables. Recent research examining the adaptive function of ruminant metabolism to prepartum nutritional imbalance has described differences in postpartum lipid and amino acid catabolism and synthesis. Cows receiving a high energy diet prepartum had increased activation of pathways and signaling involved in triglyceride synthesis (Shahzad et al., 2014). It is possible then, dams grazing meadow had an altered metabolic response to protein, and may have been primed for better nutrient utilization in the following breeding season.

Fetal Nutrition

Glucose is the primary energy substrate for the growing fetus (Boden, 1996), and previous research has indicated decreased maternal blood glucose in late gestation leads to decreased fetal birth BW (Scholl et al., 2001). Amino acids are used by the fetus for tissue synthesis and growth, but may also be used as a source of energy when maternal glucose availability is limited (Aldoretta and Hay, 1995; Dalinghaus et al., 1991; Lemons, 1979).

Supplemented dams grazing dormant range during late gestation had increased calf birth BW compared with dams receiving no supplement, which may have been a function of increased carbohydrate or protein availability, or their interaction with ruminal microbe populations (Stalker et al., 2007). Absorption and apparent digestion of several essential and nonessential AA, including lysine, methionine, arginine, and glutamic acid were linearly increased by increasing dietary CP (Mariz et al., 2018). The placenta uptakes glutamic acid and other branched chain AA and metabolizes them to glutamine before transfer to the fetus (Malek et al., 1993; McNanley and Woods, 2008). Supplementation of glutamine to gestating sows reversed the effects of fetal growth retardation and decreased preweaning mortality (Wu et al., 2015). Furthermore, arginine is a precursor to nitric oxide and polyamines, both of which have been identified as regulators of placental and fetal growth (Bird et al., 2003; Flynn et al., 2002). Imbalanced maternal protein consumption, through both restriction and overfeeding, negatively impacts fetal myogenesis and postnatal growth (Rehfeldt et al., 2011; Zhu et al., 2004).

Calf Performance through Development

There were sex-specific differences in progeny BW from birth through development. While steer progeny BW was not impacted by dam treatment, there was a pasture × month interaction for heifer progeny, although differences are not apparent using a Tukey-Kramer adjustment. Dam supplementation had no effect on BW of either sex during this period; in contrast to research by Funston et al. (2009) who showed differences in progeny weaning BW and Stalker et al. (2007) who showed differences in birth and weaning BW for supplemented dams. Corah et al. (1975) demonstrated increased milk production and calf weaning BW for dams provided a greater level of DE for 30 d prior to parturition. Nonetheless, when considered as an independent measurement, heifer 205-d adjusted wean BW was increased by both dam

supplementation and meadow grazing. In agreement with BW in this period, there were no differences in steer 205-d adjusted wean BW. It is not uncommon for sex-specific differences to occur in response to fetal programming effects (Dahlgren et al., 2001; McMullen and Langley-Evans, 2005; Tobi et al., 2009; Zambrano et al., 2006), and suggests an interaction between postnatal sex-steroid production and developmental programming.

Post-development Heifer Performance

Both heifer progeny BW and BCS were complex due to a pasture × supplement × month interaction. There are no clear trends, and as such may be a result of altered fetal metabolic imprinting to differentially favor either postnatal muscle or adipose tissue cell growth and proliferation (Wu et al., 2004b). Rehfeldt et al. (2012) was able to discern differences in semitendinosus muscle fiber type between adequate and excess protein diets, demonstrating there was an increased percentage of slow-twitch oxidative fibers in offspring born to dams fed excess protein.

There were differences in percentage of heifers attaining puberty by start of their first breeding season. There does not appear to be a correlation between percentage of mature BW reached by start of their first breeding season and pubertal attainment ($r^2 = 0.04$). While the reason for these differences is unclear, previous work has determined postnatal leptin concentrations may be impacted by developmental programming (Breier et al., 2001). Providing ewes in late gestation with 150% of energy requirements increased leptin mRNA expression in progeny in perineal and subcutaneous adipose tissue (Muhlhausler et al., 2007). Leptin is believed to contribute to pubertal attainment (Clayton and Trueman, 2000). When heifer BW at the start of the breeding season was expressed as a percentage of mature BW, differences in dam's pasture assignment and supplementation assignment were apparent. Heifers whose dams

grazed meadow or were supplemented had increased percent mature BW at breeding, which may be a function of altered muscle or adipose tissue cell size and abundance (Rehfeldt et al., 2012; Zhu et al., 2008). Furthermore, the insulin signaling cascade is altered in response to maternal over-nutrition. Ewes fed 150% NRC requirements throughout gestation exhibit an inflammatory response, which demonstrate increased circulating insulin in fetal plasma, despite decreased activation of factors in the insulin signaling pathway (Yan et al., 2010).

Although there were no differences in heifer pregnancy rate, dams grazing meadow in late gestation had heifer progeny with increased pregnancy rates as a primiparous cows. The impacts of fetal programming on progeny reproductive health are numerous and poorly understood (reviewed in Sloboda et al., 2010; Zambrano et al., 2014).

Collectively, heifers whose dams grazed meadow in late gestation attained puberty at an earlier age, had a decreased postpartum interval, and increased rebreed pregnancy rates as primiparous cows. Throughout all of these physiological processes, regulation of the hypothalamic-pituitary-gonadal axis is key. Leptin is a key mediator in all these processes, as well as in conceptus implantation (Clayton and Trueman, 2000; Sagawa et al., 2002).

The first calf born to heifer progeny tended to have increased BW through weaning based on grand-dam supplementation. This may have been a contributing factor in the increased rate of dystocia observed for S heifers. Transgenerational effects of fetal programming are poorly understood, and are a result of 1) inheritance of epigenetic markers modulating gene expression, 2) transmission of ooplasm components, or 3) altered uterine environment of the F1 generation due to developmental programming (reviewed in Aiken and Ozanne, 2013).

Steer Feedlot Performance and Carcass Characteristics

Steer progeny BW in the feedlot phase of this study was not impacted by maternal treatment in either feedlot system, similar to steer BW prior to this phase. In contrast, Funston et al. (2009) showed an increase in feedlot entry BW for steers born to dams grazing corn residue vs. winter range and for dams receiving supplementation. Rehfeldt et al. (2012) showed no difference in final BW for pigs at market age, despite increased maternal protein intake during late gestation. Summers et al. (2015a) reported a tendency for increased steer and heifer initial feedlot ADG, but not for ADG following reimplantation in progeny born to primiparous dams supplemented with a DDGS-based supplement during late gestation. Conversely, rate of gain following implantation in this study was differentially impacted based on feedlot system. Steers in the S-YRL system tended to have increased reimplant ADG if dams grazed meadow. Alternately, an interaction was observed for L-YRL steers. Differences in implant strategy may have favored either muscle or adipose tissue synthesis within each system, causing different interactions with gestational treatment (Johnson et al., 1996). Maternal nutrition differences alter fetal signaling pathways in myogenesis and adipogensis (Du et al., 2010a). In ewes fed 150% NRC requirements, fetal myogenesis is downregulated, while adipogenesis is upregulated (Zhu et al., 2008). It is possible differences in body tissue composition and signaling resulted in differences in ADG. Furthermore, plasma concentrations of inflammatory factor tumor necrosis factor α (TNFα) were increased by maternal overnutrition (Zhu et al., 2008). Inflammatory cytokines, such as TNFα, are associated with impaired insulin signaling and glucose uptake in muscle and adipose tissue (Lorenzo et al., 2008).

Total ADFI over the feeding period tended to be increased by meadow grazing for S-YRL steers, while ADFI was increased for L-YRL steers. This may be a result of altered circulating leptin concentrations due to fetal programming, as previously alluded to (Breier et al.,

2001). Zambrano et al. (2006) observed decreased circulating leptin in adult male rats if dams were placed on a protein-restricted diet throughout gestation. Conversely, Summers et al. (2015a) reported decreased feedlot DMI for progeny born to protein supplemented dams, while Stalker et al. (2006) showed no differences despite dam's late gestation nutrition level. It is possible steer feedlot ADFI is a function of level of dietary protein offered to dams. Diets in the latter studies did not contain the level of protein observed in this study. Despite increased total ADFI, no differences were detected in either feedlot system for G:F ratios or in RFI values. This is likely a function of numerically increased total ADG values.

Underwood et al. (2010) reported greater HCW in steers born to dams grazing improved pasture vs. native range. Steers in the S-YRL system showed no difference in HCW, while L-YRL steers tended to have increased HCW if dams grazed meadow. Treatment in the Underwood et al. (2010) study began earlier than the current study, during the period of fetal secondary myogenesis and initial stages of adipogenesis (Du et al., 2010a).

Timing of nutritional insult plays a role in fetal outcome, particularly of adipose tissue. In their review, Symonds et al. (2004), indicate nutrient restriction beginning in late gestation alone appears to limit fetal adipogenesis, while restriction during early- to mid-gestation, during maximal placental growth, increases adiposity at term. In the present study, S-YRL steer EBF and marbling score at slaughter were increased by meadow grazing, while dam supplementation tended to decrease marbling scores. This is surprising and may indicate differences in fetal adipose tissue accretion between maternal overconsumption of protein vs. nutrient restriction in late gestation. There were no differences in EBF or marbling score for L-YRL steers, and may be a result of altered implant strategies. Steers in the L-YRL system were administered a Ralgro implant at feedlot entry, while S-YRL steers received Synovex-Choice. The mode of action of

androgens and estrogens within an anabolic implant are likely different. Androgens, such as trenbolone acetate, may act directly on muscle cells, while synthetic estrogens, like zeranol, may act indirectly to promote growth through regulating growth hormone and insulin concentrations (Heitzman, 1979). The varying effects of maternal environment in programming progeny insulin resistance later in life are well-documented (Godfrey and Barker, 2000; Hattersley and Tooke, 1999; Zambrano et al., 2006) and the correlation between insulin resistance and increased lipid accumulation in the muscle and liver is apparent (Greenfield and Campbell, 2004; Shwartz and Kahn, 1999). Although steers in both systems received the same terminal implant (Synovex Plus), differences in exogenous anabolic steroid mechanisms of actions early in the feeding period may have been sufficient to cause carcass differences. As a result of increased marbling scores in S-YRL steers, there was a tendency for meadow grazing to increase the percentage of carcasses grading USDA low Choice or greater. Similarly, L-YRL steers also experienced a tendency for the same effect. No differences were found in either system for percentage of steers grading USDA average Choice or greater.

Steers in the S-YRL system experienced a tendency for a pasture × supplement interaction in LM area, while L-YRL steers showed no effect. Again, this may have been a result of different implant strategies, with steers in the S-YRL system receiving synthetic testosterone + estrogen implants at feedlot entry, while L-YRL steers received a synthetic estrogen implant. Yield grade was not impacted in either system by dam treatment. Long et al. (2012) reported an increase in progeny yield grade for early- to mid-gestation NEm restricted dams who also received a RUP supplement, despite no differences in HCW, percent kidney, pelvic, and heart fat, 12^{th} rib fat thickness, or LM area.

IMPLICATIONS

From this data, it is clear there are differences in progeny response exist based dam nutrition during late gestation. Although the level of dietary CP found in this study is unlikely in confined operations fed a constant ration, forage-based operations have little control over plant growth. Calving dates are often selected by defaultto match forage resources to the demands of early lactation, as is the case with May-calving herds in the Nebraska Sandhills. Never before have the fetal effects of this system been examined. Hyperammonemia increases sensitivity to lipopolysaccharide (Marini and Broussard, 2006). Several signaling pathways involved in myogenesis and adipogenesis are altered by maternal inflammation and result in altered postnatal body composition (Du et al., 2010a). It is likely excessive dietary CP contributed to increased circulating ammonia and urea, which may have been a source of inflammation. Feeding excess CP in early gestation has been shown to negatively impact embryonic development (Butler, 1998; Ferguson and Chalupa, 1989).

LITERATURE CITED

Aiken, C. E., and S. E. Ozanne. 2013. Transgenerational developmental programming. Human reproduction update 20: 63-75.

Aldoretta, P. W., and W. W. Hay. 1995. Metabolic substrates for fetal energy metabolism and growth. Clin. Perinatol. 22: 15-36.

Andreasyan, K., A. L. Ponsonby, T. Dwyer, R. Morley, M. Riley, K. Dear, and J. Cochrane. 2007. Higher maternal dietary protein intake in late pregnancy is associated with a lower infant ponderal index at birth. Euro J Clin Nutr 61: 498-508. doi:10.1038/sj.ejcn.1602552.

Bell, A. W., and D. E. Bauman. 1997. Adaptations of glucose metabolism during pregnancy and lactation. J. Mammary Gland Biol. Neoplasia 2: 265-278.

BIF. 2016. Guidelines For Uniform Beef Improvement Programs. 9th ed. Beef Improvement Federation, NMREC Prairie Research Unit, Prairie, MS.

Bird, I. M., L. Zhang, and R. R. Magness. 2003. Possible mechanisms underlying pregnancy-induced changes in uterine artery endothelial function. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 284: R245-R258.

Boden, G. 1996. Fuel metabolism in pregnancy and in gestational diabetes mellitus. Obstet. Gynecol. Clin. North Am. 23: 1-10.

Bohnert, D., T. DelCurto, A. Clark, M. Merrill, S. Falck, and D. Harmon. 2011. Protein supplementation of ruminants consuming low-quality cool-or warm-season forage: Differences in intake and digestibility. Journal of animal science 89: 3707-3717.

Boucher, S., R. Ordway, N. L. Whitehouse, F. Lundy, P. J. Kononoff, and C. G. Schwab. 2007. Effect of Incremental Urea Supplementation of a Conventional Corn Silage-Based Diet

on Ruminal Ammonia Concentration and Synthesis of Microbial Protein1. Journal of dairy science 90: 5619-5633.

Breier, B., M. Vickers, B. Ikenasio, K. Chan, and W. Wong. 2001. Fetal programming of appetite and obesity. Molecular and cellular endocrinology 185: 73-79.

Burfening, P. J., D. D. Kress, R. L. Friedrich, and D. D. Vaniman. 1978. Phenotypic and genetic relationship between calving ease, gestation length, birth weight and preweaning growth. J. Anim. Sci. 47: 595-600.

Butler, W. R. 1998. Effect of protein nutrition on ovarian and uterine physiology in dairy cattle. Journal of dairy science 81: 2533-2539.

Clayton, P., and J. Trueman. 2000. Leptin and puberty. Archives of disease in childhood 83: 1-4.

Corah, L. R., T. G. Dunn, and C. C. Kaltenback. 1975. Influence of prepartum nutrition on reproductive performance of beef females and the performance of their progeny. J. Anim. Sci. 41: 819-824. doi:10.2527/jas1975.413819.

Crampton, E., E. Donefer, and L. Lloyd. 1960. A Nutritive Value Index for Forages 1. Journal of Animal Science 19: 538-544.

Dahlgren, J., C. Nilsson, E. Jennische, H.-P. Ho, E. Eriksson, A. Niklasson, P. Björntorp, K. A. Wikland, and A. Holmäng. 2001. Prenatal cytokine exposure results in obesity and gender-specific programming. American Journal of Physiology-Endocrinology and Metabolism 281: E326-E334.

Dalinghaus, M., C. D. Rudolph, and A. M. Rudolph. 1991. Effects of maternal fasting on hepatic glucoenogenesis and glucose metabolism in fetal lambs. J. Develop. Physiol. 16: 267-275.

DelCurto, T., R. Cochran, D. Harmon, A. Beharka, K. Jacques, G. Towne, and E. Vanzant. 1990. Supplementation of dormant tallgrass-prairie forage: I. Influence of varying supplemental protein and (or) energy levels on forage utilization characteristics of beef steers in confinement. Journal of Animal Science 68: 515-531.

Du, M., J. Tong, J. Zhao, K. Underwood, M. Zhu, S. Ford, and P. Nathanielsz. 2010a. Fetal programming of skeletal muscle development in ruminant animals 1. Journal of animal science 88: E51-E60.

Du, M., X. Yan, J. F. Tong, J. Zhao, and M. J. Zhu. 2010b. Maternal obesity, inflammation, and fetal skeletal muscle development. Biology of reproduction 82: 4-12.

Ferguson, J. D., and W. Chalupa. 1989. Impact of protein nutrition on reproduction in dairy cows. Journal of dairy science 72: 746-766.

Flynn, N., C. Meininger, T. Haynes, and G. Wu. 2002. The metabolic basis of arginine nutrition and pharmacotherapy. Biomedicine & Pharmacotherapy 56: 427-438.

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.

Funston, R. N., J. L. Martin, D. C. Adams, and D. M. Larson. 2009. Effect of winter grazing system and supplementation on beef cow and progeny performance. In: 2009 Nebraska Beef Cattle Report. Rep. No. Univ. of Nebrasks, Lincoln. p. 5-8.

Godfrey, K. M., and D. J. Barker. 2000. Fetal nutrition and adult disease–. The American journal of clinical nutrition 71: 1344S-1352S.

Greenfield, J. R., and L. V. Campbell. 2004. Insulin resistance and obesity. Clinics in Dermatology 22: 289-295. doi:10.1016/j.clindermatol.2004.01.011.

Guiroy, P. J., D. G. Fox, L. O. Tedeschi, M. J. Baker, and M. D. Cravey. 2001. Predicting individual feed requirments of cattle fed in groups. J. Anim. Sci. 79.

Hattersley, A. T., and J. E. Tooke. 1999. The fetal insulin hypothesis: an alternative explanation of the association of low bir thweight with diabetes and vascular disease. The Lancet 353: 1789-1792.

Heitzman, R. 1979. The efficacy and mechanism of action of anabolic agents as growth promoters in farm animals. In: Hormonal Steroids: Proceedings of the Fifth International Congress on Hormonal Steroids. p 927-930.

Hess, S. P. Ford, and P. W. Nathanielsz. 2008. AMP-activated protein kinase signalling pathways are down regulated and skeletal muscle development impaired in fetuses of obese, over-nourished sheep. The Journal of physiology 586: 2651-2664.

Johnson, B., P. Anderson, J. Meiske, and W. Dayton. 1996. Effect of a combined trenbolone acetate and estradiol implant on feedlot performance, carcass characteristics, and carcass composition of feedlot steers. Journal of Animal Science 74: 363-371.

Lampl, M., and P. Jeanty. 2004. Exposure to maternal diabetes is associated with altered fetal growth patterns: A hypothesis regarding metabolic allocation to growth under hyperglycemic-hypoxemic conditions. Am. J. Hum. Biol. 16: 237-263. doi:10.1002/ajhb.20015.

Lardy, G., D. C. Adams, T. J. Klopfenstein, D. Clark, and J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills Native Range and subirrigated meadow diets and

application of a metabolizable protein system. In: 1997 Nebraska Beef Cattle Report. Rep. No. MP 67-A. Univ. of Nebraska, Lincoln

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. 85: 841-847.

Lemons, J. 1979. Fetal-placental nitrogen metabolism. In: Seminars in perinatology. p 177-190.

Long, N. M., C. B. Tousley, K. R. Underwood, S. I. Paisley, W. J. Means, B. W. Hess, M. Du, and S. P. Ford. 2012. Effects of early- to mid-gestational undernutrition with or without protein supplementation on offspring growth, carcass charecteristics, and adipocyte size in beef cattle. J. Anim. Sci. 90: 197-206. doi:10.2527/jas.2011-4237.

Lorenzo, M., S. Fernandez-Veledo, R. Vila-Bedmar, L. Garcie-Guerra, C. D. Alvaro, and I. Nieto-Vazquez. 2008. Insulin resistance induced by tumor necrosis factor-alpha in myocytes and brown adipocytes. J. Anim. Sci. 86: E94-E104.

Malek, A., R. Sager, E. Aegerter, and H. Schneider. 1993. Metabolism of glutamic acid studied in the dually in vitro perfused human placental cotyledon. Placenta 14: 87-102.

Marini, J. C., and S. R. Broussard. 2006. Hyperammonemia increases sensitivity to LPS. Molecular genetics and metabolism 88: 131-137.

Mariz, L., P. Amaral, S. Valadares Filho, S. Santos, E. Detmann, M. Marcondes, J. Pereira, J. Silva Júnior, L. Prados, and A. Faciola. 2018. Dietary protein reduction on microbial protein, amino acids digestibility and body retention in beef cattle: 2. Amino acid intestinal absorption and their efficiency for whole-body deposition. Journal of animal science: sky018.

McMullen, S., and S. C. Langley-Evans. 2005. Maternal low-protein diet in rat pregnancy programs blood pressure through sex-specific mechanisms. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 288: R85-R90.

McNanley, T., and J. Woods. 2008. Placental physiology. Global library of women's. Paula and David Bloomer, Medicine.

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.

Nocek, J., and J. Russell. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. Journal of Dairy Science 71: 2070-2107.

NRC. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. The National Academies Press, Washington, DC.

Rehfeldt, C., I. Lang, S. Görs, U. Hennig, C. Kalbe, B. Stabenow, K.-P. Brüssow, R. Pfuhl, O. Bellmann, and G. Nürnberg. 2011. Limited and excess dietary protein during gestation affects growth and compositional traits in gilts and impairs offspring fetal growth 1 2. Journal of animal science 89: 329-341.

Rehfeldt, C., B. Stabenow, R. Pfuhl, J. Block, G. Nürnberg, W. Otten, C. Metges, and C. Kalbe. 2012. Effects of limited and excess protein intakes of pregnant gilts on carcass quality and cellular properties of skeletal muscle and subcutaneous adipose tissue in fattening pigs. Journal of animal science 90: 184-196.

Rolfe, K. M., L. A. Stalker, T. J. Klopfenstein, J. A. Musgrave, and R. N. Funston. 2012. Influence of weaning date and prepartum nutrition on cow-calf productivity. In: 2012 Nebraska Beef Cattle Report. Rep. No. MP95. Univ. of Nebraska, Lincoln. p. 15-17.

Sagawa, N., S. Yura, H. Itoh, H. Mise, K. Kakui, D. Korita, M. Takemura, M. Nuamah, Y. Ogawa, and H. Masuzaki. 2002. Role of leptin in pregnancy—a review. Placenta 23: S80-S86.

Schelling, G. T. 1984. Monensin mode of action in the rumen. Journal of Animal Science 58: 1518-1527.

Scholl, T. O., M. Sowers, X. Chen, and C. Lenders. 2001. Maternal glucose concentration influences fetal growth, gestation, and pregnancy complications. Am. J. Epidemiol. 154: 514-520.

Selk, G., R. Wettemann, K. Lusby, J. Oltjen, S. Mobley, R. Rasby, and J. Garmendia. 1988. Relationships among weight change, body condition and reproductive performance of range beef cows. Journal of animal science 66: 3153-3159.

Shahzad, K., M. Bionaz, E. Trevisi, G. Bertoni, S. L. Rodriguez-Zas, and J. J. Loor. 2014. Integrative analyses of hepatic differentially expressed genes and blood biomarkers during the peripartal period between dairy cows overfed or restricted-fed energy prepartum. PLoS One 9: e99757.

Shwartz, M. W., and S. E. Kahn. 1999. Insulin resistance and obesity. Nature 402: 860-861. doi:10.1038/47209.

Sinclair, K., M. Kuran, F. Gebbie, R. Webb, and T. McEvoy. 2000. Nitrogen metabolism and fertility in cattle: II. Development of oocytes recovered from heifers offered diets

differing in their rate of nitrogen release in the rumen. Journal of animal science 78: 2670-2680.

Sloboda, D. M., M. Hickey, and R. Hart. 2010. Reproduction in females: the role of the early life environment. Human reproduction update 17: 210-227.

Springman, S. A., H. R. Nielson, J. A. Musgrave, J. Nollette, A. Applegarth, and R. N. Funston. 2017. Impact of heifer development system in two different breeding seasons. In: 2017 Nebraska Beef Cattle Report. Rep. No. MP104. Univ. of Nebraska, Lincoln. p. 8-10.

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.

Stalker, L. A., L. A. Ciminski, D. C. Adams, T. J. Klopfenstein, and R. T. Clark. 2007. Effects of weaning date and prepartum protein supplementation on cow performance and calf growth. Rangeland Ecol. Manag. 60: 578-587.

Summers, A. F., A. D. Blair, and R. N. Funston. 2015a. Impact of supplemental protein source offered to primiparous heifers during gestation on II. Progeny performance and carcass charecteristics. J. Anim. Sci. 93: 1871-1880. doi:10.2527/jas2014-8297.

Summers, A. F., T. L. Meyer, and R. N. Funston. 2015b. Impact of supplemental protein source offered to primiparous heifers during gestation on I. Average daily gain, feed intake, calf birth body weight, and rebreeding in pregnant beef heifers. J. Anim. Sci. 93: 1865-1870. doi:10.2527/jas2014-8296.

Symonds, M. E., S. Pearce, J. Bispham, D. S. Gardner, and T. Stephenson. 2004. Timing of nutrient restriction and programming of fetal adipose tissue development. Proceedings of the Nutrition Society 63: 397-403.

Tamminga, S. 2006. The effect of the supply of rumen degradable protein and metabolisable protein on negative energy balance and fertility in dairy cows. Animal reproduction science 96: 227-239.

Tobi, E. W., L. Lumey, R. P. Talens, D. Kremer, H. Putter, A. D. Stein, P. E. Slagboom, and B. T. Heijmans. 2009. DNA methylation differences after exposure to prenatal famine are common and timing-and sex-specific. Human molecular genetics 18: 4046-4053.

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 cross-bred beef steers. Meat Sci. 86: 588-593. doi:10.1016/j.meatsci.2010.04.008.

Volesky, J. D., W. H. Schacht, P. E. Reece, and T. J. Vaughn. 2007. Diet composition of cattle grazing Sandhills range during spring. Rangeland Ecol. Manag. 60: 65-70. doi:10.2111/05-232R2.1.

Volesky, J. D., W. H. Schacht, and D. M. Richardson. 2004. Stocking rate and grazing frequency effects on Nebraska Sandhills meadows. J. Range Manag. 57: 553-560.

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 requirment during winter. J. Anim. Sci 66: 603-612.

Walter, L. J., T. A. McAllister, W. Z. Yang, K. A. Beauchemin, M. He, and J. J. McKinnon. 2012. Comparison of wheat or corn dried distillers grains with solubles on rumen fermentation and nutrient digestibility by feedlot heifers. J. Anim. Sci. 90: 1291-1300. doi:10.2527/jas.2011-3844.

Wu, G., F. W. Bazer, T. A. Cudd, C. J. Meininger, and T. E. Spencer. 2004a. Maternal nutrition and fetal development. J. Nutr. 134: 2169-2172.

Wu, G., F. W. Bazer, T. A. Cudd, C. J. Meininger, and T. E. Spencer. 2004b. Maternal nutrition and fetal development. The Journal of nutrition 134: 2169-2172.

Wu, X., C. Xie, Y. Zhang, Z. Fan, Y. Yin, and F. Blachier. 2015. Glutamate–glutamine cycle and exchange in the placenta–fetus unit during late pregnancy. Amino acids 47: 45-53.

Yan, X., M. J. Zhu, W. Xu, J. F. Tong, S. P. Ford, P. W. Nathanielsz, and M. Du. 2010. Up-regulation of Toll-like receptor 4/nuclear factor-κB signaling is associated with enhanced adipogenesis and insulin resistance in fetal skeletal muscle of obese sheep at late gestation. Endocrinology 151: 380-387.

Zambrano, E., C. J. Bautista, M. Deas, P. M. Martinez-Samayoa, M. Gonzalez-Zamorano, H. Ledesma, J. Morales, F. Larrea, and P. W. Nathanielsz. 2006. A low maternal protein diet during pregnancy and lactation has sex- and window of exposure-specific effects on offspring growth and food intake, glucose metabolism and serum leptin in the rat. The Journal of Physiology 571: 221-230. doi:10.1113/jphysiol.2005.100313.

Zambrano, E., C. Guzmán, G. L. Rodríguez-González, M. Durand-Carbajal, and P. W. Nathanielsz. 2014. Fetal programming of sexual development and reproductive function. Molecular and cellular endocrinology 382: 538-549.

Zhu, M.-J., S. P. Ford, P. W. Nathanielsz, and M. Du. 2004. Effect of maternal nutrient restriction in sheep on the development of fetal skeletal muscle. Biology of reproduction 71: 1968-1973.

Zhu, M. J., B. Han, J. Tong, C. Ma, J. M. Kimzey, K. R. Underwood, Y. Xiao, B. W.

Table 1. Predicted[1] composition of diets offered to May-calving dams in late gestation[2]

	Meadow		Range	
	NS	S	NS	S
January				
CP, % (DM)	6.1	6.8	5.0	5.7
CP, % req.[3]	85.9	95.8	70.4	80.3
RUP, % CP (DM)	25.9	27.7	25.2	27.4
TDN, % (DM)	46.7	47.5	52.0	52.7
ME, Mcal/kg	1.69	1.72	1.88	1.91
NEm, Mcal/kg	0.95	0.97	1.16	1.18
NEm, % req.[4]	96.9	99.0	118.4	120.4
February				
CP, % (DM)	11.0	11.6	5.8	6.5
CP, % req.[5]	139.2	146.8	73.8	82.3
RUP, % CP (DM)	13.6	15.8	20.8	23.3
TDN, % (DM)	44.0	45.0	51.7	52.7
ME, Mcal/kg	1.59	1.63	1.87	1.90
NEm, Mcal/kg	0.84	0.87	1.15	1.17
NEm, % req.[6]	76.4	79.1	104.5	106.4
March				
CP, % (DM)	19.9	20.2	12.1	12.6
CP, % req.[5]	251.9	255.7	153.2	159.5
RUP, % CP (DM)	10.6	11.7	12.4	14.1
TDN, % (DM)	63.0	63.4	63.0	63.4
ME, Mcal/kg	2.28	2.29	2.28	2.29
NEm, Mcal/kg	1.58	1.58	1.58	1.58
NEm, % req.[6]	143.6	143.6	143.6	143.6
April				
CP, % (DM)	25.3	25.5	12.7	13.2
CP, % req.[5]	320.7	322.8	160.3	167.1
RUP, % CP (DM)	15.2	74.5	17.1	18.4
TDN, % (DM)	63.3	63.7	67.0	67.3
ME, Mcal/kg	2.29	2.30	2.42	2.43
NEm, Mcal/kg	1.59	1.59	1.72	1.72
NEm, % req.[6]	144.5	144.5	156.4	156.4

[1]Diet composition predicted using a computer model based on (NRC, 2000) equations and accounting for differences in DMI.

[2]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.

[3]CP expressed as a percentage of requirement for mid-gestation multiparous dams (7.1% CP, DM; NRC, 2000).

[4]NEm expressed as a percentage of the requirement for mid-gestation multiparous dams (0.98 Mcal/kg) (NRC, 2000).
[5]CP expressed as a percentage of requirement for late gestation multiparous dams (7.9% CP, DM) (NRC, 2000).
[6]NEm expressed as a percentage of the requirement for late gestation multiparous dams (1.11 Mcal/kg) (NRC, 2000).

Table 2. Nutrient analysis and composition of supplement provided to May-calving cows in late gestation[1]

Item	
Nutrient	
CP, % (DM)	32.9
RUP, % CP (DM)	39.7
TDN, % (DM)	78.4
ME, Mcal/kg[2]	2.83
NEm, Mcal/kg[2]	1.57
Ingredient, % DM	
Dried distillers grains meal	52.5
Soybean meal (46.5% CP)	14.7
Vitamin and mineral package[3]	13.3
Wheat middlings	6.3
Sunflower meal (35% CP)	6.3
Molasses, liquid	3.7
Urea	1.6
Cull Beans	1.5

[1]May-calving dams were assigned to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) from approximately gestational d 160 – 245.

[2]Calculated using the equations proposed by the NRC, 2000.

[3]Formulated to provide 178 mg/kg monensin (Rumensin, Elanco Animal Health, Indianapolis, IN).

Table 3. Effects of late gestation nutrition [1] on May-calving dam BW, BCS, and reproductive performance.

	Treatment[1]										
	M		R			*P* – value[2]					
	NS	S	NS	S	SEM	P	P × M	S	S × M	P × S	M
n	181	162	160	149							
Cow BW, kg											
Initial	420	421	424	422	4	0.08	0.36	0.05	0.07	0.64	< 0.01
April	466[a]	474[a]	446[b]	463[a]	4						
July	493	500	493	499	4						
January	444	442	445	442	4						
Dam BW Change, kg											
Initial - April	45[ab]	52[a]	23[c]	42[b]	3	< 0.01		< 0.01		0.02	
April - July	28[yz]	26[z]	47[x]	36[y]	2	< 0.01		< 0.01		0.07	
July - January	-49	-58	-48	-56	2	0.55		< 0.01		0.91	
Cow BCS[3]											
Initial	4.62	4.54	4.64	4.59	0.04	0.88	0.60	0.49	0.41	0.44	0.92
April	4.65	4.73	4.59	4.75	0.04						
July	5.61	5.69	5.59	5.65	0.04						
January	4.63	4.55	4.61	4.54	0.04						
Dam BCS Change, kg											
Initial - April	0.01	0.19	-0.01	0.16	0.04	0.58		< 0.01		0.94	
April - July	0.96	0.96	1.00	0.91	0.05	0.82		0.35		0.29	
July - January	-0.98	-1.14	-0.99	-1.10	0.05	0.74		< 0.01		0.58	
Dystocia, %[4]	0	2	2	1	1	0.91		0.98		0.14	
Calving d, Julian d	143	145	144	142	1	0.50		0.71		0.07	
Calved first 21 d, %[5]	82	73	81	80	4	0.40		0.12		0.26	
Pregnancy rate, %	90	89	82	87	3	0.09		0.50		0.35	

[a,b]Means within a row lacking a common superscript differ ($P \leq 0.05$).

[x,y]Means within a row lacking a common superscript tend to differ ($P \leq 0.10$).

[1]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.
[2]P= main effect of dam's pasture assignment, P × M = interaction of dam's pasture assignment and month, S = main effect of dam's supplement assignment, S × M = interaction of dam's supplementation assignment and month, P × S = interaction between dam's pasture and supplement assignment, and M = effect due to month.
[3]BCS = Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).
[4]At parturition a calving ease (CE) score was assigned (1 = no assistance to 4 = caesarian section; Burfening et al., 1978). A score of 2 or greater was considered as dystocia.
[5]The first day 2 or more cows calved was considered the start of the calving season.

Table 4. Effect of late gestation nutrition[1] on May-born steer and heifer progeny growth through development.

	Treatment[1]										
	M		R			*P* – value[2]					
	NS	S	NS	S	SEM	P	P × M	S	S × M	P × S	M
Steer Progeny BW, kg											
Birth	36	35	34	34	5	0.32	0.30	0.93	0.19	0.38	< 0.01
2 mo	101	100	97	103	5						
Wean (8 mo)	202	218	195	200	6						
Post-development (12 mo)	263	259	256	258	5						
205-d adj. wean BW[3]	204	204	201	205	2	0.54		0.39		0.45	
Heifer Progeny BW, kg											
Birth	32	32	31	32	5	0.32	0.01	0.63	0.57	0.78	< 0.01
2 mo	95	96	92	109	5						
Wean (8 mo)	198	200*	192	197	6						
Post-development (12 mo)	254	253	240*	247	5						
205-d adj. wean BW[3]	190*	196	184*	191*	2	< 0.01		< 0.01		0.79	

*Heifer vs. Steer ($P \leq 0.05$) within variable and dam treatment.

[1]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.

[2]P= main effect of dam's pasture assignment, P × M = interaction of dam's pasture assignment and month, S = main effect of dam's supplement assignment, S × M = interaction of dam's supplementation assignment and month, P × S = interaction between dam's pasture and supplement assignment, and M = effect due to month.

[3]Calculated according to the equation proposed by (BIF, 2016).

Table 5. Effect of late gestation nutrition on post-development May-born heifer progeny BW, BCS, reproductive performance and first calf BW

	Treatment[1]										
	M		R			*P* – value[2]					
	NS	S	NS	S	SEM	P	P × M	S	S × M	P × S	M
n	81	76	74	78							
Heifer BW, kg*											
Prebreed (14 mo)	317	318	315	315	3	0.12	0.40	0.98	0.92	0.29	< 0.01
Pregnancy diagnosis (17 mo)	358	358	356	356	3						
Precalve (23 mo)	383[b]	391[ab]	396[ab]	400[a]	4						
Prebreed (26 mo)	396	400	401	395	4						
Pregnancy diagnosis (30 mo)	393[b]	408[a]	404[ab]	408[a]	4						
Heifer BCS[3]†											
Pregnancy diagnosis (17 mo)	5.87	5.90	5.82	5.84	0.04	0.79	0.70	0.60	0.54	0.04	< 0.01
Precalve (23 mo)	5.28[a]	5.21[ab]	5.21[ab]	5.12[b]	0.06						
Prebreed (26 mo)	5.45[ab]	5.52[a]	5.43[ab]	5.26[b]	0.07						
Pregnancy diagnosis (30 mo)	5.17[b]	5.50[a]	5.34[ab]	5.29[ab]	0.07						
First calf BW, kg											
Birth	30	31	29	29	2	0.35	0.36	0.06	0.12	0.70	< 0.01
2 mo	89	86	88	90	2						
Wean (8 mo)	160	162	160	168	2						
205-d adj. wean BW[4,5]	247	257	253	256	6	0.65		0.30		0.61	
Pubertal, %[6]	72	80	77	69	5	0.56		0.88		0.10	
Percent mature BW, %[7]	60	61	58	59	0.7	0.01		0.06		0.59	
Heifer pregnancy rate, %	78	79	72	75	5	0.29		0.76		0.86	
Calved in first 21 d, %[8]	71	76	80	80	7	0.33		0.73		0.78	
Dystocia, %[9]	10	15	9	27	7	0.51		0.04		0.32	
PPI, d[10]	89	89	96	95	3	0.03		0.99		0.83	
Primiparous pregnancy rate, %	87	94	76	77	8	0.02		0.34		0.40	

[a,b] Means within a row lacking common superscripts differ ($P \leq 0.05$)

*Interaction of P × S × M ($P = 0.10$)

*Interaction of P × S × M (*P* = 0.10)
† Interaction of P × S × M (*P* = 0.02)
[1]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.
[2]P= main effect of dam's pasture assignment, P × M = interaction of dam's pasture assignment and month, S = main effect of dam's supplement assignment, S × M = interaction of dam's supplementation assignment and month, P × S = interaction between dam's pasture and supplement assignment, and M = effect due to month.
[3]BCS = Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).
[4]Calculated according to the equation proposed by (BIF, 2016).
[5] Covariate adjusted (*P* = 0.03) for calf sex even though percentage of bulls at birth did not differ (*P* ≥ 0.14).
[6]Considered pubertal if blood serum progesterone concentration > 1 ng/ml.
[7]Percent of mature BW at 14 mo. of age. Calculated using a May-herd mature cow BW of 532 kg.
[8]The first day 2 or more cows calved was considered the start of the calving season.

Table 6. Effect of late gestation nutrition[1] on S-YRL steer[2] feedlot BW, ADG, ADFI, performance, and carcass characteristics

	Treatment[1]										
	M		R			*P* – value[3]					
	NS	S	NS	S	SEM	P	P × M	S	S × M	P × S	M
n	35	27	35	34							
Feedlot BW, kg											
Initial	270	258	253	255	9	0.49	0.68	0.42	0.56	0.61	< 0.01
Reimplant	492	465	481	492	10						
Final[4]	646	635	619	635	10						
ADG, kg/d											
Initial[5]	1.98	1.90	1.95	2.07	0.09	0.37		0.77		0.24	
Reimplant[6]	1.56	1.70	1.34	1.48	0.12	0.06		0.22		1.0	
Total	1.77	1.80	1.69	1.77	0.04	0.13		0.17		0.53	
ADFI, kg	12.04	11.87	11.35	11.86	0.23	0.10		0.41		0.11	
G:F, kg:kg	0.148	0.153	0.151	0.151	0.004	0.90		0.48		0.44	
Unadj. RFI[7]	0.141	-0.039	-0.269	-0.018	0.197	0.25		0.83		0.20	
Adj. RFI[8]	0.162	-0.007	-0.323	-0.014	0.200	0.15		0.68		0.16	
HCW, kg	407	404	393	403	7	0.26		0.61		0.31	
EBF, %[9]	34.7	34.5	33.7	33.5	0.5	0.04		0.74		1.0	
Marbling score[10]	483	445	443	430	15	0.04		0.06		0.37	
12th rib fat, cm	1.60	1.66	1.53	1.48	0.08	0.11		0.96		0.47	
LM area, cm^2	37.7	36.9	36.2	37.8	0.7	0.71		0.54		0.08	
Yield grade	3.2	3.4	3.3	3.1	0.1	0.40		0.83		0.14	
Quality grade, %											
Sm or higher[11]	92	75	70	69	11	0.06		0.16		0.18	
Md or higher[12]	25	20	24	13	10	0.56		0.29		0.63	

[1]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.
[2]After development, steers were blocked by development treatment and BW and randomly assigned to 1 of 2 feedlot systems: steers entered the immediately following completion of development treatment (**S-YRL**) or steers were allowed to graze upland range 90 d before entering the feedlot (**L-YRL**).
[3]P= main effect of dam's pasture assignment, P × M = interaction of dam's pasture assignment and month, S = main effect of dam's supplement assignment, S × M = interaction of dam's supplementation assignment and month, P × S = interaction between dam's pasture and supplement assignment, and M = effect due to month.
[4]Final BW calculated from HCW adjusted to a common dressing percent of 63.0%.
[5]Period from feedlot entry to reimplant.
[6]Period reimplant to slaughter.
[7]Unadj RFI = unadjusted residual feed intake where RFI = Actual ADFI – [Group Avg. ADFI + [b_m*(Indiv. mid-test $BW^{0.75}$ – group avg. mid-test $BW^{0.75}$ + [b_g*(Indiv. ADG – group avg. ADG)] where b_m is the slope coefficient for mid-test BW and b_g is the slope coefficient for ADG when regressed on ADFI.
[8] Adj. RFI = RFI adjusted for differences in empty body fat. Empty body fat calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12th rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).
[9]EBF = empty body fat. Calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12th rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).
[10]400 = small^0.
[11]Sm = small quality grade, USDA low Choice. Marbling score ≥ 400.
[12]Md = modest quality grade, USDA average Choice. Marbling score ≥ 500.

Table 7. Effect of late gestation nutrition[1] on L-YRL steer[2] feedlot BW, ADG, ADFI, performance, and carcass characteristics.

	Treatment[1]										
	M		R			*P* – value[3]					
	NS	S	NS	S	SEM	P	P × M	S	S × M	P × S	M
n	35	37	26	33							
Feedlot BW, kg						0.69	0.71	0.25	0.24	0.91	< 0.01
Initial	361	354	350	367	10						
Reimplant	475	463	480	471	10						
Final[4]	693	666	664	678	10						
ADG, kg/d											
Initial[5]	1.72	1.72	1.64	1.90	0.15	0.73		0.11		0.32	
Reimplant[6]	2.08	2.08	1.94	1.74	0.12	0.13		0.74		0.10	
Total	1.93	1.93	1.82	1.83	0.07	0.31		0.26		0.53	
ADFI, kg	12.37	13.34	12.75	12.65	0.29	0.01		0.79		0.91	
G:F, kg:kg	0.145	0.136	0.140	0.142	0.005	0.92		0.38		0.19	
Unadj. RFI[7]	-0.051	0.173	0.014	-0.260	0.201	0.28		0.88		0.14	
Adj. RFI[8]	0.042	0.188	0.000	0.323	0.212	0.12		0.62		0.19	
HCW, kg	439	428	418	426	8	0.10		0.81		0.18	
EBF, %[9]	35.4	35.0	35.1	34.9	0.6	0.74		0.57		0.75	
Marbling score[10]	502	496	509	463	17	0.39		0.09		0.18	
12th rib fat, cm	1.63	1.56	1.62	1.63	0.10	0.76		0.77		0.64	
LM area, cm^2	38.3	37.2	37.7	37.7	0.7	0.64		0.18		0.60	
Yield grade	3.4	3.4	3.3	3.5	0.2	0.88		0.56		0.63	
Quality grade, %											
Sm or higher[11]	87	75	70	75	6	0.09		0.40		0.12	
Md or higher[12]	40	47	47	26	12	0.47		0.45		0.16	

[1]May-calving dams were arranged in a 2 × 2 factorial at approximately d 160 of gestation and were assigned to 1 of 2 forage types: sub-irrigated meadow (**M**) or upland range (**R**) for 116 d and then to 1 of 2 supplementation groups: 0.45 kg/d of 33% CP (DM) supplement (**S**) or no supplement (**NS**) for 85 d.

[2]After development, steers were blocked by development treatment and BW and randomly assigned to 1 of 2 feedlot systems: steers entered the immediately following completion of development treatment (**S-YRL**) or steers were allowed to graze upland range 90 d before entering the feedlot (**L-YRL**).

[3]P= main effect of dam's pasture assignment, P × M = interaction of dam's pasture assignment and month, S = main effect of dam's supplement assignment, S × M = interaction of dam's supplementation assignment and month, P × S = interaction between dam's pasture and supplement assignment, and M = effect due to month.

[4]Final BW calculated from HCW adjusted to a common dressing percent of 63.0%.

[5]Period from feedlot entry to reimplant.

[6]Period reimplant to slaughter.

[7]Unadj RFI = unadjusted residual feed intake where RFI = Actual ADFI – [Group Avg. ADFI + [b_m*(Indiv. mid-test $BW^{0.75}$ – group avg. mid-test $BW^{0.75}$ + [b_g*(Indiv. ADG – group avg. ADG)] where b_m is the slope coefficient for mid-test BW and b_g is the slope coefficient for ADG when regressed on ADFI.

[8] Adj. RFI = RFI adjusted for differences in empty body fat. Empty body fat calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12th rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).

[9]EBF = empty body fat. Calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12th rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).

[10]400 = small^0.

[11]Sm = small quality grade, USDA low Choice. Marbling score ≥ 400.

[12]Md = modest quality grade, USDA average Choice. Marbling score ≥ 500.

APPENDIX A.

Differences in BW, BCS, and ADG of May-calving heifers, primiparous cows, and multiparous cows grazing upland Sandhills range from May to November

A.C. Lansford, J.A. Musgrave, and R.N. Funston

University of Nebraska, West Central Research and Extension Center, North Platte, NE

ABSTRACT: An ongoing study to investigated differences in BW, BCS, and ADG of different age classification of May-calving females is being conducted at the Gudmundsen Sandhills Laboratory. Females were classified by age as follows: heifers (**H**; n = 12, 262 ± 4 kg), primiparous cows (**PC**; n = 12, 338 ± 8 kg), and multiparous cows (**MC**; n = 12, 451 ± 11 kg). The percentage of females cycling was similar (P = 0.38) between classes at start of the breeding season. Females were weighed and BCS recorded every 2 wk from late-May to Nov. Calves belonging to primiparous and multiparous cows were weighed every 4 wk until wean, either Oct. 19 or Nov. 7, for PC and MC, respectively. Additionally, forage samples were collected from esophageally fistulated cows at 3 time points throughout the breeding season and IVOMD and CP analysis performed. Both IVOMD and TDN experienced a linear decline from July to September. From May to start of the breeding season, PC had the lowest ($P < 0.01$) change in BW, while H and MC had similar BW change. Conversely, MC had the lowest ($P < 0.01$) change in BW throughout the breeding season, while H and PC were similar. Body condition increased similarly for both PC and MC, while H maintained BCS from May to start of breeding ($P < 0.01$). In contrast, H maintained BCS over the breeding season, PC experienced intermediate loss, and MC underwent the greatest loss of BCS ($P < 0.01$). While there were differences in BW and BCS change between classes over the

breeding season, pregnancy rate was similar ($P = 0.58$) between classes. Calf BW for PC and MC increased ($P < 0.01$) from May to wean, but was not different ($P = 0.37$) between classes.

Key Words: breeding season, May-calving, reproductive performance

INTRODUCTION

Previous research has indicated depressed pregnancy rates for May vs. March heifers, while no difference was observed for multiparous cows (Griffin et al., 2012; Springman et al., 2017). The breeding season for a May-calving herd occurs when forage begins to mature and CP and TDN values decline. Declining nutrition in the post-insemination period has been associated with decreased conception rates and increased embryonic mortality (Arias et al., 2012; Kruse et al., 2017). Decreasing diet quality may not meet the protein and energy requirements of young, growing cows, such as heifers and primiparous cows. This may result in increased mobilization of body stores to meet energy demands. The objective of this study is to evaluate differences in range forage diet quality on BW, BCS, and ADG of May-calving heifers, primiparous cows, and multiparous cows.

MATERIALS AND METHODS

The University of Nebraska Animal Care and Use Committee approved the procedures and facilities used in this experiment.

Female Management

A subset of May-calving heifers (n = 12), primiparous cows (n = 12) and multiparous cows (n = 12) were allotted to an upland range pasture from late May to

early November each year. Pastures were stocked at a rate of 0.5 AUM. Body weight and BCS of females was recorded every 2 wk during this period.

Approximately July 15, females were synchronized with a single PGF2α injection 5 d after fertile bulls were placed. Females were exposed to bulls for a 45 d breeding season at a ratio of 1:18. Calf BW was recorded every 4 wk until pregnancy diagnosis and wean. Pregnancy diagnosis for primiparous cows occurred approximately Oct. 19 and for multiparous cows approximately Nov. 7.

After weaning, cows were moved back to their respective age group within the larger herd and managed similarly for the remainder of the year. Females were removed from the study for reproductive failure, calf death, or injury.

Forage Analysis

Forage analysis is presented in Table 1. Three times (approximately July 30, August 20, and September 15) throughout the breeding season, esophageally fistulated cows were allowed to graze for 30 minutes on each pasture (n = 4) before extrusa was collected. Each sample was ground to pass a 1-mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ). Samples were analyzed for DM and OM by AOAC (1990) standards.

In vitro digestibility

In vitro organic matter disappearance was measured using a modified Tilley and Terry (1963) method with modifications as follows. Rumen inoculum was obtained by collecting whole rumen contents from 4 ruminally cannulated steers (2 steers/run). Inoculum was strained through 4 layers of cheesecloth and mixed to reduce individual steer variation. McDougal's Buffer (1:1 ratio) and 1 g urea/L (Weiss, 1994) were added

to strained ruminal fluid. Forage samples of 0.5 g previously weighed and deposited into a 100 mL tube were mixed with 50 mL of inoculum. Test tubes were capped and placed in a 39°C water bath for 48 h. After 48 h, HCL acid and pepsin were added to the tube, before being placed back into the water bath for 24 h. Samples were removed after this period and immediately placed in a freezer. Tubes were removed from the freezer and allowed to thaw in a 39°C water bath for 10 minutes before filtering. Samples were rinsed from the tube with distilled water, filtered through a Whatman 541 paper filter and then dried in a 100° C oven for 6 h (Van Soest and Robertson, 1977). This process was repeated twice, where run was considered experimental unit (n = 2). Samples were replicated 3 times for each run, and averaged across runs for digestibility estimates.

Five chopped hays with known in vivo digestibility values were used as standards to adjust forage sample IVOMD values (Geisert, 2007). The hays utilized were immature meadow hay, immature smooth bromegrass, mature smooth bromegrass, mature brome hay, and a mixture of warm and cool season grass species.

Crude Protein

Forage samples of 0.06 g were weighed and analyzed for nitrogen content using a combustion chamber (FlashSmart N/Protein Analyzer CE, Elantech, Inc., Lakewood, NJ; AOAC, 1999; method 990.03). Nitrogen content was multiplied by a standard 6.25 to determine protein content. Forage samples were run in duplicate. Samples with a CV above 5% were reran in duplicate and combined with previous results. Outliers within sample were removed from the data analysis, and were considered values ± 4 SD from the mean. Average protein percentage was corrected to a common standard between runs.

Statistical Analysis

The PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC, version 9.4) was used for analysis of all repeated measurements on the same subject using heterogeneous compound symmetry. The model statement contained age classification and month, where month was considered the month of the year when the measurement was taken. Calf gender was included as a covariate and removed when $P \geq 0.05$. For the remaining analysis, PROC GLIMMIX was used where the model statement included the dam's age classification. The Tukey-Kramer adjustment was used to obtain superscripts for all multiple comparisons of LS means. *P*-values ≤ 0.05 were considered significant, and those between $0.05 < P \leq 0.10$ were considered a tendency.

IMPLICATIONS

In agreement with Lardy et al., 1997, forage CP and TDN values decline throughout the breeding season and fall below the NRC (2000) requirements for growing heifer calves (9% CP, 58% TDN) and primiparous cows (13% CP, 66% TDN). This likely results in catabolism of body tissues, which is observed in decreasing BCS throughout the breeding season for primiparous cows. Interestingly, heifer BCS was similar throughout the study, and may indicate greater metabolic plasticity of this age class. Multiparous cows follow a similar BCS trend to primiparous cows, although their BCS is higher at all time points. Due to the low number of females enrolled in the study, no differences in pregnancy rate were detected, despite large numerical differences. It is interesting to note primiparous cows had increased BW and BCS gain prior to the breeding season and throughout compared with multiparous cows, despite 33% lower pregnancy rates. Furthermore, primiparous and multiparous cow BCS were at their

lowest immediately following calving in May, and at wean, in either October or November, respectively. No differences in class were detected in calf BW, and may be a result of increased nutrient partitioning to milk production rather than reproductive performance.

LITERATURE CITED

AOAC. 1990. Official Methods of Analysis. 14th ed. ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Arias, R. P., P. J. Gunn, R. P. Lemenager, and S. L. Lake. 2012. Effects of post-AI nutrition on growth performance and fertility of yearling beef heifers. J. Anim. Sci. 63: 117-121.

BIF. 2016. Guidelines For Uniform Beef Improvement Programs. 9th ed. Beef Improvement Federation, NMREC Prairie Research Unit, Prairie, MS.

Geisert, B. G. 2007. Development of a set of forage standard to estimate *in vivo* digestibility of forages and prediction of forage quality of diets consumed by cattle grazing Nebraska Sandhills range pastures, Univ. of Nebraska, Lincoln.

Griffin, W. A., L. A. Stalker, D. C. Adams, R. N. Funston, and T. J. Klopfenstein. 2012. Calving date and wintering system effects on cow and calf performance I: A systems approach to beef production in the Nebraska Sandhills. Prof. Anim. Sci. 28: 249-259. doi:10.15232/S1080-7446(15)30355-7.

Kruse, S. G., G. A. Bridges, B. J. Funnell, S. L. Bird, S. L. Lake, R. P. Arias, O. L. Amundson, E. L. Larimore, D. H. Keisler, and G. A. Perry. 2017. Influence of post-insemination nutrition on embryonic development in beef heifers. Theriogenology 90: 185-190. doi:10.1016/j.theriogenology.2016.11.021.

Lardy, G., D. C. Adams, T. J. Klopfenstein, D. Clark, and J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills Native Range and subirrigated meadow diets and application of a metabolizable protein system. In: 1997 Nebraska Beef Cattle Report. Rep. No. MP 67-A. Univ. of Nebraska, Lincoln.

NRC. 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000. The National Academies Press, Washington, DC.

Springman, S. A., H. R. Nielson, J. A. Musgrave, J. Nollette, A. Applegarth, and R. N. Funston. 2017. Impact of heifer development system in two different breeding seasons. In: 2017 Nebraska Beef Cattle Report. Rep. No. MP104. Univ. of Nebraska, Lincoln. p. 8-10.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forages. J. Br. Grassl. Soc. 18: 104-111.

Van Soest, P. J., and J. B. Robertson. 1977. What is fibre and fibre in food? Nutr. Rev. 35.

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 requierment during winter. J. Anim. Sci 66: 603-612.

Weiss, W. P. 1994. Estimation of digestibility of forages by laboratory methods In: G.C. Fahey Jr., M. Collins, D.R. Mertens, and L.E. Moser (ed.) Forage Quality, Evaluation, and Utilization. p 644-681. Am. Soc. of Agron., Crop Sci. Soc. of Am., Soil Sci. Soc. of Am., Madison, WI.

Table 1. Nutrient analysis[1] of Sandhills upland range forage grazed by May-calving cows and heifers.

	Jul.	Aug.	Sept.
CP, % DM	5.6	6.5	5.0
IVOMD, %	60.8	57.1	54.6
TDN[2], %	54.8	49.8	48.4

[1]Samples collected from esophogeally fistulated cows (n = 3). Samples then analyzed for CP (FlashSmart N/Protein Analyzer CE, Elantech, Inc., Lakewood, NJ; AOAC, 1999; method 990.03). IVOMD analysis was conducted using a modified Tilley and Terry (1963) method with modifications described above.

[2]TDN = IVOMD × OM.

Table 2. Differences in BW, BCS, and ADG of May-calving heifers, primiparous cows and multiparous[1] cows grazing upland Sandhills range from May to November

	Class[2]				*P*-value[3]		
	H	PC	MC	SEM	Class	C × M	Month
n	12	12	12				
BW							
May	262^{c,z}	338^{b,y}	451^{a,y}	10	< 0.01	< 0.01	< 0.01
June	294^{c,z}	361^{b,y}	497^{a,x}	10			
July	324^{c,y}	376^{b,x}	499^{a,xy}	10			
August	349^{b,y}	396^{b,x}	516^{a,x}	10			
September	372^{b,y}	411^{b,x}	526^{a,x}	10			
October	371^{b,y}	393^{b,x}	496^{a,xy}	10			
November	385^{b,x}	428^{b,x}	514^{a,x}	11			
BCS[3]							
May	6.00^{a,x}	4.88^{c,z}	5.46^{b,y}	0.08	< 0.01	< 0.01	< 0.01
June	6.00^{a,x}	5.00^{b,yz}	5.69^{a,x}	0.08			
July	6.00^{a,x}	5.29^{b,x}	5.92^{a,x}	0.08			
August	6.00^{a,x}	5.36^{b,x}	5.89^{a,x}	0.08			
September	6.00^{a,x}	5.19^{b,xy}	5.90^{a,x}	0.08			
October	6.00^{a,x}	5.00^{b,yz}	5.36^{b,y}	0.08			
November	6.00^{a,x}	5.44^{b,x}	5.58^{b,x}	0.09			
Cycling, %[4]	92	67	100	14	0.38		
Pregnancy rate, %	92	75	100	13	0.58		
ADG, kg/d							
Prebreeding[5]	1.17^{a}	0.75^{b}	0.98^{a}	0.06	< 0.01		
Breeding Season[6]	0.64^{a}	0.50^{a}	0.13^{b}	0.05	< 0.01		
Total[7]	0.74^{a}	0.37^{b}	0.38^{b}	0.03	< 0.01		
BW change, kg							
Prebreeding[5]	59^{a}	38^{b}	50^{a}	3	< 0.01		
Breeding Season[6]	61^{a}	48^{a}	16^{b}	5	< 0.01		
Total[7]	109^{a}	55^{b}	63^{b}	5	< 0.01		
BCS[3] change							
Prebreeding[5]	0.00^{b}	0.33^{a}	0.54^{a}	0.09	< 0.01		
Breeding Season[6]	0.00^{a}	-0.29^{ab}	-0.42^{b}	0.09	0.01		
Total[7]	0.00	0.13	0.13	0.08	0.46		
Calf BW, kg							
May		47^{z}	43^{z}	5	0.37	< 0.01	< 0.01
June		70^{y}	76^{y}	5			
July		94^{x}	103^{x}	5			
August		111^{w}	125^{w}	5			
September		169^{v}	184^{v}	5			
205 d adj. wean[8]		254^{u}	246^{u}	5			
Calf ADG, kg/d							

Prebreeding[5]	0.92[b]	1.18[a]	0.04	< 0.01
Breeding Season[6]	0.82	0.82	0.04	0.99
Total[7]	0.85	0.93	0.03	0.12

[a,b,c]Means within a row lacking a common superscript differ ($P \leq 0.05$).

[u,v,w,x,y,z]Means within a column lacking a common superscript differ ($P \leq 0.05$).

[1]Considered a multiparous cow if she was in her 2[nd] parity or greater.

[2]H = heifers, PC = primiparous cow, MC = multiparous cow.

[3]Class = main effect of class (H, PC, or MC), C × M = interaction of class and month, M = effect due to month.

[3]Body condition score (1 = emaciated to 9 = obese; Wagner et al., 1988).

[4]Blood samples were taken on all females at d -10 and 0 of the breeding season. Considered to be cycling if blood serum progesterone concentration > 1 ng/ml at either or both time points.

[5]Considered the time from May 25 to July 15 (51 d).

[6]Considered the time from July to 15 to pregnancy diagnosis. Pregnancy diagnosis occurred Oct. 19 for heifers and primiparous cows (96 d) or Nov. 7 for multiparous cows (115 d).

[7]Considered the time from May 25 to pregnancy diagnosis. Pregnancy diagnosis occurred Oct. 19 for heifers and primiparous cows (147 d) or Nov. 7 for multiparous cows (166 d).

[8]Calculated using the equation proposed by BIF, 2016)

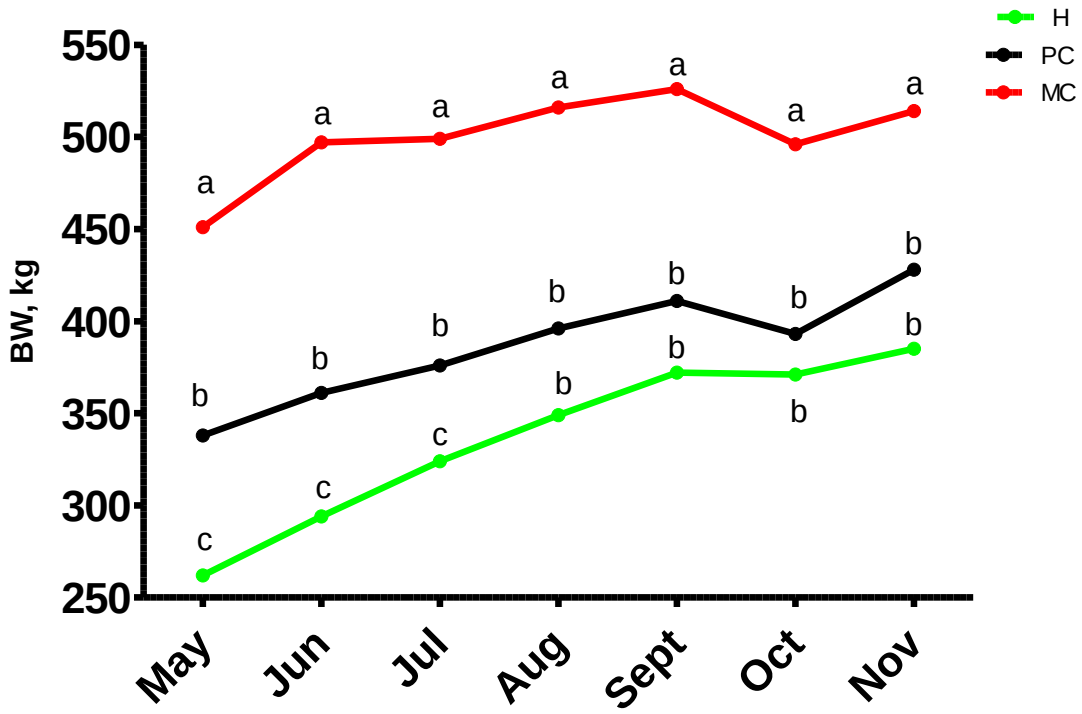

Figure 1. Differences in BW for heifers (**H**, n = 12), primiparous cows (**PC**, n = 12), and multiparous cows (**MC**, n = 12) grazing Sandhills upland range from late-May to Nov. Pregnancy diagnosis and wean occurred Oct. 19 for heifers and primiparous cows, and Nov. 7 for multiparous cows. Means within a month with different superscripts differ ($P < 0.05$).

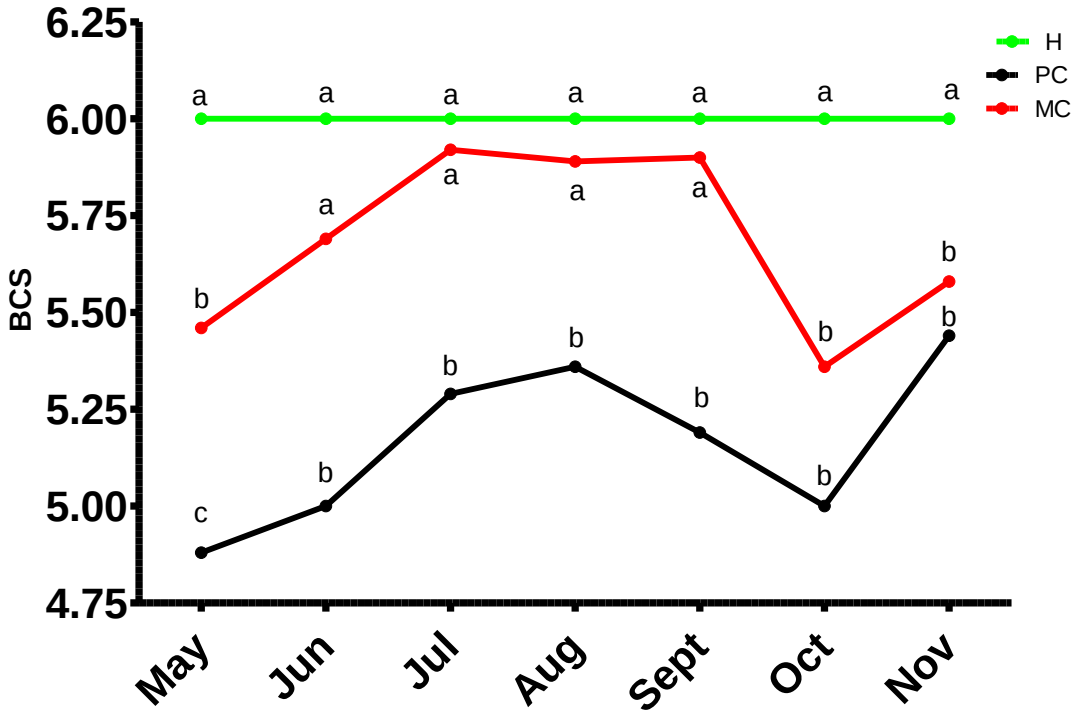

Figure 2. Differences in BCS (1= emaciated to 9 = obese; Wagner et al., 1988) for heifers (**H**, n = 12), primiparous cows (**PC**, n = 12), and multiparous cows (**MC**, n = 12) grazing Sandhills upland range from late-May to Nov. Pregnancy diagnosis and wean occurred Oct. 19 for heifers and primiparous cows, and Nov. 7 for multiparous cows. Means within a month with different superscripts differ ($P < 0.05$).

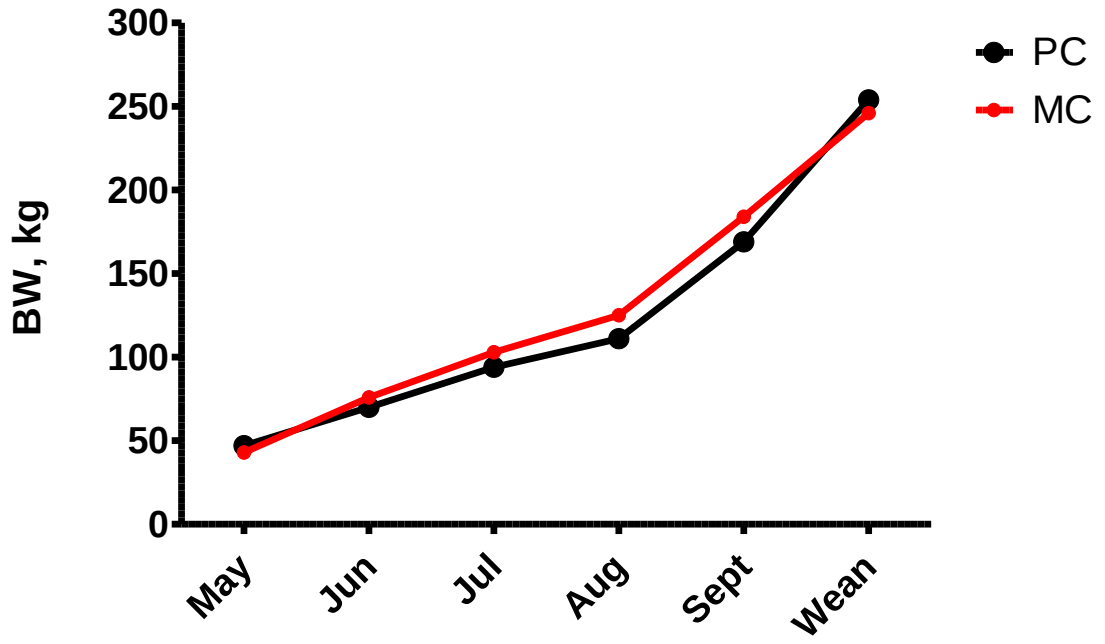

Figure 3. Differences in calf BW for primiparous cows (**PC**, n = 12) and multiparous cows (**MC**, n = 12) grazing Sandhills upland range from late-May to Nov. Wean BW is considered a 205-d adjusted weaning weight using the equation proposed by BIF, 2016. Weaning occurred Oct. 19 for heifers and primiparous cows, and Nov. 7 for multiparous cows.

APPENDIX B.

Effect of backgrounding and feedlot system strategies on May-born steer performance

A.C. Lansford, J.A. Musgrave, and R.N. Funston

University of Nebraska, West Central Research and Extension Center, North Platte, NE

ABSTRACT: A 6-yr study examined the effects of differing backgrounding and feedlot systems on May-born steer performance was conducted at Gudmundsen Sandhills Laboratory (**GSL**), Whitman, NE, and West Central Research and Extension Center (**WCREC**), North Platte, NE. Weaned steers (n = 392) were blocked by BW and randomly assigned to 1 of 2 backgrounding treatments: meadow hay ad libitum and 1.81 kg/d of a 33% CP (DM) supplement (**HI**) or allowed to graze dormant sub-irrigated meadow with 0.45 kg/d supplement (**LO**). Steers were placed on backgrounding treatments for 136 d from January to May. In May, one-half of the steers from each backgrounding treatment were placed in the WCREC feedlot system (**S-YRL**). The remaining steers grazed upland range at GSL and were transported to the WCREC feedlot mid-September (**L-YRL**). In yr 2 to 5, steers were fed in a GrowSafe (GrowSafe Systems Ltd., Airdrie, AB, Canada) feeding system. Over the period from wean to slaughter, backgrounding treatment did not ($P \geq 0.37$) influence BW; however, HI steers had a greater ($P < 0.01$) development period ADG (0.64 vs. 0.35 ± 0.03 kg/d, HI vs. LO) and May BW (275 vs. 244 ± 2 kg, HI vs. LO). Feedlot system increased ($P < 0.01$) steer BW over time. Gain:Feed ratios tended ($P = 0.06$) to be greater for LO steers (0.147 vs. 0.143 ± 0.002 kg:kg, LO vs. HI). At slaughter, HCW was greater ($P < 0.01$) for HI steers (418 vs. 407 ± 3 kg, HI vs. LO) and L-YRL steers (425 vs. 400 ± 3 kg, L-YRL vs. S-

YRL). Marbling score was greater ($P < 0.01$) for steers in the L-YRL system (491 vs. 459 ± 6, L-YRL vs. S-YRL) and a greater ($P < 0.01$) percentage of L-YRL steers graded USDA average Choice or greater (25 vs. 7 ± 3%, L-YRL vs. S-YRL). Furthermore, the LO backgrounding treatment tended ($P = 0.08$) to increase the percentage of steers grading USDA average Choice or greater (29 vs. 21 ± 4%, LO vs. HI). Alternative backgrounding and feedlot systems impacted steer feedlot and carcass traits.

Key Words: backgrounding system, feedlot system, May-calving

INTRODUCTION

Traditional backgrounding treatments have been focused on increased weight gain of steer progeny prior to feedlot entry; however, use of compensatory growth following mild nutrient restriction may alter metabolic function and energy utilization. Young cattle wintered on a low-rate of gain have the highest summer range gains (Bohman and Torell, 1956). Fox et al., (1972) reported fewer days on feed for steers who were restricted during the backgrounding phase and allowed to undergo compensatory growth. This may have been a result of increased protein % relative to BW and decreased F:G ratios for compensatory steers. Furthermore, utilization of a low-cost, high-quality forage during the summer months to increase steer BW may be an effective method to increase profitability for Sandhill's producers. Use of this forage allows for fewer days in the feedlot to reach target slaughter BW and fatness.

MATERIALS AND METHODS

The University of Nebraska Animal Care and Use Committee approved the procedures and facilities used in this experiment.

A 6-yr study was conducted at the Gudmundsen Sandhills Laboratory (**GSL**), Whitman, NE, and West Central Research and Extension Center (**WCREC**), North Platte, NE to examine the effects of differing development systems and feeding systems on May-born steers.

Preweaning Management

In July, at approximately 2 mo of age, all calves were vaccinated against infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine respiratory syncytial virus and bovine viral diarrhea type I and II (BoviShield 5; Zoetis Animal Health, Parsippany, NJ). Calves were also weighed, branded, and castrated. At weaning, calves were weighed, given an injection of BoviShield 5 (Zoetis Animal Health) and electronic ear tags applied. Calves were also vaccinated against bovine rotavirus-coronavirus, clostridium perfringens type C and D, and *E. Coli* bacterin-toxoid (Guardian; Intervet, Millsboro, DE); and a topical insecticide applied (Ivermectin; Aspen Veterinary, Liberty, MO).

Development System

Following weaning in January, steers were blocked by wean BW and randomly assigned to 1 of 2 development systems until approximately May 8. Development treatments were replicated twice within yr. Steers assigned to a high-input system (**HI**; n = 194, 194 ± 4 kg) were offered meadow hay ad libitum and 1.81 kg/d of a 33% CP (DM) supplement (Table 1). The remaining steers were assigned to a low-input system (**LO**; n = 198, 199 ± 4 kg) and allowed to graze dormant sub-irrigated meadow with 0.45 kg/d of the same supplement.

Feedlot System

At the end of development treatment, one-half of the steers from each development system were transported to WCREC (162 km) and placed in a feedlot (**S-YRL**; n = 195, 250 ± 2 kg). Steers in the S-YRL system were implanted with 100 mg trenbolone acetate and 14 mg estradiol benzoate (Synovex Choice; Ft. Dodge Animal Health, Overland Park, KS) at feedlot entry. The steers remaining at GSL were implanted with 40 mg trenbolone acetate and 8 mg estradiol (Revalor G; Merck Animal Health, Summit, NJ) and grazed upland range for the summer at GSL. These steers were transported to the WCREC feedlot approximately Sept. 14 (**L-YRL**; n = 197, 347 ± 2 kg) and implanted with 36 mg zeranol (Ralgro; Merck Animal Health) at feedlot entry.

Upon entry to the feedlot, both groups of steers were limit fed 5 d at 2.0% of BW, and weighed 3 consecutive days. The average of these weights was considered feedlot entry BW. Steers were adapted over 21 d to a common diet (Table 3). Steers were reimplanted with 200 mg trenbolone acetate and 28 mg estradiol benzoate (Synovex Plus; Ft. Dodge Animal Health) 110 d after feedlot entry for S-YRL steers and 70 d for L-YRL steers. Hot carcass weight was recorded at slaughter and carcass data was collected following a 24 h carcass chill. Final BW was calculated from HCW adjusted to a common dressing percentage of 63.0%. Percentage of empty body fat was calculated using an equation proposed by Guiroy et al. (2001) where EBF = 17.76107 + [11.8908 × 12^{th} rib fat (cm)] + (0.0088 × HCW) + (0.0081855 × marbling score) – (0.4356 × LM area).

GrowSafe Feeding System

No intake data was available for steers enrolled in the first year of the study. In yr 2 to 6, steers were placed in a GrowSafe feeding system (GrowSafe Systems Ltd.,

Airdrie, AB, Canada) upon feedlot entry. No intake data was recorded over the initial 2 wk adaptation period to the system or on the day of shipping. Steers remained in the GrowSafe feeding system for 190 or 142 d for S-YRL or L-YRL steers, respectively. Recorded intakes from the GrowSafe system were used to calculate ADFI, G:F, and residual feed intake (**RFI**). Residual feed intake was considered as the actual ADFI minus predicted ADFI. Predicted ADFI was calculated using the following equation: Group avg. ADFI + [$b_m \times$ (Indiv. midBW$^{0.75}$ – Group avg. midBW$^{0.75}$)] + [$b_g \times$ (Indiv. ADG – Group avg. ADG)] where midBW$^{0.75}$ = mid-test metabolic BW and was predicted using the equation: Feedlot entry BW + [ADG × (Total no. of days in feedlot ÷ 2)]. Any daily DMI values above or below 4 standard deviations from the group mean for system within year were considered outliers and excluded from the data. The first year of calculated RFI values (yr 2) was removed from the data set due to low R^2 values when ADFI was regressed against midBW$^{0.75}$ and ADG for both feedlot systems (0.36 and 0.12, S-YRL and L-YRL, respectively). For yr 3 to 6, R^2 values for the S-YRL system were 0.56, 0.64, 0.73, and 0.46, respectively, and for the L-YRL system were 0.66, 0.74, 0.69, and 0.81, respectively.

Statistical Analysis

All data were analyzed using the PROC GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC, version 9.4) with denominator degrees of freedom determined using the Kenward-Roger approximation. Development treatment × feedlot system × yr was considered the experimental unit for steers. The model statement included the fixed effects of development treatment, feedlot system, and resulting interaction. Year was included as a covariate in all analysis, and was removed when $P \geq 0.05$. Steer BW was

analyzed using repeated measures where month since wean was considered the repeated variable. Due to generation of the lowest Akaike and Bayesian information criterion values, heterogeneous compound symmetry was selected for the covariance structure.

When analyzing steer feedlot ADG, the experimental unit for analyses was considered as period × treatment × feedlot system × yr where initial period was feedlot entry to reimplant, reimplant period was reimplant to slaughter, and total feedlot period was feedlot entry to slaughter. Conversely, the experimental unit for steer feedlot DMI, G:F, and RFI values was considered as treatment × feedlot system × yr. Coefficients necessary for RFI calculation were obtained using the PROC GLM procedure (SAS). The model statement included ADG, $midBW^{0.75}$, yearr, and EBF. The slope coefficient b_m was considered as the residual estimate for $midBW^{0.75}$, and for b_g was considered the residual estimate for total feedlot ADG when total feedlot ADFI was regressed against those variables. Data were considered significant if $P \leq 0.05$ and a tendency if $0.05 < P \leq 0.10$. The Tukey-Kramer adjustment was used for all comparisons of LS means. Data were considered significant at $P \leq 0.05$ and a tendency if $P \leq 0.10$ and $P > 0.05$. Data are presented as mean ± SEM, unless otherwise denoted.

IMPLICATIONS

Steers backgrounded on the LO system exhibit reduced backgrounding ADG and final BW at conclusion of the backgrounding treatment, these steers have decreased feedlot ADFI and increased G:F ratios. Furthermore, LO steers tended to have a greater percentage grading USDA average Choice or higher, although HCW was reduced. Alternately, steers in a L-YRL feedlot system, had increased ADG from reimplant to slaughter, but had decreased G:F ratios. Furthermore, L-YRL steers had increased HCW,

which resulted in an increased percentage of overweight carcasses. Use of summer grazing also increased EBF, yield grade, and percentage of steers grading USDA average Choice or greater. Producers should consider alternate development and feeding strategies to reduce costs and increase profits.

LITERATURE CITED

Bohman, V.R. and C. Torell. 1956 Compensatory growth of beef cattle: The effect of protein supplements. J. Anim. Sci. 15:1089.

Fox, D.G., R.R. Johnson, R.L. Preston, T.R. Dockertt, and E.W. Klosterman. 1972. Protein and energy utilization during compensatory growth in beef cattle. J. Anim. Sci. 34:310-318.

Guiroy, P. J., D. G. Fox, L. O. Tedeschi, M. J. Baker, and M. D. Cravey. 2001. Predicting individual feed requirments of cattle fed in groups. J. Anim. Sci. 79.

Table 1. Nutrient analysis of supplement[1] provided to steers during backgrounding phase[2]

Item	
Nutrient	
CP, % (DM)	32.9
RUP, % CP (DM)	39.7
TDN, % (DM)	78.4
ME, Mcal/kg[2]	2.83
NEm, Mcal/kg[2]	1.57
Ingredient, % DM	
Dried distillers grains meal	52.5
Soybean meal (46.5% CP)	14.7
Vitamin and mineral package[3]	13.3
Wheat middlings	6.3
Sunflower meal (35% CP)	6.3
Molasses, liquid	3.7
Urea	1.6
Cull Beans	1.5

[1]Formulated to provide 177 mg/ kg monensin (Rumensin, Elanco Animal Health, Indianapolis, IN).

[2]At weaning in January, steers were blocked by BW and assigned to 1 of 2 development treatments until May 8: HI = steers offered meadow hay ad libitum plus 1.8 kg/d 33% CP (DM) cube, LO = steers grazed dormant subirrigated meadow plus 0.45 kg/d of the same supplement.

Table 2. Common feedlot diet and nutrient composition fed to growing steers[1]

	DM, %
Item	
Corn	39.0
Prairie hay	6.0
Wet corn gluten feed	52.0
Supplement[2]	3.0
Nutrient	
CP, %	13.4
RUP, % CP	38.2
TDN, %	84.0

[1]Steers were adapted to a common diet over a 21 d period following feedlot entry.
[2]Formulated to provide 177 mg/kg monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and 89 g/kg Tylosin (Tylan 40, Elanco Animal Health).

Table 3. Effect of backgrounding system and feedlot system on May-born steer BW, ADG, DMI, G:F, and RFI values

	Treatment[1]										
	HI		LO		SEM	*P* – value[3]					
	S-YRL	L-YRL	S-YRL	L-YRL		D	D × M	FS	FS × M	D × FS	M
n	97	97	100	98							
BW, kg											
Wean	193	194	202	193	5	0.71	0.37	< 0.01	< 0.01	0.90	< 0.01
Yearling	274[a]	275[a]	244[b]	243[b]	5						
Feedlot entry	274[c]	362[a]	244[d]	350[b]	5						
Reimplant	477[ab]	487[a]	471[b]	482[ab]	5						
Final[4]	641[c]	686[a]	628[c]	663[b]	5						
BG ADG, kg/d[3]	0.63	0.66	0.31	0.40	0.05	< 0.01		0.20		0.50	
Feedlot ADG, kg/d											
Initial[5]	1.89	1.76	1.99	1.84	0.06	0.16		0.02		0.89	
Reimplant[6]	1.73	2.09	1.68	1.87	0.07	0.06		0.01		0.24	
Total	1.81[b]	1.92[a]	1.83[ab]	1.84[ab]	0.03	0.31		0.05		0.10	
Total ADFI, kg/d	11.94	13.25	11.64	12.91		0.03		< 0.01		0.86	
G:F, kg:kg	0.147	0.139	0.154	0.141		0.06		< 0.01		0.20	
Unadj. RFI[7]	-0.031	0.083	-0.032	-0.062		0.48		0.68		0.49	
Adj. RFI[8]	-0.005	0.115	-0.060	-0.093		0.21		0.68		0.50	

[a,b,c,d]Means within a row that lack a common superscript differ ($P \leq 0.05$).

[x,y]Means within a row that lack a common superscript tend to differ ($0.05 < P \leq 0.10$).

[1]At weaning in January, steers were blocked by BW and assigned to 1 of 2 development treatments until May 8: HI = steers offered meadow hay ad libitum plus 1.8 kg/d 33% CP (DM) cube, LO = steers grazed dormant subirrigated meadow plus 0.45 kg/d of the same supplement. Feedlot system: S-YRL = steers entering feedlot at an average date of May 8, L-YRL = steers entering feedlot at an average date of Sept. 14.

[2]D = effect due to development treatment, D × M = interaction of development system and month, FS = effect due to feedlot system, FS × M = interaction of feedlot system and month, D × FS = interaction of development system and feedlot system, M = effect due to month.

[3]BG ADG = backgrounding period ADG. Period from January 8 weaning to an average date of May 8 (yearling).

[4]Final BW calculated from HCW adjusted to a common dressing percent of 63.0%.

[5]Period from feedlot entry to reimplant.

[6]Period from reimplant to slaughter.

[7]Unadj RFI = unadjusted residual feed intake where RFI = Actual ADFI – [Group Avg. ADFI + [b_m*(Indiv. mid-test $BW^{0.75}$ – group avg. mid-test $BW^{0.75}$ + [b_g*(Indiv. ADG – group avg. ADG)] where b_m is the slope coefficient for mid-test BW and b_g is the slope coefficient for ADG when regressed on ADFI.

[8]Adj. RFI = RFI adjusted for differences in empty body fat. Empty body fat calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12^{th} rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).

Table 4. Effects of development system and feedlot system on steer carcass characteristics

	Treatment[1]							
	HI		LO			*P* – value[2]		
	S-YRL	L-YRL	S-YRL	L-YRL	SEM	D	FS	D × FS
n	97	97	100	98				
HCW, kg	404	432	396	418	4	< 0.01	< 0.01	0.40
EBF, %[3]	34	35	34	35	0.3	0.88	< 0.01	0.72
Marbling score[4]	451	485	466	498	8	0.11	< 0.01	0.86
12th rib fat, cm	1.5	1.5	1.5	1.6	0.1	0.65	0.31	0.81
LM area, cm^2	36.9	38.1	36.7	37.2	0.4	0.14	0.02	0.36
Yield grade	3.2	3.3	3.2	3.3	0.1	0.90	0.04	0.97
Quality grade								
% Sm or higher[5]	77	87	85	88	4	0.27	0.09	0.50
% Md or higher[6]	15	28	23	36	6	0.08	< 0.01	0.83
Carcass size								
% ≥ 454 kg or higher[7]	6	33	6	18	5	0.27	< 0.01	0.24
% ≥ 476 kg or higher[8]	1	14	1	4	4	0.40	0.01	0.38

[1]At weaning in January, steers were blocked by BW and assigned to 1 of 2 development treatments until May 8: HI = steers offered meadow hay ad libitum plus 1.8 kg/d 33% CP (DM) cube, LO = steers grazed dormant subirrigated meadow plus 0.45 kg/d of the same supplement. Feedlot system: S-YRL = steers entering feedlot at an average date of May 8, L-YRL = steers entering feedlot at an average date of Sept. 14.

[2]D = effect due to development treatment, FS = effect due to feedlot system, D × FS = interaction of development system and feedlot system.

[3]EBF = empty body fat. Calculated using Guiroy et al. (2001) prediction equation: EBF = 17.76107 + (11.8908 × 12th rib fat depth) + (0.0088 × HCW) + [0.81855 × (marbling score/100 + 1)] – (0.4356 × LM area).

[4]400 = small^0.

[5]Sm = small quality grade, USDA low Choice. Marbling score ≥ 400.

[6]Md = modest quality grade, USDA average Choice. Marbling score ≥ 500.

[7]Equivalent to carcass size of ≥ 1,000 lb.

[8]Equivalent to carcass size of ≥ 1,050 lb