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Management Strategies for Beef Heifer Development

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Management Strategies for Beef Heifer Development

by

Shelby Ann Springman

A THESIS

Presented to the faculty of

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Management Strategies for Beef Heifer Development

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University of Nebraska, 2017

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Four experiments were conducted to determine the impact of development systems, trace mineral source, and trace mineral supplementation on beef heifers. Experiment 1 utilized 300 Angus-based, spring-born heifers to evaluate postweaning heifer development systems on gain, reproductive performance, and feed efficiency as a pregnant heifer. Heifers were blocked by BW and randomly assigned to graze corn residue, upland range, or were fed 1 of 2 diets in a drylot differing in energy levels: high or low. Heifer development system did not impact AI or final pregnancy rates. Development cost per pregnant heifer was not different among treatments. Furthermore, pregnant heifer feed efficiency was not impacted by development system.

In Experiment 2, March-born and May-born crossbred heifers were stratified by BW and randomly assigned to 1 of 2 postweaning treatments from mid-January to mid-April: (1) ad libitum meadow hay and 1.64 kg/d of a 32% CP supplement (HAY) or (2) grazed meadow and 0.41 kg/d of supplement (MDW). March and May-born HAY heifers experienced greater ADG during the treatment period. During the summer period, however, MDW heifers had greater ADG than HAY heifers, likely due to compensatory gain. Heifer development system did not impact pregnancy rate in the March or May replacement heifers; however, March-born heifer pregnancy rate was greater than May-born. The lower pregnancy rate in May heifers may be due to declining forage quality during the late-summer breeding season.

In Experiment 3, heifers were synchronized with a 14-d CIDR-prostaglandin $F_{2\alpha}$ protocol and either injected with a trace mineral or received no injection at CIDR insertion. Prior to synchronization, heifers were range developed and offered free-choice mineral. Mineral status prior to mineral treatment did not differ among heifers. The proportion of heifers pregnant within the first 21 d and 33 d of the breeding season was not different nor was overall pregnancy rates. In summary, injectable trace mineral at CIDR insertion 33 d before artificial insemination did not influence reproductive performance in heifers with adequate trace mineral status.

In a final study, beef heifers previously managed on 3 separate development systems were stratified by previous development treatment and BW and allocated into 1 of 8 pens per yr. Pens were randomly assigned to 1 of 2 mineral sources, hydroxy (HD) or sulfate (CON). Mineral status was analyzed via two liver biopsies prior to and following the 68-d mineral treatment. Heifer BW, ADG, and reproductive performance was not different in heifers receiving either mineral source treatments. Mineral source treatment did not affect final Mn or Zn concentrations. Liver Cu concentrations were greater for CON than HD heifers at the end of the trace mineral trial; however, all heifers maintained adequate status throughout the study. The difference in Cu status may be due to ruminally insoluble hydroxy Cu allowing thiomolybdate absorption, thus reducing hepatic Cu stores and resulting in decreased Cu status.

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Chapter I

Literature Review

Introduction

Producing the next generation of females in a beef herd is a critical and expensive enterprise for producers (Hall and Glaze, 2015). Traditional recommendations suggest heifers reach 65% of mature BW at the time of breeding to maximize pregnancy rates (Patterson et al., 1992). Due to the cost of retaining replacement heifers, there have been more efforts made to devise economical heifer development methods. Lowering traditional target BW may allow for development on a lower rate of gain and potentially decrease feed costs (Funston and Deutscher, 2004). Utilizing grazing systems and reducing the amount of harvested feedstuffs has grown considerable interest (Larson et al., 2011). Developing heifers on winter range and corn residue has demonstrated to be an alternative to confinement-feeding (Summers et al., 2014). Additionally, exposing young livestock to environments encountered in the future could lead to increased forage efficiency and animal production (Provenza and Balph, 1988).

Producers consider many variables when selecting a calving date and each operation must select a system dependent upon its available resources. By choosing a suitable calving season, producers may be able to maximize profitability and effectively utilize available resources. Shifting the calving date to match forage quantity and quality may reduce inputs, although supplementation may be necessary in periods of nutritional deficiencies.

Trace minerals are dietary elements required in small quantities in beef cattle for growth, lactation, reproduction, and health. Adequate trace mineral status in beef cattle is crucial as deficiencies or toxicities result in economic and production loss (Spears and Weiss, 2014). A deficiency in Cu results in delayed estrus, reduced first-service conception and pregnancy rates, and fetal abnormalities. Manganese participates in hormone synthesis within the ovary by its involvement in cholesterol synthesis. Zinc is involved in many enzymatic reactions linked to carbohydrate metabolism, nucleic acid metabolism, and protein synthesis (Smith and Akinbamijo, 2000). Therefore, its role in the gonads is essential due to the active growth and division that occurs. A common perception exists among beef producers that cattle can instinctually sense when a diet is deficient in a mineral (Olson, 2007). Unfortunately, beef cattle do not have this "nutritional wisdom," thereby mineral supplementation is necessary in confined and grazing cattle.

Estrous Cycle

The estrous cycle characterizes the cyclical pattern of ovarian activity that mediates female animals to transition from a state of reproductive non-receptivity to receptivity (Forde et al., 2011). In the female bovine, estrous cycle length ranges from 18 to 24 days. The cycle consists of 2 phases: follicular and luteal (Forde et al., 2011). The follicular phase begins after luteolysis and ends with ovulation of the dominant follicle, which can be divided into proestrus and estrus and lasting 4 to 6 days. The luteal phase describes the period following ovulation when the corpus luteum is developed. The luteal phase can be partitioned further into metestrus and diestrus and generally persists for 14 to 18 days. Hormones produced from the hypothalamus (GnRH), anterior pituitary (FSH

and LH), ovaries (estradiol and progesterone), and uterus ($PGF_{2\alpha}$) function via positive and negative feedback loops to regulate this cycle (Forde et al., 2011; Smith et al., 2015).

Two or three follicular waves characterize the bovine estrous cycle, which involves 3 stages: recruitment, selection, and dominance (Jaiswal et al., 2009). Recruitment stage involves the recruitment of a cohort of small follicles and begins due to the rise in FSH (Atkins et al., 2013). The second stage, selection, refers to secretion of estradiol and inhibin by the cohort of follicles. This secretion subsequently results in FSH concentrations decreasing. One follicle among the cohorts is selected to survive the low FSH levels. The remaining follicles will thereby undergo atresia. Dominance represents growth of the selected follicle and inhibition of new follicular waves until ovulation of dominant follicle occurs. Low FSH inhibits new follicular waves due to the dominant follicle secreting estradiol and inhibin.

Follicular Phase

Following regression of the corpus luteum (luteolysis), progesterone concentrations are low. Therefore, progesterone's negative feedback to the pituitary is reduced and this causes an increase in LH pulse frequency and a rise in estradiol concentration. The process begins when the hypothalamus receives a signal from the higher brain centers to secrete GnRH. This decapeptide binds to 7-transmembrane G-protein coupled receptors on the gonadotroph cells of the anterior pituitary and works through G_q and G_s proteins to stimulate the release of LH and FSH. These 2 gonadotropins also bind to 7-transmembrane G-protein coupled receptors and work through G_q and G_s proteins on 2 different cell types.

Luteinizing hormone binds to its receptor on theca cells of the follicle and stimulates steroidogenesis of testosterone. Testosterone is aromatized into estrogen in the granulosa cells of the follicle, and when FSH binds to its receptor on these specific cells, estrogen is secreted. Additionally, FSH will stimulate ovarian follicular growth and maturation apart from estrogen synthesis and secretion. The follicular phase has a positive and a negative feedback loop. Inhibin, secreted from the granulosa cells, presents a negative feedback on the anterior pituitary to FSH stimulation (Bleach et al., 2001). Inhibin along with Activin are stimulated by increased FSH. While inhibin inhibits FSH secretion, Activin acts to stimulate FSH secretion. Estrogen exhibits a positive feedback on the hypothalamus and anterior pituitary for the continuation of follicular growth and a dominant follicle greater than or equal to 10 mm can be ovulated by GnRH if it is the dominant follicle (Perry et al., 2005).

When estrogen reaches a certain threshold, it induces a GnRH surge from the hypothalamus into the hypophysial portal system, which stimulates an LH surge and thus ovulation. Follicular rupture represents the end of the follicular phase, and increasing levels of estradiol initiates estrous behavior. Duration of estrus is usually 10 to 18 h in bovine females. The primary sign of estrus is standing to be mounted. Additional indications include frequent mounting, restlessness, and clear mucus from the vulva.

Luteal Phase

The luteal phase begins with development of a corpus luteum and ends with luteolysis. The primary ovarian structure is the corpus luteum, which secretes progesterone. This steroid hormone maintains pregnancy, and throughout pregnancy, decreases gonadotropin secretion and prevents occurrence of estrus. Additionally, estrous

cycle length is predominantly determined by progesterone (Smith et al., 2015). In the absence of an embryo, prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) is released from the uterus to lyse the corpus luteum. This luteolytic mechanism occurs when progesterone loses its ability to block estrogen synthesis and oxytocin receptors due to its prolonged exposure. Therefore, estrogen binds to its receptor and upregulates oxytocin receptors, which allows oxytocin to bind and stimulate the release of $PGF_{2\alpha}$. A positive feedback loop between oxytocin and $PGF_{2\alpha}$ is generated and when $PGF_{2\alpha}$ reaches a specific threshold within a given time period, luteolysis can be induced.

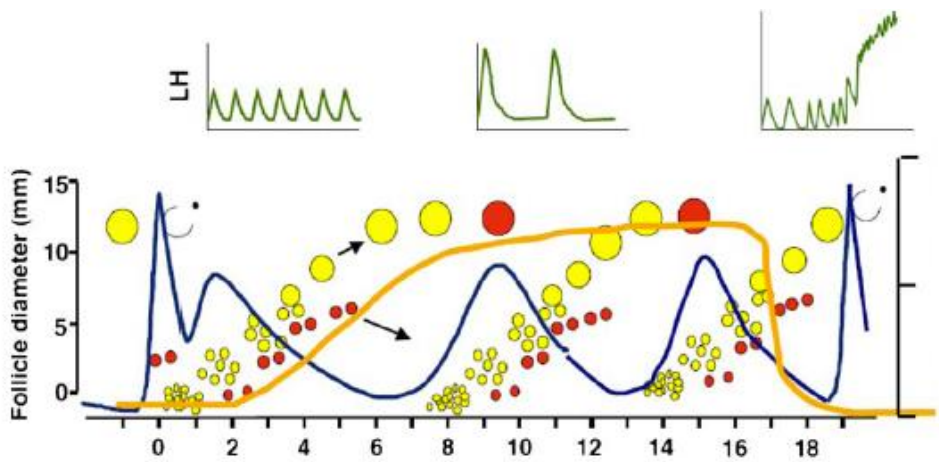

Figure 1. Illustration of bovine estrous cycle. Blue line depicts secretion pattern of follicle-stimulating hormone. Orange line dictates progesterone secretion pattern during the estrous cycle. The pulsatile secretion of luteinizing hormone is presented in the graphs above the illustration. Yellow circles represent growing follicles while red circles depict atretic follicles. (adapted from Forde et al., 2011).

Puberty

Age at puberty is an important production trait. Puberty attainment before the breeding season can increase first-service conception, earlier pregnancy, and increase lifetime productivity (Gasser et al., 2006). Puberty has been defined as the first ovulatory estrus followed by a luteal phase of normal length (Atkins et al., 2013). Puberty must be

reached by 15 mo of age if a heifer is expected to conceive and calve by 24 months (Patterson et al., 1992). Heifers calving early as 2-yr olds continue calving early in future years and wean more pounds of calf in their lifetime (Gonzalez-Padilla et al., 1975). Failure to reach puberty at an appropriate age largely contributes to a heifer not becoming pregnant in the first breeding season (Gasser et al., 2006). Puberty is induced via maturation of the neuroendocrine system. Additional factors affecting puberty timing include nutrition, genetics, photoperiod, and exogenous progestins.

When transitioning to sexual maturity, estradiol's negative feedback on LH and GnRH declines (Gasser et al., 2006). Therefore, the hypothalamus matures, and the frequency of LH pulses increase. The increased frequency of LH pulses stimulates puberty and development of dominant ovarian follicles during the peripubertal period (Gasser et al., 2006; Kinder et al., 1995). Peripuberty is classified as 50 days prior to puberty (Day and Anderson, 1998). Dominant follicle size increases as puberty approaches and estradiol secretion increases accumulating in a preovulatory LH surge. Progesterone concentrations begin to rise in short periods following ovulation in the later phases of peripuberty. Puberty is attained once behavioral estrus is followed by ovulation and corpus luteal development within a typical time period.

Activation of GnRH neurons is key in puberty initiation (Han et al., 2005). Kisspeptin, an arginine-phenylalanine amide peptide, has been acknowledged as a crucial regulator of puberty and gonadotropin and sex steroid secretion (Jayasena et al., 2009). Kisspeptin is recognized to act as part of an intricate neuropeptide network that works to regulate GnRH secretion and is secreted in a pulsatile manner similar to GnRH (George and Seminara, 2012). These neuropeptides are encoded by the metastasis suppressor

gene, *KISS*-1 (Han et al., 2005). The receptor for kisspeptin, KISS1R, is expressed in the hypothalamus, pituitary, and the placenta. Thus, it can easily extend to GnRH neurons (George and Seminara, 2012). Previous studies in humans and mice demonstrated kisspeptin's role in puberty when mutations or deletions of KISS1R prevented normal pubertal maturation (Clarkson et al. 2010). Furthermore, exogenous administration of kisspeptin in rodents and primates have been shown to activate the HPG axis at puberty or prior to puberty (Clarkson et al., 2010). Therefore, it is reasonable to acknowledge kisspeptin's critical role in the pubertal activation of GnRH neurons.

Metabolic signals, such as leptin, play a role in initiation of puberty. Leptin, a polypeptide comprised of 167 amino acids, has been regularly associated with increasing the feeling of satiety by acting on CART and POMC neurons of the anorexigenic center in the hypothalamus. Leptin's role in puberty was initially inferred when mutant mice lacking leptin production or leptin receptors did not experience normal puberty (Ebling, 2005). Receptors have been found to be located in the lungs, kidneys, ovaries, and adrenal glands to name a few; however, the arcuate nucleus contains the greatest concentration of leptin receptors (Goumenou et al., 2002). Unfortunately, the GnRH neurons of the hypothalamus do not contain the leptin receptor. Within the arcuate nucleus, leptin receptor mRNA has been found to be expressed in around 40% of Kiss1 mRNA-expressing cells (Liu et al., 2016). Therefore, it is believed GnRH release by leptin is facilitated through kisspeptin. Thus, leptin serves as a permissive gate rather than a trigger signal for the onset of puberty (Hausman et al., 2012).

Nutrition

Nutritional management of heifers significantly influences the timing of puberty. Low planes of nutrition delay puberty by postponing the peripubertal decline in estradiol's negative feedback on LH (Day and Anderson, 1998). Roberts et al. (2009) randomly assigned heifers to receive ad libitum or restricted access to feed for a 140-d period at 6 mo of age. Following the treatment period, a greater proportion of heifers offered ad libitum feed attained puberty by 14 mo of age than restricted heifers. Body weight is also a critical factor affecting the onset of puberty. Gonzalez-Padilla et al. (1975) observed a smaller percentage of heifers attaining puberty at a weight below 260 kg compared with heifers greater than 260 kg.

Early weaning and a high-concentrate diet results in precocious puberty that mechanistically occurs by reducing the estradiol negative feedback on LH secretion (Gasser et al., 2006b). Gasser et al. (2006c) weaned crossbred heifers at 73 d of age and fed either a high-concentrate diet or a control diet. Target BW gains for the heifers receiving the high-concentrate diet was 1.50 kg/d while the control heifers were targeted at 0.75 kg/d. Precocious puberty occurred in the majority of high-concentrate heifers. High-concentrate heifers also had a greater number of LH pulses than control heifers. Therefore, precocious puberty can be achieved through early weaning and a high-concentrate diet. Another study by Gasser et al. (2006a) evaluated whether induction of precocious puberty accelerates ovarian maturation. Heifer calves were weaned at 104 d or 208 d of age. Early-weaned heifers were assigned to a high-concentrate or control diet. The normal-weaned heifers received the control diet. Early-weaned heifers receiving the high-concentrate diet reached puberty at an earlier age than early-weaned control and

normal-weaned heifers. Heifers experiencing precocious puberty had a greater maximum diameter of the dominant follicle, longer follicular wave duration, and greater peak estradiol concentrations, thereby accelerating ovarian maturation.

Progestins

Puberty can be modified by genetics and plane of nutrition; however, a fair proportion of heifers do not reach puberty by the start of the breeding season. Therefore, an alternative method of puberty induction before breeding needed to be investigated. The short-term usage of progestins has induced estrus in prepubertal heifers. During puberty induction in heifers and prior to resumption of estrous cyclicity in cows, progesterone elevates. Therefore, increased progesterone concentrations are believed to be a prerequisite for normal estrous cycle development (Patterson et al., 2000). Heifers will respond to progestins if they are within 30 days of attaining puberty (Hall and Glaze, 2015). Thus, utilizing an estrous synchronization protocol that comprises a progestin is key to induce cycling in prepubertal heifers or anestrous cows. Melengestrol acetate (MGA) and controlled internal drug releasing (CIDR) devices are common progestins used in the beef industry today. Initially, MGA was utilized as a feed additive in feedlot heifers to inhibit estrus and ovulation, thus allowing for greater feed efficiency (Bloss et al., 1966). Currently, MGA is an orally-active progestin approved for heifer estrous synchronization and is provided at an individual dose of 0.5 mg/ day. Vaginal inserts (CIDRs) release progesterone for at least 7 days to suppress estrus and ovulation and are approved for use in heifers and cows to synchronize estrus.

Nutritional status and age influence progestin effectiveness. Gonzalez-Padilla et al. (1975) induced cyclicity in prepubertal heifers via progestogens and noted a greater

effect of the progestogen when combined with increased dietary energy. Hall et al. (1997) observed crossbred heifers fed a rapid or slow-then-rapid postweaning gain to determine the effect of a progestin on age or pattern of gain on timing of puberty. Progestin-treated heifers displayed a pubertal estrus 5 days following progestin removal compared with control heifers at 12.5 months. However, at 9.5 or 11 months of age, the progestin did not induce puberty nor was it affected by gain pattern.

Ionophores

Ionophores such as monensin or lasalocid have been recommended for use in heifer development programs. Recognized as feed additives to improve feed efficiency, ionophores also alter age of puberty in beef heifers. Moseley et al. (1982) observed 34% more monensin-fed heifers reaching puberty compared with control heifers when developed in the drylot. Furthermore, adding ionophores during heifer development hastens puberty by 15 days (Moseley et al., 1982). Purvis and Whittier (1996) found heifers fed monensin attained puberty at an earlier age and showed greater first-service conception rates than untreated heifers. Sprott et al. (1988) described the pubertal age adjustment as a hormonal response to an increased propionate:acetate ratio in the rumen from feeding ionophores. Monensin, for example, decreases ruminal acetate and butyrate concentrations while increasing propionate, thereby increasing the efficiency of feedstuff utilization (Moseley et al., 1977). Heifers fed a diet with a low propionate: acetate ratio were older at puberty than controls (McCartor et al., 1979).

Postweaning Management

Traditional recommendations suggest heifers reach 65% of mature BW at the time of breeding (Patterson et al., 1992). The target weight concept for mature BW was

introduced to provide producers a percentage-based threshold heifers should achieve at breeding. Due to increasing heifer development costs, more efforts have been made to devise economical heifer development methods. Lowering traditional target BW may allow heifers to be developed on a lower rate of gain and potentially decrease feed costs (Funston and Deutscher, 2004). Funston and Deutscher (2004) conducted a 3-yr study to evaluate the effects of developing heifers to 55 or 60% of mature BW at time of breeding. More high-gain heifers were pubertal prior to breeding; however, pregnancy rates did not differ between low-gain and high-gain heifers. Feed costs were $22/heifer lower in heifers targeted to 55% of mature BW. Martin et al. (2008) also indicated economic savings in heifers targeted to 51% of mature BW versus 57%. In this study, overall pregnancy rates did not differ between targeted BW; however, heifers developed to a lighter target BW had later calving dates and lighter calf weaning weights.

Utilizing grazing systems and reducing the amount of harvested feedstuffs has grown considerable interest (Larson et al., 2011). Previous research has evaluated the use of alternative development systems on animal performance. Funston and Larson (2011) compared a traditional postweaning drylot (DL) development with an extensive winter grazing system (EXT) that combined corn residue and winter range. Extensively-developed heifers gained less during the winter and were lighter at breeding. Conception rate to AI and pregnancy rates did not differ between EXT and DL-treated heifers, although, AI pregnancy rates tended to be less in EXT heifers. Furthermore, the cost of producing a pregnant DL heifer was $45 greater. Larson et al. (2011) conducted 2 experiments at 2 separate locations in Nebraska to evaluate winter range or corn residue grazing on growth and reproduction in beef heifers. A daily 0.45 kg of a 31% CP

supplement was offered to heifers at both locations during development. Prior to breeding, corn residue-developed heifers tended to have decreased ADG compared with range-developed heifers. In both experiments, percent of mature BW, prebreeding BW, and pregnancy diagnosis BW did not differ between heifers grazing winter range or corn residue. The proportion of heifers pubertal at breeding and pregnancy rates were similar between grazing treatments. Therefore, developing heifers on corn residue or winter range postweaning resulted in similar reproductive performance.

Exposing young livestock to environments similar to what may be encountered in the future could lead to increased forage efficiency and animal production (Provenza and Balph, 1988). Thus, heifer development system may impact performance as a pregnant female. Heifers developed in the drylot from weaning to breeding may experience a negative energy balance when immediately moved to graze forage. With grazing skills and dietary habits being acquired early in life, drylot-developed heifers have not yet learned the motor skills necessary to efficiently harvest forages (Provenza and Balph, 1988). Summers et al. (2014) observed heifers developed on corn residue gained more BW when grazing corn residue as a pregnant heifer than drylot-developed heifers. Perry et al. (2013) found heifers with less grazing experience lost BW the first week following AI when moved to graze forage, resulting in reduced AI pregnancy rates. Therefore, development system may impact grazing behavior as a pregnant heifer.

Selection of Calving Date

Selecting an optimum calving date is dependent upon many variables: environmental conditions (temperature, humidity, and wind), forage quality and quantity, proportion of warm and cool season grasses, and economics. By choosing a suitable

calving season, producers may maximize profitability and effectively utilize available resources.

A large proportion of cows in the Nebraska Sandhills calve in the spring. A potential disadvantage of a spring calving season is economics. A study by Stockton et al. (2007) noted lower production costs and greater net returns for June-calving when compared with March-calving. Spring-calving systems commonly market cattle in November, which leads to an increase in calf supply and lower calf price. This market trend may push producers to consider an alternate calving date with the possibility of receiving a higher calf price due to a decreased supply at weaning and marketing.

In a spring-calving system, lactation occurs at a time when range plant species are dormant and low in energy and protein. Due to the high nutrient requirements for lactation, harvested feeds may be utilized during this time period to ensure a large proportion of cows rebreed and produce a calf the following year. Clark et al. (2004) discussed savings of 728 kg/yr of hay per cow for producers who began calving at the start of April when compared with those that started calving in the latter half of February. Essentially, nutrient requirements are not met with range forage when a spring-calving cow is at her peak lactation, resulting in protein and energy supplementation.

Weather can also pose a threat to a spring-calving herd. Harsh weather in early spring can lead to greater risk of calf sickness, resulting in more health expenses. Additionally, severe weather can produce a nutrient imbalance for cattle grazing on winter range (Adams et al., 1996). The cold temperatures require more energy while also reducing intake and digestibility of range forage. Deep snow may limit access to forage, not only from snow cover but from the formation of a snow crust during freezing and

thawing. Therefore, it is important a cow's body condition score is appropriate for the start of winter grazing.

One method to reduce the amount of harvested feeds and forages and thus reduce feed input costs is shifting the calving date to better match the nutrient requirements of the cow with the nutrient content of the forages. In the Nebraska Sandhills, this leads to a late-spring calving system. Matching the calving date with spring green-up presents females with an increasing plane of nutrition, which relates to the nutritional demands prior to and following calving. Lactation demands are met through the high crude protein and TDN of range grasses when grazed, therefore, supplementation should not be necessary.

During the dry period, cows in a late-spring calving system will graze low quality, dormant forage. This corresponds well with the low nutritional demand of the cow in that particular time point. By pairing high quality forage with high nutritional demands and low-quality forage with low nutritional demands, the grazing period can be extended and the amount of harvested forage used decreased. Reducing harvested forage and extending the grazing period may lead to greater profitability for producers. Additionally, hay was reduced by 1,363 kg in a late-spring calving system compared with late-winter calving (Adams et al., 2001b). In 2008, Kruse et al. noted a 45% decrease in the feed cost per cow in eastern Montana for late-spring calving systems compared with early-spring or late-winter calving dates over a 3 yr period. Furthermore, it has been reported that May-calving saved an estimated $39/cow in feed costs, and June-calving saved an estimated $43/cow in feed costs when compared with February-calving (May et al., 1999).

Calving date selection is a critical decision for producers that is dependent on many variables. Therefore, each operation must determine which system is most suitable based on available resources. Selecting a calving system most appropriate to a producer's operation may result in reduced inputs and increased profitability. Shifting the calving date to match forage quantity and quality may be a method to reduce inputs, although supplementation may still be necessary in periods of nutritional deficiencies.

Trace Minerals

Beef cattle require trace or micro minerals for growth, lactation, reproduction, and health. Although desired in minute quantities, trace minerals' role in enzymatic activity, hormone production, tissue synthesis, and energy production cannot be ignored (Paterson and Engle, 2005). Common trace minerals supplemented to beef cattle include Cu, Co, I, Mn, Se, and Zn (Olson, 2007). However, Cu, Mn, and Zn will be the primary focus in this review, as they are the trace minerals under investigation in this thesis research. At times, trace minerals are the "forgotten nutrient" within the animal diet as their physiological role and presence in the feed is underestimated (Lopez-Alonso, 2012). In addition, it is difficult to detect symptoms of mineral imbalances. Adequate trace mineral status in beef cattle is crucial as deficiencies or toxicities result in economic and production loss (Spears and Weiss, 2014). Three different structural forms of trace minerals are currently available: inorganic, organic, and hydroxy. Even though all types are approved for producer usage, they differ in chemical structure, bioavailability, and cost. Method of supplementing these different mineral forms vary according to a producer's operation, cost, and labor.

Supplementation Methods

A common perception exists among beef producers that cattle can instinctually sense when a diet is deficient in a mineral (Olson, 2007). Unfortunately, beef cattle do not have this “nutritional wisdom,” thereby mineral supplementation is necessary in confined and grazing cattle. Grazing livestock are less likely to meet required mineral levels as forages seldom provide adequate mineral concentrations or a high concentration of antagonists exist. Direct supplementation methods include free-choice supplementation, drenching, injection, adding mineral to drinking water or feed, and oral boluses. Drenching minerals allow all animals to receive known amounts of the mineral. However, this labor-intensive method may not provide enough time for mineral absorption due to elements passing through the digestive tract too rapidly (Olson, 2007). Continual drenching for multiple days is believed to be more effective than a single dose, but the time and labor required is impractical (Greene, 1999). In grazing livestock, drenching is not a realistic approach. Cattle must be driven long distances, handled more frequently, and labor costs increase (McDowell, 1996).

Oral dosing of mineral boluses is another supplementation method that requires animal handling and physical administration of the mineral supplement, but ensures each animal receives the prescribed mineral dose being administered (Greene, 1999). Trace mineral boluses allow for the sustained release of trace minerals over an extended period. Sprinkle et al. (2006) observed increased liver Cu concentrations in cows that received a trace mineral oral bolus. MacPherson (1983) also noted increased Cu status in cows given copper oxide needles. When these small rods enter the abomasum, they secure

themselves in the abomasal folds and dissolve, releasing Cu for absorption by the small intestine.

Trace Mineral Injection. An injectable trace mineral (ITM) bypasses the gastrointestinal tract and dietary antagonists, making it advantageous in increasing trace mineral status (Genther and Hansen, 2014). Injection of Cu, Se, Zn, and Mn has increased trace mineral concentrations, but the response is not long-term (Greene, 1999). In bull calves, Cu was mobilized rapidly following subcutaneous injection, leading to a temporary rise in plasma Cu concentrations (Bohman et al., 1984). Once mobilized, Cu was immediately stored in the liver. Once injected, trace minerals are circulated throughout the body and absorbed by cells in need (Suttle, 2010). The remaining trace minerals will filter through the liver to be excreted or bound to storage proteins. Pogge et al. (2012) observed increased liver Cu and Se concentrations through d 15 post-injection in steers when compared with the non-injected control group. Genther and Hansen (2014) found liver Cu and Se to be elevated through d 30 in beef steers receiving an ITM.

Previous research has investigated the use of an ITM on gain, reproduction, and health in cattle. Administering an ITM prior to calving and breeding may have certain reproductive benefits. Crossbred heifers treated with a subcutaneous ITM in conjunction with free-choice mineral supplementation 17 d prior to embryo transfer experienced increased conception rates at 23 and 48 d after timed embryo transfer (Sales et al., 2011). A study conducted by Mundell et al. (2012) utilized mature beef cows to determine the effects of pre- and post-partum trace mineral injections on reproductive performance. Cows either received an ITM at 105 d before calving and 30 d before fixed-time AI or a saline injection at these 2 time points. Throughout the study, all animals were offered

free-choice mineral supplement. More cows receiving the ITM conceived to fixed-time AI and calved earlier than saline-treated cows.

Improved feed efficiency, DMI, and ADG has been observed in ITM-treated calves (Berry et al., 2000). In addition, calves tended to be treated less frequently for sickness. Richeson and Kegley (2011) evaluated the effects of an ITM on health and performance of high-stressed, newly received beef heifers. Females were assigned to receive either; 1) ITM containing 20 mg/mL Zn, 20 mg/mL Mn, 10 mg/mL Cu, and 5 mg/mL Se; 2) ITM containing 48 mg/mL Zn, 10 mg/mL Mn, 16 mg/mL Cu, and 5 mg/mL Se; or 3) no ITM. Average daily gain, DMI, and feed efficiency was greater for heifers that received either ITM treatment when compared with the control. Bovine respiratory disease morbidity rate was also less in heifers administered both trace mineral injections, leading to a greater antibiotic cost for the control heifers.

Free-choice Supplementation. Trace mineral supplementation for feedlot cattle can be readily supplied via the feed, therefore cattle are likely to receive an adequate mineral supply (Bohman et al., 1984). In grazing beef cattle, free-choice mineral supplementation is the most widely used method as it is the most practical to producers. Free-choice or free-access refers to voluntary consumption of minerals. One main concern with this method is the variation in animal intake. In addition, free-choice mineral supplementation is not always sufficient to combat antagonists that may be present in the diet (Pogge et al., 2012). Arthington and Swensont (2004) reported cows offered a free-choice supplement consumed 23% less mineral when compared with cows assigned a control-fed mineral, thus leading to decreased liver Zn and Cu. Tait et al. (1992) utilized a computer system to electrically monitor mineral consumption for

grazing Holstein steers on range. Mineral consumption ranged between 60 to 330 g/day with an average of 3 daily visits per animal and the majority of these visits occurred late evening.

Mineral palatability is crucial as free-choice minerals are much less palatable compared with mineral added to concentrates (McDowell, 1996). Animals will selectively eat a palatable, poor quality diet than an unpalatable, nutritious diet (Arnold, 1964). Therefore, palatability and appetite stimulators have been established to lessen intake variability. Salt, cottonseed meal, dried molasses, dried yeast culture, and fat assist in achieving more uniform consumption (McDowell, 1996). Livestock have a universal liking for salt, and it remains to be the only mineral cattle desire. When providing a salt-based free-choice supplement, other sources of salt should be regulated. Other salt sources can reduce consumption of the free-choice mineral mixture by grazing livestock (Greene, 1999). Free-choice trace minerals can be produced in loose or block form. Offering mineral in block form resulted in 10% less mineral being consumed compared with loose form (McDowell, 1996). Blocks can be produced on varying levels of hardness depending on environmental factors. If a block is too soft, heavy rainfall dissolves the block, leading to mineral losses. In contrast, if the block is not accessed often, block hardness develops, reducing consumption. Loose free-choice mineral may be easier for livestock to consume, increasing intake. However, rainproof mineral feeders should be utilized to prevent caking, molding, and blowing away in times of inclement weather.

Trace Mineral Sources

A variety of mineral sources exists to supplement animal diets. Unfortunately, considerable differences in the bioavailability among the sources affect trace mineral absorption (McDowell, 1996). Traditional supplementation of trace minerals has been in the form of inorganic salts. Inorganic forms represent minerals bound to an inorganic ion, for instance an oxide or sulfate (Olson, 2007). Previous research suggests inorganic sources have lower availability when compared with organic mineral sources (Andrieu, 2008; Olson, 2007). Differences in charge between organic and inorganic sources may be one explanation for the bioavailability difference. When inorganic minerals are digested, the inorganic ions are moved toward the villi of the small intestine and encounter an unstirred water layer. The increasing pH causes inorganic ions to hydroxy-polymerize, forming complexes that cannot be absorbed. Thus, when these complexes reach the negatively charged mucus layer of the enterocytes, absorption is decreased (Andrieu, 2008). Organic trace minerals are assumed to be more stable in the rumen and abomasum, therefore maintaining their structural integrity upon reaching the small intestine (Spears, 1996). Additionally, organic minerals carry a neutral charge, which is thought to enhance the efficiency of absorption and metabolism 300% to 500% (Olson, 2007).

Apart from the belief of increased bioavailability, organic trace minerals have been reported to improve feed efficiency, growth, and reproduction. Organic minerals are primarily characterized as chelates, proteinates, or complexes. Variation among these specific forms occur due to the type of ligand or ligands used to form the metal complex or chelate (Spears, 1996). A study performed by Stanton et al. (2000) evaluated 3

different mineral supplements on growth, reproduction, and health. Cows receiving the organic-high level treatment had greater pregnancy rates to AI compared with cows assigned the inorganic-low level or inorganic-high level treatments. Furthermore, a shorter calving interval was observed in young cows consuming organic versus inorganic minerals (Arthington and Swensont, 2004). Kropp (1990) noted increased conception rates and proportion of heifers exhibiting estrus following synchronization when assigned the chelated mineral mixture versus the inorganic mineral. Chelated-treated heifers also conceived 19 days earlier than their counterparts. Greene et al. (1988) fed 45 Angus steers for 112 d to determine Zn source on carcass quality. Steers fed Zn methionine had a greater quality grade and marbling score than Zn oxide-fed steers. Also zinc methionine has been found to affect growth and health. Calves fed a diet supplemented with Zn methionine gained faster, had decreased morbidity, and fewer calves became sick (Spears, 1996).

Little evidence indicates no growth or reproductive advantage of using minerals complexed with organic molecules (Brown and Zeringue, 1994; McDowell, 1996). Muehlenbein et al. (2001) did not observe any advantages in 2-yr-old cows offered inorganic or organic copper on 60-d pregnancy rates and calf health and performance. Steers fed a CuLys or $CuSO_4$ mineral source over a 98-d period experienced similar feed efficiency, growth, and feed intake, thereby implying equal bioavailability between mineral sources (Ward et al., 1993). This contrasts a study conducted by Nockels et al. (1993) which observed steers retained Cu better in the form of CuLys. This was in comparison to steers provided Cu in the form of $CuSO_4$. In Cu-depleted steers consuming excess Mo, Cu proteinate and Cu sulfate had similar bioavailability (Wittenberg et al.,

1990). In addition to mixed results on mineral sources, organic trace minerals are generally more expensive than inorganic minerals (Olson, 2007). Due to contrasting data previously discussed, more research needs to be conducted on the bioavailability and effects of organic versus inorganic mineral sources.

Reproductive role of Cu, Mn, and Zn

Copper. Copper plays a pivotal role in a variety of enzymes, cofactors, and proteins, ultimately contributing to many processes, including reproduction. A Cu deficiency limits production and fertility in beef cattle (Gooneratne and Christensen, 1989). Pronounced decreases in first-service conception and overall pregnancy rates occur in Cu-deficient states (Corah, 1996). Delayed estrus leading to low fertility has been observed in beef cows grazing Cu-deficient pastures. In ewes, infertility and abortions have been noted in Cu-deprived conditions (Suttle, 2010). Hawk et al. (1998) obtained rat embryos from Cu-deficient or Cu-adequate dams. Copper-deficient embryos cultured in a Cu-deficient serum developed abnormally, while control embryos cultured in a Cu-adequate serum developed normally (Hawk et al., 1998). Furthermore, a deficiency in pregnant females can lead to abnormalities in the fetus including reduced growth, skeletal defects, and defective brain developments (Gooneratne and Christensen, 1989). For normal fetal development to occur, Cu must be provided to the fetus via the maternal bloodstream in adequate concentrations. Copper is also involved in many steroidogenic enzymes (Yatoo et al., 2013).

Previous literature suggests copper's effects on reproduction may not be due to a deficiency in Cu, but an excess in Mo and S. Phillippo et al. (1987) evaluated reproductive performance in heifers fed a basal diet containing 4 mg Cu/kg DM to heifers

fed the same diet fortified with 5 mg Mo or 500 to 800 mg Fe/kg DM. Dietary inclusion of Mo delayed puberty onset by 8 to 12 weeks and reduced conception rates in cows from 68% to 22% (Phillippo et al., 1987). More Mo-supplemented heifers also failed to ovulate following synchronization. A pulsatile reduction in LH was observed within 11 weeks of Mo supplementation, suggesting Mo may impact puberty by altering LH release due to an altered ovarian steroid secretion.

Manganese. Beef cattle require Mn in low concentrations for bone development and reproduction. Manganese supplementation has increased conception rates in British cattle (Hidiroglou, 1979). Low dietary intake of Mn also resulted in anestrus in many ruminants, possibly due to its connection in the metabolism of reproductive hormones (Hidiroglou and Shearer, 1976). Manganese acts as a cofactor for the enzyme that converts mevalonic acid to squalene and promotes cholesterol synthesis (Hostetler et al., 2003). Therefore, Mn is believed to be involved in hormone synthesis within the ovary and indirectly influence steroid hormone synthesis through its involvement in stimulating cholesterol synthesis (Corah and Ives, 1991). With squalene being a precursor in steroid hormone production, Mn may stimulate estradiol secretion by the pig conceptus as a signal for pregnancy recognition (Hostetler et al., 2003). In the ovine Graafian follicle and corpus luteum, greater Mn uptake has been reported when compared with other reproductive tissues, reinforcing the essential role Mn plays in ovarian function (Paterson and Engle, 2005). This trace mineral's association with hormone synthesis could potentially describe observations of delayed ovulation and longer postpartum anestrus interval in cattle receiving low dietary inake of Mn (Hidiroglou, 1979).

Zinc. Zinc is involved in many enzymatic reactions linked to carbohydrate metabolism, nucleic acid metabolism, and protein synthesis (Smith and Akinbamijo, 2000). Therefore, its role in the gonads is essential due to the active growth and division that occurs. Zinc is also involved in the establishment of prostaglandin as Zn enzymes regulate the arachidonic acid cascade (Hostetler et al., 2003). Prostaglandin $F_{2\alpha}$ is important in pregnancy establishment in mice and swine and it initiates uterine contractions at parturition and expulsion of the fetus. Zinc also influences pregnancy due to its connection with insulin-like growth factors (IGFs). These growth factors function in uterine remodeling at the time of embryonic implantation, fetal development, and conceptus growth (Hostetler et al., 2003). On a cellular level, Zn decreases the binding affinity of IGF to IGF binding proteins (IGFBP), therefore increasing the IGF binding affinity for Type I IGF receptors on the cell surface (Sackett and McCusker, 1998; McCusker et al., 1998). When Zn is deficient, IGF-1 levels are depressed (MacDonald, 2000). Thus, more available Zn allows more IGF to be transferred from IGFBP to IGF receptors on the cell surface to promote growth and differentiation (Hostetler, 2003).

Assessment of Trace Mineral Status

Assessing trace mineral status determines the prevalence of nutrient deficiencies or toxicities within a population in addition to evaluating efficacy of a dietary supplement (Kincaid, 2000). Deficiencies can be characterized as primary or secondary. Primary deficiencies describe inadequate intake of a specific mineral whereas secondary deficiencies refer to abnormal absorption, distribution, or retention of a mineral (Olson, 2007). Various methods of measuring trace mineral status were investigated; however, many of these techniques do not accurately reflect an animal’s trace mineral status. Hair,

wool, and hooves may appear to be practical assessment options due to the ease of collection, but these samples are easily contaminated and respond slowly to intake. Therefore, such techniques are unreliable.

Blood samples are frequently utilized to determine mineral status, unfortunately, many limitations exist. Due to the 160 d lifespan of red blood cells in cattle, mineral levels in whole blood change slowly (Kincaid, 2000). In plasma, homeostasis can limit trace mineral fluctuations until endogenous reserves are exhausted. Blood samples can also be easily contaminated if proper care is not taken. Selenium and magnesium are two minerals that blood serves as a useful measure (Herdt et al., 2000). Liver, acquired via biopsy, is the best indicator of several trace minerals' endogenous stores. For example, the liver represents the storage pool of Cu and inadequate Cu consumption is initially recognized by hepatic Cu depletion. The liver also indicates the long-term availability of dietary Cu to the animal (Herdt and Hoff, 2011).

Copper. Adequate liver concentrations of Cu are 125 to 600 mg/kg (Kincaid, 2000). Copper levels in the liver of cattle are correlated to Cu bioavailability in the diet. The amount of Cu in the liver will change depending on the physiological state of the animal. For example, liver Cu declines throughout a cow's pregnancy due to the transfer of Cu to the fetus. Copper absorption in ruminants is low in relation to nonruminants due to complex interactions that occur within the rumen (Spears, 2003). Dietary sources of Fe, S, and Mo act as Cu antagonists. Ingested Mo can react with endogenous sulfide to form thiomolybdates in the rumen, which create insoluble complexes with Cu (Spears, 2003). The formation of thiomolybdates can directly inhibit Cu-dependent enzymes and prevent the involvement of Cu in biochemical processes (NRC, 2000). Sulfur can also act

independently of Mo. Increasing dietary S reduces Cu bioavailability through the formation of insoluble cupric sulfide in the rumen (Judson and McFarlane, 1998). Iron also has an inhibitory effect on Cu. In sheep and cattle, dietary Fe levels of 500-6000 mg/kg DM have been shown to reduce Cu availability (Judson and McFarlane, 1998). In beef cattle diets, the Cu requirement is 10 mg/kg as long as S and Mo do not exceed 0.25% and 2 mg/kg, respectively (NRC, 2000).

Breed may influence Cu requirements, as it is well understood genetic variation affects Cu metabolism (Lopez-Alonso, 2012). Simmental and Charolais cattle have greater Cu requirements compared with Angus (Greene, 1999). Gooneratne et al. (1994) reported a two-fold increase in biliary Cu excretion in Simmental when compared with Angus cattle. Additionally, previous research observed Simmental cattle with less Cu indices than Angus when fed a Cu-deficient diet (Fry et al., 2013). The greater Cu requirement in Simmentals may be due to a decreased ability in absorption and utilization of dietary Cu. Fry et al. (2013) demonstrated less Cu transporter 1 (CTR1) in Simmental vs. Angus and decreased expression in duodenal *Ctr1*. Therefore, clinical signs of Cu deficiency are more prominent in the Simmental breed than Angus (Fry et al., 2013). In dairy cattle, Jersey cows are more susceptible to Cu toxicosis than Holsteins (Lopez-Alonso, 2012).

Manganese. Adequacy of Mn in liver is greater than 8 mg/kg in cattle; however, the liver does not adequately represent dietary intakes of this trace mineral (Kincaid, 2000). Adequate concentration of serum Mn is between 6 to 70 mg/kg (Kincaid, 2000). Manganese has been described as a “hidden” trace mineral as it may have more influence than is realized (Corah, 1996). Manganese is poorly utilized with no more than 1% from

the diet in ruminants being absorbed (Spears, 2003). Limited research has focused on dietary interactions affecting the bioavailability of Mn. Hidiroglou (1979) suggested a substantial excess of P, Ca, or both may disrupt Mn utilization. At time of breeding, Mn is required in higher concentrations. The recommended Mn requirement is 40 mg/kg compared with 20 mg/kg in growing and finishing cattle (NRC, 2000).

Zinc. Adequate liver concentrations of Zn are 25 to 200 mg/kg (Kincaid, 2000). In plasma, adequacy of Zn falls between 0.8 to 1.4 mg/kg (Kincaid, 2000). As dietary Zn increases, the amount of dietary Zn absorbed by the ruminant decreases (Spears, 2003). Dietary factors that affect Zn bioavailability are not clearly understood. Elevated Ca levels have shown reduced serum Zn concentrations in lambs, but Zn requirement did not increase. Previous research indicated elevated dietary Zn intake stimulates production of metallothionein, a compound that transports Zn across the intestinal wall and enables Zn storage in the liver (Olson, 2007). The elevated levels of Zn, which leads to increased production of metallothionein, can have an antagonistic effect on Cu absorption (Bremner and Beattie, 1990). Metallothionein preferentially binds more strongly with Cu, which can exacerbate Cu deficiency (Bremner and Beattie, 1990). The Zn requirement in beef cattle diets is 30 mg/kg (NRC, 2000).

Objectives

- Determine effects of postweaning heifer development system on ADG, pregnancy rates, and subsequent feed efficiency as a pregnant heifer.
- Determine the impact of heifer development system on subsequent growth and reproductive performance in early and late summer breeding seasons.
- Determine the effects of an injectable trace mineral on reproductive performance of range-developed beef heifers at CIDR insertion.
- Investigate the effects of a hydroxy versus sulfate trace mineral on gain and reproductive performance in Angus-based beef heifers.

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Chapter II

Effect of postweaning heifer development system on average daily gain, pregnancy rates, and subsequent feed efficiency as a pregnant heifer

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Abstract

A 3-yr study utilized 300 Angus-based, spring-born heifers to evaluate postweaning heifer development systems on gain, reproductive performance, and feed efficiency as a pregnant heifer. Heifers were blocked by BW and randomly assigned to graze corn residue (CR), upland range (RANGE), or were fed 1 of 2 diets in a drylot differing in energy levels: high (DLHI) or low (DLLO). Heifers developed on DLHI and DLLO were managed within the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3. Heifers developed on RANGE grazed winter range for an equivalent amount of days each yr as the DLHI and DLLO heifers. Heifers assigned to CR grazed for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3 before being transported to graze winter range for the remainder of the treatment period. All heifers were managed as a single group following the treatment period. Artificial insemination and natural mating were utilized during breeding. Percent of mature BW prior to the breeding season was greater (P = 0.02) for DLHI (67%) compared with RANGE (59%) and CR (58%). Pregnancy rates to AI were not different (P = 0.51) among treatments (59 ± 6%), and final pregnancy rates were also not different (87 ± 4%, P = 0.54). A subset of AI-pregnant heifers from each treatment were placed in a Calan gate feeding system. Heifers were allowed a 20-d acclimation

period before beginning the 90 d trial at approximately 170 d in gestation. Heifers were offered ad libitum hay; amount offered was recorded daily and orts collected weekly. Initial BW was not different (*P* = 0.58) among treatments (459 ± 11 kg). Body weight at the end of the trial (497 ± 17 kg) was also not different (*P* = 0.41). Intake was not different (*P* = 0.33), either as DMI (10.00 ± 1.07 kg) or residual feed intake (0.018 ± 0.190). There was no difference in ADG (*P* = 0.36, 0.42 ± 0.23 kg/d) among treatments. Although the total development cost was not different among treatments (*P* = 0.99), there was a $41 difference (*P* < 0.01) between the mean of the most expensive diet (DLHI) and the mean of the two least expensive diets (CR and RANGE). Developing heifers to a greater prebreeding BW did not influence subsequent AI or overall pregnancy rates or feed efficiency as a pregnant heifer.

Key words: beef heifers, feed conversion, heifer development

Introduction

Retaining and developing replacement heifers presents a significant expense to the cow-calf producer, only surpassed by feed expense. Developing *Bos taurus* heifers to a 10 to 15% lower target BW than previously recommended has reduced development cost, without reducing pregnancy rate (Feuz, 1992; Clark et al., 2005). Previous research comparing corn residue and drylot systems demonstrated heifers in the drylot gained more during the development period than on corn residue (Summers et al., 2014). However, heifers developed on corn residue experienced increased post-AI ADG on summer range compared with drylot-developed heifers. The difference may be due to compensatory gain or retained learned grazing behavior as suggested by Summers et al. (2014). Recently, greater emphasis has been made to select feed efficient animals.

However, selecting for greater efficiency in heifers may negatively impact reproduction. Heifers with low residual feed intake (RFI) calve later in the calving season compared with high RFI heifers (Donoghue et al., 2011). Additionally, low RFI heifers demonstrated decreased conception and pregnancy rates (Basarab et al., 2011). However, other research reports no significant differences in pregnancy rates between high and low RFI in beef cattle (Arthur et al., 2005; Basarab et al., 2007). Limited research has demonstrated the effect of heifer development system on feed efficiency as a pregnant heifer or the impact of restricted growth in confinement on subsequent performance to elucidate a compensatory gain vs. learned behavior response. Therefore, objectives of the current study were to compare effects of postweaning heifer development system on ADG and pregnancy rates, as well as subsequent feed efficiency as a pregnant heifer.

Materials and Methods

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all procedures and facilities used in this experiment.

Postweaning Development

A 3-yr study conducted at the West Central Research and Extension Center (**WCREC**), North Platte, NE, utilized Angus-based, crossbred, spring-born heifers. Heifers were received at WCREC each October (n = 100/yr) and allowed a 30 d acclimation period. After acclimation each year, heifers were blocked by BW and randomly assigned to 1 of 4 development treatments: graze corn residue (**CR**), graze upland range (**RANGE**), developed in a drylot consuming a high energy diet (**DLHI**), or developed in a drylot consuming a low energy diet (**DLLO**, Figure 1). Each year, 25

heifers were assigned to a treatment, allowing for 75 heifers/treatment over the 3-yr study.

Heifers developed on CR were transported 100 km to graze one corn residue field each year from mid-November and returned to WCREC mid-February to graze winter range. Heifers grazed corn residue with pregnant heifers, which had previous corn residue grazing experience. The irrigated CR field was approximately 40 ha and heifers were stocked at a rate equivalent to 2.5 weaned heifers/ha during the grazing period. Fields were planted in April and harvested in October with an average annual yield of 12,544 kg/ha. Heifers grazed CR for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3. Weather dictated how many days CR was grazed each year. Following CR grazing, heifers were transported to winter range until the end of the treatment period. Corn residue heifers grazed winter range for 61 d in yr 1, 64 d in yr 2, and 63 d in yr 3.

Heifers developed on RANGE grazed winter range for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3. The stocking rate for RANGE heifers was approximately 0.70 heifer/ha with an average annual herbage production of 1,430 kg/ha. When grazing winter range or corn residue, each heifer received the equivalent of 0.45 kg/d of a 32% CP (DM), dried distillers grain-based supplement 3 times/wk containing 80 $mg \cdot animal^{-1} \cdot d^{-1}$ monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and vitamins and minerals. A brome, rye, and prairie hay mixture (7.5% CP, 54.4% TDN, 0.58% Ca, 0.14% P) was fed at 3.9 kg/d during times of deep snow. Range warm-season grass species consisted of little bluestem (*Schizachyrium scoparium* (Michx.) Nash.), big bluestem (*Andropogon gerardii* Vitman), side oats grama (*Bouteloua curtipendula* (Michx.) Torr.), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) lag. Ex Griffiths), and

switchgrass (*Panicum virgatum* L.). Primary cool-season grasses were Scribner's panicum (*Dichanthelium oligosanthes* (Schult.) Gould var. *scribnerianum* (Nash) Gould), western wheatgrass (*Agropyron smithii* Rydb.), and needle and thread (*Stipa comata* Trin. & Rupr.). Cheatgrass (*Bromus tectorum* L.), smooth bromegrass (*Bromus inermis* L.), and Kentucky bluegrass (*Poa pratensis* L.) were introduced grass species.

The composition of the DLHI and DLLO diets for the duration of the study are shown in Table 1. Heifers assigned to DLHI and DLLO were fed according to their respective development treatment diet for 166 d in yr 1, 150 d in yr 2 and 162 d in yr 3. Drylot, high energy-developed heifers were offered a diet formulated to target 65% of mature BW with DLLO-developed heifers targeted to 60% of mature BW. Heifers assigned to DLHI received 1.31 kg/d wet corn gluten feed (WCGF) with 4.6 kg/d grass hay (DM), while DLLO heifer received 0.65 kg/d WCGF and 4.6 kg/d grass hay (DM). Mature BW was based on an average mature cowherd BW of 552 kg. Due to previous evidence of retained grazing behavior in corn residue and winter range-developed heifers, DLLO heifers were managed to mimic the mature BW of CR and RANGE heifers, thereby determining if CR and RANGE8I heifers display a learned grazing behavior and similar performance postbreeding as previously documented (Funston and Larson, 2011; Summers et al., 2014). Heifers placed on the drylot treatments were fed once daily in the morning. Thirty-five days before AI, all heifers were combined, managed together, and received the DLHI diet in the drylot. Average daily gain during the development trial, post-development BW, and BW before breeding were calculated.

Heifers were estrous synchronized using the melengestrol acetate-prostaglandin $F_{2\alpha}$ (**MGA-PG**) protocol (Vraspir et al., 2013). Synchronization began in late-April with

each heifer receiving 0.5 mg/d MGA pellets (Zoetis, Florham Park, NJ) in the diet for 14 d. Nineteen days following MGA withdrawl, PG (25 mg, Lutalyse, Zoetis) was injected i.m. and estrous detection aids applied (Estrotect, Rockway Inc, Spring Valley, WI). Following PG injection, estrus was detected twice daily (0600 to 0800h and 1800 to 2000h) for 5 d. Heifers with greater than 50% of the Estrotect coating removed were considered to have expressed estrus. Heifers in standing estrus were randomly AI by 3 technicians to 1 of 4 bulls approximately 12 h later, thus AI sire was not included in statistical analysis. Heifers not expressing estrus received a PG injection 6 d following the first PG injection and placed with bulls. Inseminated heifers were combined with the non-AI heifers and bulls 10 d following AI on upland range at a 1:50 bull to heifer ratio for 60 d. Pregnancy diagnosis was conducted via transrectal ultrasonography (ReproScan, Beaverton, OR) 45 d following AI. Forty-five d after bull removal a second pregnancy diagnosis determined final pregnancy rate. Body weight was recorded at AI and final pregnancy diagnosis, and ADG during the breeding season was calculated.

Pregnant Heifer Feed Efficiency

In mid-October, following final pregnancy diagnosis, a subset of randomly selected AI-pregnant heifers from each treatment were placed in a covered Calan Broadbent (American Calan, Northwood, NH) individual feeding system (**CALAN**). Three replicates utilized a total of 36 RANGE, 28 CR, 28 DLHI, and 23 DLLO heifers to evaluate AI-pregnant heifer feed efficiency. Heifers were allowed a 20 d acclimation period before beginning a 90 d trial at approximately gestational d 170. Initial acclimation period diet consisted of 15% WCGF and 75% grass hay (DM basis) ad libitum. During the acclimation period, WCGF was slowly removed from the diet until

heifers were receiving only grass hay before the feeding trial. The efficiency period began on gestational d 170 to allow time prior to the calving season. Pregnant heifers that did not acclimate to Calan Broadbent feeding system were removed from the feed efficiency trial. Heifers were offered an ad libitum brome, rye, and prairie grass hay mixture (8.3% CP, 56.4% TDN, 0.62% Ca, 0.16% P, DM); individual amounts offered were recorded daily and orts collected by hand weekly. The chopped hay included water to control dust. Diet was tested for nutrient analysis 30 d following initiation of feed efficiency trial. Initial and final BW, ADG, DMI, RFI, and G:F were measured. Residual feed intake was calculated as actual DMI minus predicted DMI. Following the trial period, pregnant heifers grazed winter range. The remaining heifers in the study (**STALK**, n = 185) grazed corn residue throughout the fall. Body weight prior to calving was recorded. Calf birth BW, calving ease, calf vigor, dystocia, and calf sex was measured at parturition. A calving ease scoring system of 1 to 5 was utilized with 1 representing no assistance and 5 indicating a Caesarean section. Calf vigor was determined with a 1 to 5 scoring system where 1 referred to the calf nursing immediately and 5 signified dead on arrival. Dystocia rate was characterized as a calving ease score of 2 and greater. Proportion of bull calves was recorded as calf sex can influence dystocia rate (Summers et al., 2014). Calving rate and the proportion of heifers calving in the first 21 d was also recorded.

Economic Analysis

Due to price fluctuations during this study, an average of prices from 2010 to 2014 was used for economic analysis. Heifer value was obtained for the wk heifers were received (USDA-AMS, 2015). Pasture values were calculated as half the cost of a cow-

calf pair in the Southwest region of Nebraska and obtained from the Nebraska Farm Real Estate Market Highlights (Johnson et al., 2010, 2011, 2013; Johnson and Van Newkirk, 2012; Jansen and Wilson, 2014). Wet corn gluten prices were obtained from the USDA-AMS for the third wk in September using Kansas City values (USDA-AMS, 2015). Hay prices were also obtained for the third wk of September in the Platte Valley from the Nebraska and Iowa Hay report (USDA-AMS, 2015). Actual supplement costs, both drylot and cube, were used. Other expenses include interest (6.5% of heifer value), vaccine, yardage, trucking for CR heifers, breeding expenses, and other miscellaneous expenses. Cull values of non-pregnant heifers were obtained for the wk of final pregnancy diagnosis (USDA-AMS, 2015). The net cost of 1 pregnant heifer was calculated using the procedure defined by Feuz (1992). The value of 1, non-pregnant heifer was divided by 1 minus pregnancy rate to determine the value of cull heifers per pregnant heifer. This value was subtracted from the total development cost. Finally, the adjusted development cost was divided by pregnancy rate to determine the net cost of 1 pregnant heifer.

Statistical Analysis

Treatment (RANGE, CR, DLHI, and DLLO) within yr was considered the experimental unit, with development treatment fitted as a fixed effect to measure BW, ADG, and reproductive performance during and after the development treatment period. Therefore, 3 replications per treatment represented this study, and power tests were necessary for AI pregnancy rate and calving rate. Data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Inst. Inc., Cary NC). Pregnant heifer feed efficiency analyses included pen as a random effect to evaluate BW, ADG, DMI, RFI,

and G:F. The interaction of development treatment × winter treatment was included in the initial model for assessing calving performance and first-calf characteristics. The interaction was not significant and thus removed from the model. A *P*-value ≤ 0.05 was considered significant, with *P*-values between 0.05 and 0.1 considered tendencies. Pregnancy rate, calving rate, pubertal status, the proportion of heifers that calved in the first 21 d, and sex of calves represent binomial distribution and were analyzed using an odds ratio. Least squared means and SE of the proportion were obtained using the ILINK function.

Results and Discussion

Postweaning Development

Heifer BW, ADG, and reproductive performance are summarized in Table 2. During development, ADG was greater ($P = 0.01$) for DLHI heifers (0.75 ± 0.05 kg/d) compared with RANGE and CR (0.44 and 0.40 ± 0.05 kg/d, respectively), resulting in post-development BW differences where DLHI heifers were heavier than RANGE and CR heifers ($P = 0.01$) but not different from DLLO heifers. At prebreeding, BW and percent of mature BW was greater ($P = 0.02$) for DLHI heifers compared with RANGE and CR heifers. Synchronization ADG from start of MGA delivery to BW taken before breeding did not differ ($P = 0.44$) among treatments. Average daily gain following AI to the first pregnancy diagnosis was greater ($P < 0.01$) for RANGE and CR heifers when compared with DLHI heifers. Funston and Larson (2011) noted an increased ADG in the period between the first breeding service and final pregnancy diagnosis in extensively-developed heifers when compared with drylot-developed heifers. Furthermore, the increased ADG in RANGE and CR heifers may be due to a learned grazing behavior in addition to

compensatory gain. Perry et al. (2013) found heifers with less grazing experience to have lost BW the first week following AI when moved to graze forage. This is also supported by the response seen in the DLLO heifers where postbreeding ADG was less ($P < 0.05$) than CR heifers despite similar development ADG ($P = 0.16$) and prebreeding ($P = 0.26$) weights. Pregnancy rates to AI (64, 57, 61, 45 ± 8%; RANGE, CR, DLHI, DLLO; $P = 0.47$), and final pregnancy rates (83, 87, 88, 91 ± 4%; RANGE, CR, DLHI, DLLO; $P = 0.54$) did not differ. Due to the range in AI pregnancy values between RANGE and DLLO, a power test was conducted. To achieve a statistical difference in AI pregnancy rate between RANGE and DLLO heifers, an additional 3 yr with 25 heifers/treatment each yr would be necessary. Previous research has reported similar final pregnancy rates in heifers restricted in ADG postweaning (Funston and Deutscher, 2004; Martin et al., 2008). Although DLHI heifers had the lowest ADG following AI, BW at first pregnancy diagnosis was greatest ($P = 0.03$) for DLHI heifers compared with RANGE and CR. However, final pregnancy diagnosis BW was not different ($P = 0.16$) among treatments. Calving rate was not different ($P = 0.32$) among treatments; however, there is a numerical difference between RANGE and the other groups. Therefore, a power test was performed. In order to observe a detectable difference between RANGE and the other treatments, an additional 2 yr with 25 heifers per treatment each yr is needed. Eborn et al. (2013) reported similar pregnancy rates for heifers developed on high- or low-gain diets from 8 mo to d 21 of the breeding season. However, a greater proportion of high-gain heifers became pregnant in the first 21 d of the breeding period, whereas in the current study the proportion of heifers calving within the first 21 d did not differ ($P = 0.12$) among heifers.

Pregnant Heifer Feed Efficiency

Pregnant heifer feed efficiency data are reported in Table 3. In the feed efficiency trial, initial and final BW was not different ($P \geq 0.41$). Intake did not differ either as DMI ($P = 0.33$) or as residual feed intake ($P = 0.74$). There was no difference ($P \geq 0.35$) in ADG or G:F among development treatments. Recent emphasis on genetic selection for feed efficiency in the feedlot has led to the discussion of increased feed efficiency in the cow herd. Although increased feed efficiency may reduce feed costs, reproductive performance could be compromised. In the current study, development treatment did not impact feed efficiency as a pregnant first-calf heifer. Future studies investigating how heifer development impacts lifetime feed efficiency and longevity are needed.

Calving Performance

Calving performance and first-calf characteristics are presented in Table 4. Precalving BW of pregnant heifers did not differ ($P = 0.34$) among development treatment; however, CALAN heifers had a greater ($P < 0.01$) precalving BW compared with STALK heifers during the winter treatment. Calf birth BW did not differ ($P \geq 0.35$) among development or winter treatments. Additionally, calving ease, calf vigor score, and dystocia rate were not different ($P \geq 0.44$) among treatments. The proportion of bull calves born did not differ ($P \geq 0.26$) across development or winter treatment.

Economic Analysis

Economic analysis for the 4 heifer development treatments are presented in Table 5. Heifers began development with the same value and receiving diet expense. Diet cost was different ($P < 0.01$) among treatments except for RANGE and CR, which were similar ($P = 0.56$). The most expensive diet, DLHI, and the mean of the 2 least expensive diets,

RANGE and CR, differed by \$41/heifer. Summer pasture and additional expenses did not differ across treatments. Numerical differences in pregnancy rates and BW at pregnancy diagnosis caused cull heifer value to differ (P < 0.01) among treatments where RANGE heifers, with the numerically lowest pregnancy rate, had the greatest cull heifer value. These data differ from previous studies reporting similar cull heifer value with intensive and extensive heifer development systems (Funston and Larson, 2011; Summers et al., 2014). Numerically higher final pregnancy rates resulted in lower cull value for DLHI and DLLO heifers. Net cost per pregnant heifer was not different (P = 1.00) among treatments using 5 yr average prices. This magnitude of difference in development cost was not different to previous data suggesting extensive development reduced cost by \$45 per pregnant heifer (Funston and Larson, 2011). The lack of statistical difference in the current study may be due to the extreme feed price fluctuation in the years (2010 to 2014) this experiment was conducted.

In the current experiment, heifer development system did not impact AI or final pregnancy rates. Development cost per pregnant heifer was not different among treatments. Pregnant heifer feed efficiency was not impacted by development system. Furthermore, wintering system as a pregnant heifer did not impact calving characteristics. These results indicate a variety of heifer development systems may be utilized with no detriment to pregnancy rates, feed efficiency as first-calf heifers, or first-calf calving characteristics.

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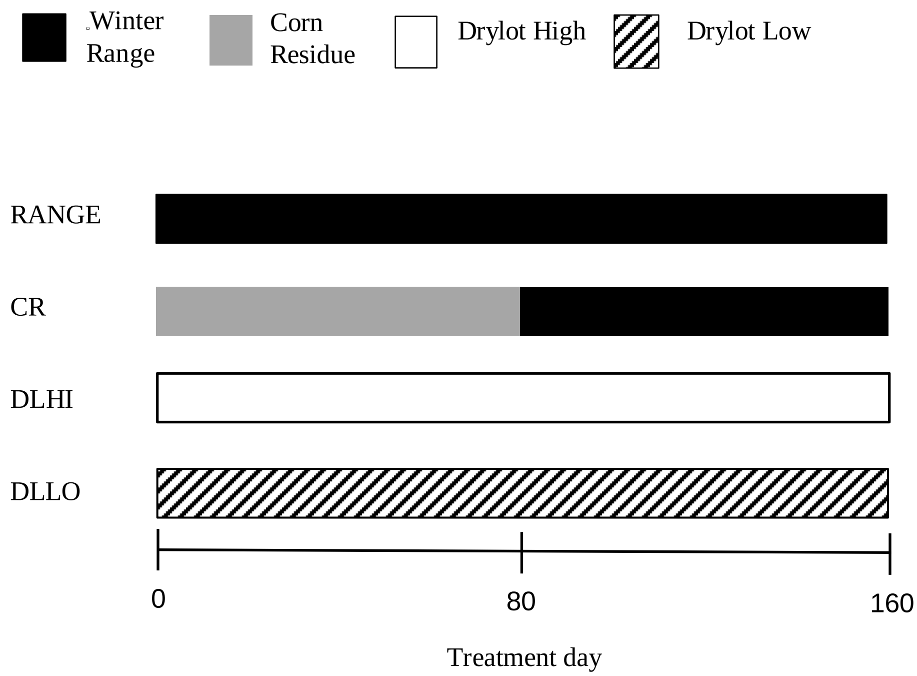
Winter Range
Corn Residue
Drylot High
Drylot Low
RANGE
CR
DLHI
DLLO
0
80
160
Treatment day

Figure 1. Developmental timeline for beef heifers. Time heifers grazed winter range (RANGE, black), grazed corn residue (CR, gray), were fed a higher energy drylot diet (DLHI, white), or fed a low energy drylot diet (DLLO, diagonal lines) during the 160 d treatment period (approximately mid-November to late April) between a 30 d receiving period and co-mingling in the drylot for estrous synchronization. Heifers on RANGE grazed winter range throughout the treatment period. Heifers on CR grazed corn residue for the first half of the treatment period and then were moved to winter range. Heifers on DLHI and DLLO were placed in the drylot for the duration of the treatment period.

Table 1. Drylot diet composition (DM basis) offered to replacement heifers

Ingredient, %	DLHI[1]	DLLO[2]
Hay	74	83
Wet corn gluten feed	21	12
Heifer supplement[3]	5	5

[1] DLHI = heifers received a high-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3.
[2] DLLO = heifers received a low-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3.
[3] Supplement (DM basis) = ground corn (81.35%), limestone (11.11%), iodized salt (5.55%), trace mix (1.39%), Rumensin-90 (0.37%), and Vitamins A-D-E (0.22%).

Table 2. Effect of development system on heifer gain and reproductive performance

Item	RANGE[1]	CR[2]	DLHI[3]	DLLO[4]	SEM	*P*-value
n[5]	3	3	3	3		
Initial BW, kg	231	233	231	231	5	0.93
Post development BW[6], kg	301[b]	297[b]	349[a]	321[a,b]	9	0.01
Development ADG[7], kg	0.44[b]	0.40[b]	0.75[a]	0.57[a,b]	0.05	0.01
Prebreeding BW, kg	324[b]	322[b]	372[a]	347[a,b]	9	0.02
Percent of mature BW[8], %	59[b]	58[b]	67[a]	63[a,b]	2	0.02
Synchronization ADG[9], kg	0.63	0.69	0.62	0.69	0.07	0.44
AI pregnancy diagnosis BW, kg	364[b]	365[b]	394[a]	376[a,b]	6	0.03
Final pregnancy diagnosis BW, kg	432	432	455	437	12	0.16
Breeding ADG[10], kg	0.77[a,b]	0.83[a]	0.44[c]	0.58[b,c]	0.13	< 0.01
AI pregnancy, %	64	57	61	45	8	0.47
Final pregnancy, %	83	87	88	91	4	0.54
Calving rate[11], %	73	84	81	85	5	0.32
Calved in first 21 d, %	82	69	76	56	11	0.12

[1] RANGE = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing winter range for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 before entering the drylot for estrous synchronization and AI.

[2] CR = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3 and winter range for 61 d in yr 1, 64 d in yr 2, and 63 d in yr 3 before entering the drylot for estrous synchronization and AI.

[3] DLHI = heifers were developed in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI on a high-energy diet.

[4] DLLO = heifers received a low-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI.

[5]Represents number of replications, 1 yr = 1 replication.

[6] BW at the time of blood collection prior to estrous synchronization.

[7] ADG during the 160 d treatment period.

[8] Percent of mature BW at breeding based on mature cow size of 552 kg.

[9] ADG between estrous synchronization and prebreeding.

[10] ADG between prebreeding and first pregnancy diagnosis.

[11] Percentage of heifers that calved.

[a,b,c] Means in a row with different superscripts differ ($P \leq 0.05$).

Table 3. Effects of heifer development system on pregnant heifer feed efficiency measured from d 170 to 260 of gestation

Item	RANGE[1]	CR[2]	DLHI[3]	DLLO[4]	SEM	*P*-value
n[5]	3	3	3	3		
Initial BW, kg	450	454	467	463	11	0.58
Mid BW, kg	468	474	488	482	10	0.49
Final BW, kg	486	495	508	500	17	0.41
DMI, kg	9.76	10.00	10.20	10.03	1.07	0.33
ADG, kg	0.39	0.45	0.44	0.41	0.23	0.36
RFI[6]	0.088	0.118	-0.058	-0.077	0.190	0.74
G:F	0.040	0.046	0.043	0.042	0.022	0.35

[1] RANGE = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing winter range for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 before entering the drylot for estrous synchronization and AI.
[2] CR = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3 and winter range for 61 d in yr 1, 64 d in yr 2, and 63 d in yr 3 before entering the drylot for estrous synchronization and AI.
[3] DLHI = heifers were developed in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI on a high-energy diet.
[4] DLLO = heifers received a low-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI.
[5] Represents number of replications, 1 yr = 1 replication.
[6] Residual feed intake.

Table 4. Effect of heifer development system and winter treatment on calving performance and first calf characteristics

	Development Treatment						Winter Treatment			
Item	RANGE[1]	CR[2]	DLHI[3]	DLLO[4]	SEM	*P*-value	STALK[5]	CALAN[6]	SEM	*P*-value
n[7]	3	3	3	3			3	3		
Precalving BW, kg	460	465	483	469	15	0.34	477	497	6	<0.01
Calf birth BW, kg	31.4	30.5	31.9	31.4	0.6	0.35	31	31	0.5	0.75
Sex of calves, % bulls	51	53	58	50	7	0.80	50	57	5	0.26
Calving ease[8]	1.14	1.24	1.20	1.24	0.08	0.81	1.22	1.19	0.05	0.59
Calf vigor[9]	1.15	1.27	1.25	1.16	0.1	0.72	1.22	1.19	0.07	0.74
Dystocia[10], %	11	18	18	16	5	0.71	17	14	3	0.44

[1] RANGE = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing winter range for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 before entering the drylot for estrous synchronization and AI.

[2] CR = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3 and winter range for 61 d in yr 1, 64 d in yr 2, and 63 d in yr 3 before entering the drylot for estrous synchronization and AI.

[3] DLHI = heifers were developed in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI on a high-energy diet.

[4] DLLO = heifers received a low-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI.

[5]STALK = each pregnant heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue following pregnancy diagnosis.

[6]CALAN = AI-pregnant heifers placed in Calan Broadbent individual feeding system and offered ad libitum hay following pregnancy diagnosis.

[7]Represents number of replications, 1 yr = 1 replication.

[8]Calving ease scoring system: 1 = no assistance, 2 = easy pull, 3 = mechanical pull, 4 = hard mechanical pull, and 5 = Caesarean section.

[9]Calf vigor scoring system: 1 = nursed immediately, 2 = nursed on own, took some time, 3 = required some assistance to suckle, 4 = died shortly after birth, and 5 = dead on arrival.

[10]Percentage of females with a calving ease score of 2 or greater.

Table 5. Economic analysis of heifer development systems using averaged prices from 2010 to 2014

Item	RANGE[1]	CR[2]	DLHI[3]	DLLO[4]	SEM	*P*-value
Heifer value, $/heifer	876	876	877	877	138	1.00
Feed cost:						
Receiving diet[5], $/heifer	32	32	32	32	3.43	1.00
Treatment diet, $/heifer	113[a]	109[a]	152[b]	137[c]	4.87	< 0.01
Summer pasture[6], $/heifer	68	68	68	68	3.69	1.00
Other expenses[7], $/heifer	311	319	311	311	8.96	0.91
Total development cost[8]	1,401	1,404	1,440	1,425	152	0.99
Less: cull heifer value	228[a]	127[b]	100[b,c]	69[c]	19	< 0.01
Net cost	1,173	1,277	1,340	1,356	137	0.77
Net cost per pregnant heifer[9], $	1,420	1,413	1,447	1,432	150	1.00

[1] RANGE = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing winter range for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 before entering the drylot for estrous synchronization and AI.
[2] CR = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue for 103 d in yr 1, 84 d in yr 2, and 97 d in yr 3 and winter range for 61 d in yr 1, 64 d in yr 2, and 63 d in yr 3 before entering the drylot for estrous synchronization and AI.
[3] DLHI = heifers were developed in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI on a high-energy diet.
[4] DLLO = heifers received a low-energy diet in the drylot for 166 d in yr 1, 150 d in yr 2, and 162 d in yr 3 and through estrous synchronization and AI.
[5] Heifers received a common receiving diet for 30 d prior to the initiation of the treatments.
[6] Summer pasture was calculated as half the cost of 1 cow-calf pair.
[7] Other expenses included breeding expense, interest (6.5% of heifer value), yardage, trucking for CR heifers, vaccinations and other miscellaneous health expenses.
[8] Comprises fixed and variable costs of initial heifer value, feed, supplement, transportation for CR heifers, and breeding.
[9] Calculated using the equation defined by Feuz (1992).
[a,b,c] Means in a row with different superscripts differ ($P \leq 0.05$).

Chapter III

Impact of heifer development system on subsequent growth and reproduction in two breeding seasons

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Abstract

A 4-yr study evaluated heifer development system effects on growth and reproductive performance in 2 breeding seasons. March-born and May-born crossbred heifers were stratified by BW and randomly assigned to 1 of 2 postweaning treatments from mid-January to mid-April: (1) ad libitum meadow hay (7.3% CP; 54.3 % TDN) and 1.64 kg/d of a 32% CP supplement (HAY) or (2) grazed meadow (10.3% CP; 61.7% TDN) and 0.41 kg/d of supplement (MDW). In the March-born heifers, ADG during the treatment period was greater (P < 0.01) for HAY than MDW heifers (0.78 vs. 0.51 ± 0.03 kg; HAY, MDW), however, pregnancy rates were similar (P = 0.92). Furthermore, calving rate and the proportion of heifers that calved in the first 21 d was not different (P ≥ 0.33) between treatments in March-born heifers. Similarly, May-born heifers on HAY treatment had greater ADG (P < 0.01; 0.59 vs. 0.35 ± 0.05 kg; HAY, MDW) during the treatment period, but pregnancy rates were also similar (P = 0.69). Calving rate did not differ (P = 0.88) between treatments, although; the proportion of heifers that calved in the first 21 d was greater (P = 0.02) for MDW compared with HAY. Overall, heifer development system did not impact pregnancy rate in the March or May replacement heifers; however, March-born heifer pregnancy rate was greater (P < 0.01) than May-

born (87 vs. 70 ± 3%). The lower pregnancy rate in May heifers may be due to declining forage quality during the late-summer breeding season.

Key words: beef heifer, calving date, heifer development

Introduction

Producing the next generation of females in a beef herd is an expensive enterprise for producers (Hall and Glaze, 2015). Traditional recommendations suggest heifers reach 65% of mature BW at breeding to maximize pregnancy rates (Patterson et al., 1992). Due to the high cost of retaining replacement heifers, more efforts have been made to devise economical heifer development methods. Lowering traditional target BW may allow for development on a lower rate of gain and potentially decrease feed costs (Funston and Deutscher, 2004). Previous studies have indicated heifers developed to lower target BW have comparable reproductive performance to heifers developed in higher input systems (Funston and Deutscher, 2004; Roberts et al., 2009; Funston and Larson, 2011).

Selecting an optimum calving date depends upon many variables: environmental conditions (temperature, humidity, and wind), forage type, quality and quantity, and economics. Due to a large proportion of cows in the Nebraska Sandhills calving in early spring, lactating range cows graze dormant, low-quality forages (Stockton et al., 2007). Due to the high nutrient requirements for lactation, harvested feeds may be utilized during this time period to ensure a large proportion of cows rebreed and produce a calf the following year (Adams et al., 2001). One method to reduce the amount fed, and thus reduce feed costs, is to shift the calving date to match the nutrient requirements of the cow with the nutrient content of the forages. In the Nebraska Sandhills, a late-spring calving system presents females with an increasing plane of nutrition that parallels with

the nutritional demands prior to and following calving. Nutrition demands to support lactation could be met with the greater CP and TDN intake of range, and supplementation may not be necessary. Thus, Clark et al. (2004) demonstrated a 728 kg/yr of hay per cow savings for producers that changed from February to April-calving in Nebraska. Therefore, the objective of the current study was to determine the impact of heifer development system on subsequent growth and reproductive performance in early and late-summer breeding seasons.

Materials and Methods

A 4-yr study conducted at the Gudmundsen Sandhills Laboratory, Whitman, NE, utilized replacement heifers from 2 calving seasons. March-born (n = 225) and May-born (n = 258) crossbred (5/8 Red Angus, 3/8 Continental) heifers were stratified by BW and randomly assigned to 1 of 2 postweaning nutritional treatments (2 pastures·treatment^{-1}·year^{-1}) from mid-January to mid-April. March heifers were weaned in October while May heifers were weaned in early January. Heifers were offered either: (1) ad libitum meadow hay with a 32% CP supplement fed at a rate of 1.64 kg/d (**HAY**) or (2) grazed meadow pastures and fed supplement at a rate of 0.41 kg/d (**MDW**, Table 1). Prior to and following treatment, all heifers were managed together within their respective breeding group. Following the treatment period, all March-born heifers grazed meadow until June 1 and then moved to upland native range. All May-born heifers grazed upland native range immediately following the treatment period. Spring ADG was measured from April 22 to May 22 for March-born heifers and from May 10 to July 9 for May-born heifers. Summer ADG was recorded from May 22 to Sept. 10 for March-born heifers and from July 9 to Sept. 10 in May-born heifers. Common meadow species at GSL include smooth

bromegrass (Bromus iner-mis Leyss.), redtop bent (Agrostis stolonifera L.), timothy (Phleum prat- ense L.), slender wheat-grass [Elymus trachy-caulum (Link) Gould ex Shinn.], quackgrass [Elytrigia repens (L.) — Nevski.], Kentucky blue-grass (Poa pratensis L.), prairie cordgrass (Spar-tina pectinata Link), reed-grasses (Calamagrostis spp.), and numerous species of sedges (Carexspp. and Cyperus spp.), rushes (Scirpus spp.), spikerushes (Eleocharis spp.), big bluestem (Andropogon gerardii Vitman), indian-grass [Sorghastrum nutans (L.) Nash], and switchgrass (Panicum virgatum L.). Upland native range grass species include little bluestem (*Andropogon scoparius* (Michx.) Nash), prairie sand reed (*Calamovilfa longifolia* (Hook.) Scribn.), sand bluestem (*Andropogon hallii* Hack.), sand lovegrass (*Eragrostis trichoides* (Nutt.) Wood), and blue grama (*Bouteloua gracilis* (H. K. B.) (Adams et al., 1998).

Prior to each breeding season, 2 blood samples were collected via coccygeal venipuncture 10 d apart to determine pubertal status (May for March-born heifers and early July for May-born heifers). Heifers with plasma progesterone concentrations greater than 1 ng/mL at either collection were considered pubertal. Plasma progesterone concentration was determined via direct solid phase RIA (Coat-A-Count, Diagnostics Products Corp., Los Angeles, CA). Blood samples were placed on ice following collection and centrifuged at 2,500 × g for 20 min. at 4°C. Following serum removal, samples were frozen at -20°C pending analysis.

Heifers were synchronized with a single $PGF_{2\alpha}$ (Lutalyse, Zoetis, Parsippany, NJ) injection 5 d after bull placement (1:20 bull to heifer ratio). The 45-d breeding season began May 23 for March heifers and July 10 for May heifers. Heifers grazed Sandhills upland range through final pregnancy diagnosis. Pregnancy diagnosis was conducted via

transrectal ultrasonography (ReproScan, Beaverton, OR) 40 d following bull removal. Forage samples were collected each yr to determine CP and TDN via esophageally fistulated cows for winter range, winter meadow, June range, July range, and September range (Table 2).

Calving data collected for March- and May-born heifers included birth BW, calving ease, calf vigor, and dystocia rate. A calving ease scoring system of 1 to 5 was utilized with 1 representing no assistance and 5 indicating a Caesarean section (BIF, 2010). Calf vigor was assessed with a 1 to 5 scoring system where 1 referred to the calf nursing immediately and 5 signified dead on arrival. Dystocia rate was characterized as a calving ease score of 2 and greater. Furthermore, udder score, proportion of bull calves, second pregnancy rate, and rebreed BW was determined on heifers. An udder scoring system of 1 to 5 with 1 representing poor udder quality and 5 signifying a superior udder was used on March- and May-born heifers.

From precalving to rebreeding, March-born heifers received ad libitum hay (80 d) while May heifers grazed native upland range (83 d). Age at rebreeding for the March heifer progeny was approximately 54 d while the May heifer progeny averaged 71 d of age. Therefore, progeny BW collected at dam rebreeding was standardized to 63 d of age. The average age at weaning for the March heifer progeny was 202 d whereas the May heifer progeny averaged 172 d of age, therefore, weaning weights were adjusted to 205 d of age.

Statistical Analysis

Data were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.). The main effect was heifer development treatment. Pasture was considered

a replication as each development treatment occurred in 2 pastures each year. Therefore, pasture × yr × treatment is the experimental unit. Pregnancy rate, calving rate, pubertal status, and the proportion of heifers that calved in the first 21 d represent binomial distribution and were analyzed using an odds ratio. Least squared means and SE of the proportion were obtained using the ILINK function. Differences were considered significant when $P \leq 0.05$, while differences with $0.05 < P \leq 0.10$ were tendencies.

Results and Discussion

March-born Heifer BW Gain and Reproductive Performance

Heifer BW, ADG, and reproductive performance are summarized in Table 3. Weaning and initial BW were similar ($P \geq 0.52$) between treatments. March-born HAY heifers had greater ($P < 0.01$) ADG during the treatment period than MDW heifers, leading to a greater ($P < 0.01$) BW following the treatment period. However, spring ADG was greater ($P < 0.01$) for MDW heifers compared with HAY heifers. Throughout the summer, ADG tended ($P = 0.09$) to be greater for MDW heifers. The greater spring and summer ADG most likely reflects compensatory gain by the MDW heifers. However, HAY heifer BW at breeding and pregnancy diagnosis continued to be greater ($P \leq 0.02$) than MDW heifers. Roberts et al. (2009) randomly assigned heifers to receive ad libitum or restricted access to feed for a 140-d period at 6 mo of age. A greater ADG in feed-restricted heifers than control heifers was observed from the end of the 140-d treatment period to 19.5 mo of age. This increased ADG was also believed to be compensatory gain following the restricted period. In the current study, percent of mature BW prior to the breeding season was greater ($P < 0.01$) for HAY compared with MDW. However, pubertal status prior to breeding and pregnancy rate were similar between treatments ($P \geq 0.82$) despite differences

in BW gain. Previous research has demonstrated differences in the proportion of heifers cycling prior to the breeding season due to lower input postweaning development systems. Feed-restricted heifers postweaning tended to be less pubertal prior to breeding than control heifers, however; final pregnancy rates did not differ (Roberts et al., 2009). Furthermore, calving rate and the proportion of heifers calving in the first 21 d was not different ($P \geq 0.33$) between treatments.

March-born Heifer Calving Performance

Calf birth BW did not differ ($P = 0.70$) between treatments (30, 30 ± 1 kg; HAY vs MDW, respectively). The proportion of bull calves born was similar ($P = 0.32$) between HAY and MDW. Additionally, calving ease, calf vigor, and dystocia rate were similar ($P > 0.62$) between treatments. Udder score, however, was more desirable ($P = 0.03$) for MDW vs. HAY heifers. Second pregnancy rate was not different ($P = 0.96$) between HAY and MDW (86, 87 ± 8%; HAY, MDW) in addition to ($P = 0.52$) BW at rebreeding (425, 421 ± 8 kg; HAY, MDW). Furthermore, calf BW at weaning was similar ($P = 0.35$) between treatments (205, 200 ± 4 kg; HAY and MDW, respectively).

May-born Heifer BW Gain and Reproductive Performance

Initial BW did not differ ($P = 0.99$, Table 4) between treatments. May-born heifers on HAY had greater ($P < 0.01$) ADG during the treatment period. While spring ADG did not differ ($P = 0.66$) between treatments, summer ADG was greater ($P < 0.01$) for MDW heifers, likely due to compensatory gain. Increased growth rates following the treatment period for MDW heifers did not result in similar heifer BW. Post-treatment, pre-breeding, and pregnancy diagnosis BW was greater ($P \leq 0.02$) for HAY compared with MDW heifers. Percent of mature BW prior to the breeding season was greater ($P < 0.01$) for HAY

(58%) compared with MDW (54%). More May-born heifers on HAY were (*P* = 0.02) pubertal prior to breeding than MDW. Funston and Deutscher (2004) found developing heifers to 60% of mature BW resulted in more heifers pubertal at breeding compared with heifers developed to 55% of mature BW; however, pregnancy rates did not differ between the development groups. In the current study, pregnancy and calving rates were similar ($P \geq 0.69$) between treatments, although, the proportion of heifers calving in the first 21 d was greater (*P* = 0.02) for MDW compared with HAY. This is in contrast to Eborn et al. (2013) who observed heifers developed to 55% of mature BW at breeding resulted in a 15% reduction in the proportion of heifers that calved in the first 21 d when compared with heifers reaching 64% of mature BW at breeding.

May-born Calving Performance

Calf birth BW was similar (*P* = 0.60) between development (29, 29 ± 1 kg) treatments. Additionally, calving ease, calf vigor, dystocia rate, and udder score were similar ($P \geq 0.12$) between HAY and MDW heifers. The proportion of bull calves born did not differ (*P* = 0.76) between heifer treatments. Cow rebreed pregnancy rate was not different (*P* = 0.60) from previous development (83, 77 ± 8 kg; HAY, MDW) treatment. Cow BW at rebreeding was also similar (*P* = 0.31) among treatments (399, 393 ± 5; HAY, MDW). Calf weaning BW did not differ (*P* = 0.36) in progeny from HAY and MDW dams (168, 165 ± 5 kg; HAY, MDW).

Heifer development system did not impact pregnancy rate in the March or May replacement heifers; however, March heifer pregnancy rate was greater ($P < 0.01$) than in May heifers (87 vs. 70 ± 3%, Table 5) despite lower (*P* = 0.02) pre-breeding BW. The lower pregnancy rate in May heifers may be due to declining forage quality during the

later breeding season (Funston et al., 2016). Table 2 illustrates the decrease in range quality from June to September in each yr of the study. Previous research by Griffin et al. (2012) evaluated calving date on mature cow performance in the Nebraska Sandhills. May, June, and August-calving cows experienced similar pregnancy rates. Therefore, this may be a function of the younger females not being able to consume sufficient amounts of forage declining in quality to meet nutrient requirements. Therefore, additional supplementation at time of breeding may be necessary in May-calving heifers. Currently, breeding season supplementation strategies for the May-calving herd are being investigated to determine effect on pregnancy rates (Lansford et al., 2017). The proportion of heifers calving in the first 21 d was also greater ($P = 0.04$) for March-born heifers compared with May-born heifers. Heifer rebreed BW was greater ($P = 0.04$) in March-born heifers than May-born heifers. Although numerically greater by 6 percentage points, second breeding season pregnancy rates were similar ($P = 0.28$). Calf BW at dam rebreeding was less ($P < 0.01$) in progeny from March-born dams than May-born. This difference may be a result of forage quality postpartum. March-born dams received meadow grass hay low in crude protein (Table 2) prior to rebreed, therefore resulting in decreased progeny weights. May-born dams, however, grazed forage at a time where CP is at its peak, thereby resulting in heavier calves at rebreeding (Lardy et al., 2004). Progeny ADG from dam rebreed to weaning was ($P = 0.02$) greater in calves from March-born dams. Griffin et al. (2012) observed calf ADG from birth to weaning and adjusted 205-d weaning BW to be greater in March-born calves than calves born in June and August. March heifer progeny were heavier ($P = 0.05$) at weaning compared with May heifer progeny. Funston et al. (2016) indicated calves born to an early-spring

calving system will generally be heavier at weaning than late-spring calves of similar age. Calves born to a late-spring calving system may not reach full rumen function until forage quality begins to decline, thus contributing to decreased weaning weights.

Heifer development system did not impact final pregnancy rates. Therefore, a reduced input winter heifer development system is a viable option in both early and late summer breeding seasons. However it should be noted, March-born heifers experienced significantly greater pregnancy rates, and more March-born heifers calved in the first 21 d when compared with May-born heifers. Thus, additional supplementation at time of breeding may be necessary in May-calving heifers to achieve similar reproductive rates.

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Table 1. Ingredient composition and nutrient analysis of supplement offered to heifers during overwinter treatment

Item	**% DM**
Ingredient	
Dried distillers grains	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 Analysis	
CP	31.6
TDN	89.4

[1]Vitamins and trace minerals formulated to meet heifer requirements with 80 mg/0.45 kg monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) provided.

Table 2. Nutritional composition of range, meadow, and hay (% DM) collected from esophageally fistulated cows in each development year

	2011	2012	2013	2014
Development period diet				
Winter range CP[1]	5.6	5.4	7.8	6.2
Winter range TDN[1]	51.7	52.5	54.4	51.0
Winter meadow CP[1]	7.7	10.7	9.9	12.7
Winter meadow TDN[1]	55.8	60.7	61.2	68.9
Hay CP[2]	7.3	7.3	6.8	7.7
Hay TDN[2]	54.4	55.9	48.2	58.5
March-calving breeding season				
June range CP	14.0	10.1	19.3	14.1
June range TDN	64.3	61.5	79.7	61.6
May-calving breeding season				
July range CP	11.1	10.6	14.7	10.1
July range TDN	61.2	59.6	71.0	59.0
Sept. range CP	6.9	8.2	9.8	10.4
Sept. range TDN	61.4	58.5	65.0	60.4

[1] Values for the developmental period are obtained from the previous December.

[2] Hay used during development yr was harvested the previous summer.

Table 3. Impact of heifer development system[1] on gain and reproductive performance of March-born heifers

Item	Treatment HAY	Treatment MDW	SEM	*P*-value
n[2]	8	8		
Weaning BW, kg	201	200	6	0.52
Initial BW, kg	240	240	6	0.89
Post-treatment BW, kg	310	287	7	<0.01
Treatment ADG,[3] kg/d	0.78	0.51	0.03	<0.01
Spring ADG,[4] kg/d	0.21	0.55	0.19	<0.01
Prebreeding BW,[5] kg	320	305	5	<0.01
Summer ADG,[6] kg/d	0.51	0.55	0.09	0.09
Percent of mature BW,[7] %	58	55	1	<0.01
Pregnancy diagnosis BW, kg	377	367	9	0.02
Pubertal,[8] %	64	69	19	0.82
Pregnancy rate, %	87	88	3	0.92
Calving rate[9], %	85	83	3	0.61
Calved in 1st 21 d, %	79	74	4	0.33

[1]HAY = heifers received ad libitum hay and 1.64 kg/d supplement (32% CP, DM) from Jan. 15 to April 15; MDW = heifers grazed meadow and received 0.41 kg/d supplement (32% CP, DM) from Jan. 15 to April 15.
[2]Represents number of replication per treatment.
[3]Jan. 16 to April 22 (96 d) and includes the treatment period.
[4]April 22 to May 22 (30 d).
[5]May 22.
[6]May 22 to Sept 10 (111 d).
[7]Percent of mature BW at breeding based on mature cow size of 552 kg.
[8]Considered pubertal if blood plasma progesterone concentration > 1 ng/mL.
[9]Percentage of heifers that calved.

Table 4. Impact of heifer development system[1] on gain and reproductive performance of May-born heifers

Item	Treatment HAY	MDW	SEM	*P*-value
n[2]	8	8		
Initial treatment BW, kg	190	190	4	0.99
Post-treatment BW, kg	260	230	7	<0.01
Treatment ADG,[3] kg/d	0.59	0.35	0.05	<0.01
Spring ADG,[4] kg/d	0.89	0.87	0.11	0.66
Prebreeding BW,[5] kg	350	333	7	<0.01
Summer ADG,[6] kg/d	0.49	0.57	0.11	<0.01
Percent of mature BW,[7] %	58	54	1	<0.01
Pregnancy diagnosis BW, kg	368	355	8	0.02
Pubertal,[8] %	79	65	18	0.02
Pregnancy rate, %	72	68	4	0.69
Calving rate[9], %	67	65	5	0.88
Calved in 1st 21 d, %	64	79	6	0.02

[1]HAY = heifers received ad libitum hay and 1.64 kg/d supplement (32% CP, DM) from Jan. 15 to April 15; MDW = heifers grazed meadow and received 0.41 kg/d supplement (32% CP, DM) from Jan. 15 to April 15.
[2]Represents number of replications per treatment.
[3]Jan. 15 to May 10 (115 d), includes the treatment period.
[4]May 10 to July 9 (67 d).
[5] Determined July 9.
[6] July 9 to Sept 10 (63 d).
[7]Percent of mature BW at breeding based on mature cow size of 552 kg.
[8]Considered pubertal if blood plasma progesterone concentration > 1 ng/mL.
[9]Percentage of heifers that calved.

Table 5. Comparison of March vs May gain and reproductive performance in heifers and subsequent progeny

Item	Calving Season		SEM	*P*-value
	March	May		
n	225	258		
Prebreeding BW[1], kg	313	344	7	0.02
Initial pregnancy rate, %	87	70	3	<0.01
Calved in 1st 21 d, %	85	71	4	0.04
Heifer rebreed BW[2], kg	424	396	6	0.04
Adjusted progeny rebreed BW[3], kg	76	91	2	<0.01
Progeny ADG[4], kg	1.00	0.79	0.03	0.02
Adjusted weaning BW[5], kg	209	192	4	0.05
Rebreed pregnancy rate, %	86	80	4	0.28

[1]BW prior to breeding (March = May 22; May = July 9).
[2] BW prior to second breeding season (March = May 8; May = July 22).
[3]BW of March or May heifer progeny collected at dam rebreed; adjusted to 63 d of age.
[4]Average daily gain in March or May heifer progeny from dam rebreeding to weaning.
[5]Adjusted to 205 d of age.

Chapter IV

Effect of injectable trace mineral on reproductive performance in beef heifers

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Abstract

Red Angus-based, May-born heifers (n = 799) at 2 locations were used to determine the effects of an injectable trace mineral on reproductive performance. Heifers were managed at the Maddux ranch, near Wauneta, NE. Following weaning in October, heifers were backgrounded in a feedlot until a BW of 295 kg was reached and then moved to graze native range at location 1 (L1, n = 125) or location 2 beginning in early March (L2, n = 286). A subset of heifers (n = 388) grazed corn residue with cows over winter, were weaned in April, and backgrounded in a feedlot until a target weight of 295 kg was attained. They were transported to L1 and L2 finishing in early June. Heifers were offered free choice mineral at both locations. Initial mineral status was analyzed via liver biopsy prior to mineral treatment (n = 22; 307 kg). Initial liver concentrations of copper (146 μg/g), manganese (9.22 μg/g), selenium (1.54 μg/g), and zinc (115 μg/g) were adequate and not different (P > 0.26) among heifers managed at the 2 overwinter locations. Heifers were synchronized with a 14-d CIDR-prostaglandin $F_{2\alpha}$ protocol and either injected with a trace mineral (5 mL, MULTIMIN; n = 399) or received no injection

(CON, n = 400) at CIDR insertion. Fertile bulls were placed with heifers on range for 60 d following AI. Pregnancy diagnosis was determined via transrectal ultrasonography 61 d and 91 d after AI. Heifer BW at pregnancy diagnosis was 333 and 342 kg for L1 and L2, respectively. The proportion of heifers pregnant within the first 21 d of the breeding season was not different (*P* = 0.32; 69 vs. 62 ± 3% for CON and MULTIMIN, respectively) nor was the proportion pregnant within the first 33 d (*P* = 0.57; 86 vs. 77 ± 2% for CON and MULTIMIN, respectively). Bulls remained with heifers at initial ultrasound; therefore, a second pregnancy diagnosis was performed 30 d later. Overall pregnancy rates were also not different (*P* = 0.38; 95 vs. 93 ± 1% for CON and MULTIMIN, respectively). In summary, injectable trace mineral at CIDR insertion 33 d before artificial insemination did not influence reproductive performance in heifers with adequate trace mineral status.

Key Words: beef heifers, injectable trace mineral, reproduction

Introduction

Trace minerals serve an important role in many biochemical processes, including reproduction. Supplementing Cu, Mn, and Zn reduce days to conception, services per conception, and influence hormone synthesis in the ovary (DiCostanzo et al., 1986). The primary source of trace minerals for grazing cattle is forage, with water and ingested soil representing secondary sources (Arthington et al., 2014). However, these natural sources do not fully account for trace mineral requirements in cattle, thereby emphasizing the need for trace mineral supplementation. Various forms of supplementation are available, including free-choice mineral, trace mineral-fortified salt blocks, drenching, oral boluses, and mineral injections (Arthington et al., 2014). Traditionally, grazing beef cattle are

offered trace mineral supplementation free-choice; however, intake can vary. Furthermore, dietary trace mineral absorption is reduced due to negative interactions with other nutrients during digestion. However, an injectable trace mineral (ITM) bypasses the gastrointestinal tract and dietary antagonists, making it advantageous to increase trace mineral status (Genther and Hansen, 2014). In addition, animals receive known amounts of mineral, reducing voluntary intake variability (Arthington et al., 2014).

An ITM solution used with free-choice trace minerals may be beneficial before breeding to increase mineral status. Heifers given an ITM have shown an increase in conception rates to timed embryo transfer (Sales et al., 2012). Additionally, conception to fixed-time AI was greater in ITM cows when compared with saline-treated cows (Mundell et al., 2012). Conversely, a more recent study noted no differences in reproductive performance of feedlot-developed heifers given an ITM 30 d prior to the breeding season when adequate concentrations of trace mineral were provided in the diet (Willmore et al., 2015). Limited research on the effects of an ITM administered at CIDR insertion on reproductive performance of range-developed beef heifers has been conducted. Heifers developed extensively represent those managed under dormant or scarce forage conditions, low precipitation, undulating terrain, or restricted-gain pen developed. Therefore, the objective of the current study was to determine if an ITM at CIDR insertion 33 d prior to artificial insemination affected reproductive performance of range-developed beef heifers.

Materials and Methods

Red Angus-based, May-born heifers (n = 799) at 2 locations were utilized to determine if an ITM affected reproductive performance. Heifers were managed at the

Maddux ranch, near Wauneta, NE. Following October weaning, heifers were backgrounded in a feedlot (Table 1) until a BW of 295 kg was reached. Following attainment of target BW, heifers grazed native range at location 1 (L1, n = 125) or location 2 beginning in early March (L2, n = 286). Additional heifers (n = 388) grazed corn residue with cows over winter, were weaned in April, and backgrounded in a feedlot until the target BW of 295 kg was attained. They were transported to L1 and L2 finishing in early June.

Heifers were offered free-choice mineral (850 mg/kg Cu, 16 mg/kg Se, and 3,400 mg/kg Zn, Elanco, Greenfield, IN) at both locations. Initial mineral status was analyzed via liver biopsy prior to mineral treatment (307 kg, n = 22, 13 CON, 9 MULTIMIN). Liver samples were collected utilizing the Engle and Spears (2000) method. Samples were placed in a plastic culture tube, transported on ice to the University of Nebraska-Lincoln nutrition laboratory and frozen at -20°C. Liver samples dried in a forced-air oven at 60°C and sent to the Diagnostic Center for Population and Animal Health (Lansing, MI) for trace mineral concentration analysis. Initial liver concentrations of copper (146 µg/g), manganese (9.22 µg/g), selenium (1.54 µg/g), and zinc (115 µg/g) were adequate and not different ($P > 0.26$) among heifers managed at the 2 locations (Table 2).

Heifers were synchronized mid-July with a 14-d controlled internal drug release (CIDR)-prostaglandin $F_{2\alpha}$ protocol (Figure 1). On d 0, heifers were inserted with a CIDR (Eazi-breed CIDR, Zoetis, Parsippany, NJ) and either injected with a trace mineral (5 ml, MULTIMIN, Table 3, n = 399) or received no injection (CON, n = 400). Removal of CIDR occurred d 14 and on d 30, PG was administered to heifers. Gonadotropin-

releasing hormone was administered concurrently with fixed-time AI on d 33. Fertile bulls were placed with heifers on range for 60 d following AI (1:17 bull to heifer ratio). Pregnancy diagnosis was determined via transrectal ultrasonography 61 and 91 d post-AI.

Statistical Analysis

Pregnancy data were analyzed using the GLIMMIX procedure of SAS, while trace mineral concentrations were evaluated with the MIXED procedure. Least square means and SE of the proportion of pregnant heifers by treatment were obtained using the ILINK function as pregnancy rates represent binomial distribution. Individual heifer was the experimental unit. Treatment and location were used as fixed effects. No interactions between treatment and location were observed. A P-value ≤ 0.05 was considered significant.

Results and Discussion

Pregnancy rates are presented in Table 4. The proportion of heifers pregnant within the first 21 d of the breeding season was not different (P = 0.32; 69 vs. 62 ± 3%; CON, MULTIMIN) nor was proportion pregnant within the first 33 d (P = 0.57; 86 vs. 77 ± 2%; CON, MULTIMIN). Heifer BW at pregnancy diagnosis was 338 kg. Bulls remained with heifers at initial ultrasound; therefore, a second pregnancy diagnosis was performed 30 d later. Overall pregnancy rates did not differ between treatments (P = 0.38; 95 vs. 93 ± 1%; CON, MULTIMIN). Previous research has indicated Cu and Se in the liver remain elevated through d 30 post-injection. Therefore, if a difference in pregnancy rates transpired, it would most likely occur within the first 21 d of the breeding season. However, data described above coincides with Willmore et al. (2015) in which black Angus heifers were administered an ITM 30 d prior to the breeding season.

Conception rates to AI and overall pregnancy rates were similar between ITM and control heifers being fed adequate trace minerals in the diet (Willmore et al., 2015).

More recently, Stokes et al. (2017) conducted 3 experiments at separate locations to assess heifer performance and reproduction when administered an ITM 33 d prior to breeding. Experiment 1 utilized spring-born, Angus heifers; Experiment 2 involved spring-born, Angus × Simmental heifers; and Experiment 3 used fall-born, Angus × Simmental heifers. Experiment 2 ITM heifers supplemented with free-choice mineral tended to have increased AI conception rates (62 vs. 45%) compared with saline-injected control heifers. However, this tendency may be due breed differences, calving season, or management strategies. In dairy cows, Vanegas et al. (2004) reported no beneficial effects of a single dose of an ITM before breeding on first-service conception rates. However, decreased first-service conception rates were observed in dairy cows receiving two doses of ITM: one prior to calving and one before breeding (Vanegas et al., 2004). A separate study conducted by Gadberry and Baldridge (2013) noted opposing effects to the previous statement. An ITM administered prior to fall calving and breeding did not affect pregnancy rates or postpartum interval in Angus cows when compared with cows receiving no injection.

Little evidence supports that an ITM improves AI conception rates. Mundell et al. (2012) administered an ITM 105 d before projected calving date and 30 d before fixed-time AI in addition to receiving free-choice trace minerals. Conception rates to AI were greater for ITM-treated cows than saline-treated control cows. Kirchoff (2015) also noted a greater proportion of ITM heifers pregnant to fixed-time AI than control heifers when the ITM was administered 4 weeks prior to breeding. Our findings indicate an ITM

administered at CIDR insertion did not influence reproductive performance in heifers with adequate trace mineral status.

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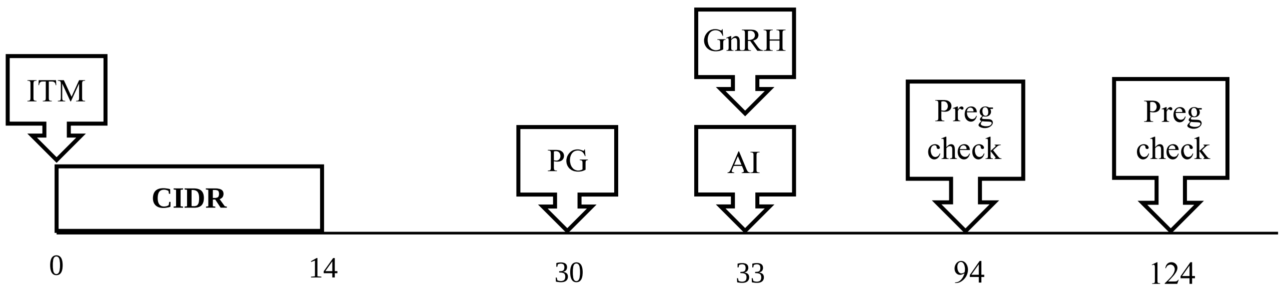
ITM
CIDR
PG
GnRH
AI
Preg check
Preg check
0
14
30
33
94
124

Figure 1. Experimental timeline for heifers receiving an injectable trace mineral or no injection. Heifers were administered an injectable trace mineral (ITM) or received no injection at controlled internal drug-releasing device (CIDR) insertion on d 0. On d 14, CIDR was removed, and prostaglandin $F_{2\alpha}$ (PG) was injected d 30. Gonadotropin-releasing hormone (GnRH) was administered concurrently with fixed-time AI on d 33. Pregnancy (Preg) was determined 61 d and 91 d post-AI.

Table 1. Composition and nutrient analysis of diet provided to heifers in the feedlot (DM basis)[1]

Ingredient	% of diet
Distillers grains	47.48
Silage	35.00
Straw	11.71
Grower Supplement	5.81
Nutrient Analysis	
CP, %	19.39
TDN	78.78

[1]Diet balanced to meet trace mineral NRC requirements

Table 2. Initial liver mineral concentrations[1] of CON and MULTIMIN beef heifers

Item	Adequate Status[2]	CON[3]	MULTIMIN[4]	SEM	*P*-value
n		13	9		
Initial Mineral					
Cu, ug/g	125-600	163	129	22	0.26
Mn, ug/g[5]	>8	9.09	9.35	0.13	0.80
Se, ug/g	1.25-2.50	1.56	1.52	0.38	0.61
Zn, ug/g	25-200	114	116	11	0.89

[1]Concentrations presented on a dry matter basis.
[2]Adequate described by Kincaid (2000).
[3]Control heifers received no trace mineral injection.
[4]Heifers injected with 5 mL of trace mineral.
[5] Adequate status range not well established (Hansen et al., 2006).

Table 3. Composition of injectable trace mineral supplement administered at CIDR insertion

Item	Multimin 90, mg/mL[1]
Copper	15
Manganese	10
Selenium	5
Zinc	60

[1]Multimin USA, Fort Collins, CO.

Table 4. Effect of an injectable trace mineral administered 33 d prior to breeding on pregnancy rate in beef heifers

Item	CON[1]	MULTIMIN[2]	SEM	*P*-value
n	400	399		
Pregnancy rate, %				
First 21 d	63	69	3	0.32
First 33 d	86	77	2	0.57
Overall	95	93	1	0.38

[1]Control heifers received no trace mineral injection.
[2]Heifers injected with 5 mL of trace mineral.

Chapter V

Effects of hydroxy trace mineral supplementation on gain and reproductive performance in beef heifers

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Abstract

Beef heifers from 3 development systems were utilized to assess the effect of trace mineral source on gain, reproductive performance, and trace mineral status. Two hundred Angus-based, spring-born heifers were stratified by BW and randomly assigned to graze corn residue (CR), upland range (RG), or were fed in a drylot (DL) postweaning. Following the development period, heifers were stratified by development treatment and BW and allocated into 1 of 8 pens per yr. Pens were randomly assigned to 1 of 2 mineral sources, hydroxy (**HD**, IntelliBond, Micronutrients USA LLC, Indianapolis, IN) or sulfate (**CON**; Phibro Animal Health, Teaneck, NJ). Heifers received mineral source treatment for 68 d. Mineral status was analyzed via liver biopsies prior to and following mineral treatment. A development treatment × mineral treatment interaction was observed for initial Cu and Zn status. Heifers developed on DL and assigned to the CON mineral treatment had greater ($P < 0.01$) initial Cu and Zn status compared with DL heifers assigned the HD treatment. No development treatment × mineral treatment interaction ($P = 0.49$) was observed for Mn. Initial trace mineral status was utilized as a covariate in the analysis of final mineral concentrations. No previous development x

mineral treatment interaction was observed ($P > 0.40$) for final Cu, Mn, or Zn. However, CON heifers had a greater ($P < 0.01$; 208 vs 123 ± 6.1 µg/g, CON vs HD) final Cu status than HD heifers. Mineral source treatment did not affect ($P \geq 0.42$) final Mn (10.7 ± 0.32 µg/g) or Zn (143 ± 15.2 µg/g) concentrations. Heifer ADG during the mineral trial did not differ ($P = 0.79$; 0.68 vs 0.69 ± 0.03 kg, CON, HD) between treatments. Final BW was also not different ($P = 0.98$; 339 vs 339 ± 3 kg) in heifers fed CON or HD mineral. Pregnancy rates to AI (62 ±5%) and final pregnancy rates (84 ± 4%) were not different ($P \geq 0.89$) between mineral sources. Overall, liver Cu concentrations were greater for CON than HD heifers at the end of the trace mineral trial; however, all heifers maintained adequate status throughout the study. Heifer gain and reproductive performance was not affected by mineral source.

Key words: beef heifer, hydroxy, reproduction, sulfate, trace minerals

Introduction

Beef cattle require minute quantities of trace minerals for growth, lactation, reproduction, and health. Three different structural forms of trace minerals are currently available: inorganic, organic, and hydroxy. Even though all types are approved for industry use, they differ in chemical structure, bioavailability, and cost. Hydroxy trace minerals are the most recent mineral source of Cu, Mn, and Zn created. This specific mineral source is formed by covalent bonds within a crystalline matrix, thereby differing from the ionic bonds present in inorganic sources (Arthington, 2015). Although similar in chemical bonds, hydroxy trace minerals covalently bind to an OH group, whereas organic trace minerals covalently bind to a carbon-containing ligand (Arthington, 2015).

Previous research has identified differences in bioavailability when comparing hydroxy to inorganic trace mineral sources. Miles et al. (1998) reported a low water solubility for tribasic Cu chloride in comparison with Cu sulfate. Spears et al. (2004) observed tribasic Cu chloride to be more bioavailable than Cu sulfate when supplemented in the presence of high S and Mo. The increased bioavailability may relate to the lower solubility of Cu chloride at a neutral or slightly acidic pH (Spears et al., 2004). Genther and Hansen (2014) found Cu and Mn from the hydroxy trace mineral source to be less soluble in the higher pH of the rumen compared with a sulfate source. Therefore, ruminal formation of insoluble interactions, such as thiomolybdates, are prevented. Due to a more acidic environment in the abomasum and small intestine, hydroxy trace minerals will solubilize and absorption will occur (Spears et al., 2004).

Similar gain performance has been observed in steers and crossbred heifers regardless of mineral source (Engle and Spears, 2000; Spears, 2007). However, limited research has evaluated the role of hydroxy trace minerals on reproductive performance in beef heifers. Therefore, the objective of the current study was to determine if trace mineral source affected mineral status, gain, and reproductive performance in beef heifers.

Materials and Methods

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all procedures and facilities used in this experiment.

Heifer Development

A 2-yr study conducted at the West Central Research and Extension Center (**WCREC**), North Platte, NE utilized 200 crossbred, Angus-based heifers. Each October,

spring-born heifers were received at WCREC and allowed a 30 d acclimation period. Following the acclimation period each year, heifers were blocked by BW and randomly assigned to graze corn residue (**CR**), upland range (**RG**), or were fed in a drylot (**DL**). Heifers developed on CR were transported to graze one corn residue field each year from mid-November to mid-February. The corn residue field was approximately 40 ha, irrigated, and located 100 km from WCREC. Fields were planted in April and harvested in October with an average annual yield of 12,544 kg/ha. Stocking rate was 2.5 heifer/ha during the grazing period. Heifers grazed CR for 84 d in yr 1 and 82 d in yr 2. Weather dictated available days for CR grazing each year. Following corn residue grazing, CR heifers were transported to winter range at WCREC until the end of the treatment period. Corn residue heifers grazed winter range for 32 d in yr 1 and 28 d in yr 2.

Heifers developed on RG grazed winter range for 119 d in yr 1 and 109 d in yr 2. The stocking rate for RG heifers was approximately 2.5 heifer/ha with an average annual herbage production of 1,430 kg/ha. Range warm-season grass species consisted of little bluestem (*Schizachyrium scoparium* (Michx.) Nash.), big bluestem (*Andropogon gerardii* Vitman), side oats grama (*Bouteloua curtipendula* (Michx.) Torr.), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) lag. Ex Griffiths), and switchgrass (*Panicum virgatum* L.). Primary cool-season grasses were Scribner's panicum (*Dichanthelium oligosanthes* (Schult.) Gould var. *scribnerianum* (Nash) Gould), western wheatgrass (*Agropyron smithii* Rydb.), and needle and thread (*Stipa comata* Trin. & Rupr.). Cheatgrass (*Bromus tectorum* L.), smooth bromegrass (*Bromus inermis* L.), and Kentucky bluegrass (*Poa pratensis* L.) were introduced grass species. When grazing winter range or corn residue, each heifer received the equivalent of 0.45 kg/d of a 32%

CP (DM), dried distillers grain-based supplement containing 80 mg·animal^{-1}·d^{-1} monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and vitamins and minerals.

Heifers assigned to DL were offered a diet formulated to target 65% of mature BW at breeding. Mature BW was based on an average mature cowherd BW of 552.5 kg. Drylot heifers were managed in the drylot for 119 d in yr 1 and 109 d in yr 2. Heifers placed on the DL treatment were fed once daily in the morning. Heifers received 4.7 kg/d grass hay, 1.3 kg/d wet corn gluten feed, and 0.29 kg/d mineral supplement on a DM basis in addition to 80 mg·animal^{-1}·d^{-1} monensin.

Mineral Source Trial

Following the development period, heifers were stratified by development treatment and BW and randomly assigned to 1 of 2 mineral supplements, hydroxy (**HD**; Intellibond; IntelliBond, Micronutrients USA LLC, Indianapolis, IN) or sulfate (**CON**; Phibro Animal Health, Teaneck, NJ). Initial BW for the mineral source experiment was recorded. Heifers were assigned to 1 of 8 pens (4 pens per mineral treatment) and managed according to their respective mineral treatment each yr. Previous development treatment was equally represented in each pen. All heifers were offered a ration consisting of 5.5 kg grass hay, 2.1 kg wet corn gluten feed, and 0.41 kg of 1 of 2 mineral supplements on a DM basis (Table 1). Supplemental Cu and Zn from each source was included in the diet. Mineral supplement treatments were fed for 68 d. An initial liver biopsy from randomly selected heifers (n = 48; 24 CON, 24 HD) was performed to determine Cu, Zn, and Mn status prior to the mineral source treatment. Previous development treatments and pen were equally represented in the liver biopsies. Liver

samples were collected utilizing the Engle and Spears (2000) method. Samples were placed in a plastic culture tube, transported on ice to the University of Nebraska-Lincoln nutrition laboratory and frozen at -20°C. Liver samples dried in a forced-air oven at 60°C and sent to the Diagnostic Center for Population and Animal Health (Lansing, MI) for trace mineral concentration analysis. Following the trial, a final liver sample was collected from the same heifers.

During the 68-d mineral trial and prior to the breeding season, 2 blood samples were collected via coccygeal venipuncture 10 d apart to determine pubertal status. Heifers with plasma progesterone concentrations greater than 1 ng/mL at either collection were considered pubertal. Plasma progesterone concentration was determined via direct solid phase RIA (Coat-A-Count, Diagnostics Products Corp., Los Angeles, CA). Blood samples were placed on ice following collection and centrifuged at 2,500 × g for 20 min. at 4°C. Following serum removal, samples were frozen at -20°C pending analysis.

On d 69, heifers were grouped together in the drylot to allow for estrous synchronization and AI. Heifers were synchronized using a melengestrol acetate (MGA) - $PGF_{2\alpha}$ protocol (Vraspir et al., 2013). Each heifer was offered 0.5 mg/d of MGA (Zoetis Animal Health, Parsippany, NJ) pellets in their diet (d 1 to 14). On d 33, heifers in yr 1 were blocked by previous mineral treatment and received either 5 mL i.m. Lutalyse (5 mg/mL dinoprost tromethamine, Zoetis, n = 50) or a 2 mL s.c. Lutalyse *HighCon* (12.5 mg/mL dinoprost tromethamine, Zoetis, n = 50) injection. In yr 2, heifers received s.c. Lutalyse *HighCon* on d 33. Differences in PG type across years were due to yr 1 heifers being part of a synchronization study (Lansford et al., 2018). Estrotect patch was applied at $PGF_{2\alpha}$ injection. Heifers were managed together to observe estrus continuously for 6 d.

Heifers were AI 12 h after estrus was observed. Heifers were considered in estrus when more than 50% of the rub-off coating was removed on the Estrotect patch or when the patch was absent. Heifers not detected in estrus were given a second $PGF_{2\alpha}$ (Lutalyse *HighCon*) injection 6 d after the initial $PGF_{2\alpha}$ injection and placed with 2 bulls. Inseminated heifers grazed a separate pasture for 10 d before being commingled with bulls and non-AI heifers for a 60 d breeding season at a bull to heifer ratio of 1:50. Pregnancy rates were diagnosed via transrectal ultrasonography (Aloka, Hitachi Aloka Medical America Inc., Wallingford, CT) at 45-50 d post-AI and 45-50 d after bull removal.

Statistical Analysis

Heifer development data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.). Development treatment was considered a fixed effect with year × development treatment the experimental unit. Proportions of pubertal and pregnant heifers were analyzed using an odds ratio. Least squared means and SE of the proportion of pubertal and pregnant heifers were obtained using the ILINK function of GLIMMIX as these variables represent a binomial distribution.

Mineral source data were analyzed using the GLIMMIX procedure of SAS. Mineral treatment was applied to animals by pen, therefore, pen served as the experimental unit. There were 8 total replicates for each mineral treatment. The preliminary model for initial mineral status, gain, and reproductive performance included previous development treatment, mineral treatment, year, and all appropriate interactions. Interactions with a $P > 0.05$ were removed from the model to obtain the final condensed model for each variable. A development treatment × mineral treatment interaction was

observed for initial Cu and Zn (Table 2). Heifers developed on drylot and assigned to the CON mineral treatment had greater ($P < 0.01$) initial Cu and Zn status compared with DL heifers assigned the HD treatment. No development treatment × mineral treatment interaction ($P = 0.49$) was observed for Mn.

The preliminary model for final mineral status utilized the initial trace mineral × development treatment as a covariate. Covariate interaction was removed due to non-significant *P*-values, therefore initial trace mineral was used as a covariate. Proportions of pubertal and pregnant heifers were analyzed using an odds ratio. Least squared means and SE of the proportion of pubertal and pregnant heifers were obtained using the ILINK function of GLIMMIX. Differences were considered significant when $P \leq 0.05$, while differences with $0.05 < P \leq 0.10$ were considered tendencies.

Results and Discussion

Heifer Development Gain and Reproductive Performance

Initial BW prior to development did not differ ($P = 0.72$, Table 3) among heifers. Average daily gain during the development period was greater ($P = 0.01$) for DL than CR or RG heifers; however, RG heifers tended ($P = 0.08$) to have greater ADG when compared with CR. Final development BW was greater ($P = 0.01$) for DL heifers compared with RG and CR heifers. Body weight at prebreeding remained greater ($P < 0.01$) in DL heifers compared with CR and RG. Drylot heifers tended ($P = 0.06$) to have a greater percent of mature BW than CR. However, no differences were observed between DL and RG heifers or RG and CR heifers for percent of mature BW. Throughout the breeding season, ADG tended ($P = 0.10$) to be lower in DL heifers compared with CR but did not differ when compared with RG heifers. Grazing behavior may account for

decreased breeding ADG in the DL heifers. Funston and Larson (2011) noted an increased ADG in the period between the first breeding service and final pregnancy diagnosis in extensively-developed heifers when compared with drylot-developed heifers. Perry et al. (2013) found heifers with less grazing experience lost 1.6 ± 0.08 kg/d the first week following AI when moved to graze forage. Although the DL heifers in the current study experienced a decline in ADG during the breeding season, BW at AI pregnancy diagnosis remained greater ($P = 0.03$) for DL heifers in comparison with CR or RG. Final pregnancy diagnosis BW continued to be greater ($P = 0.04$) for DL heifers when compared with CR heifers and tended to be greater ($P = 0.08$) compared with RG heifers. Pregnancy rates to AI and overall pregnancy rates did not differ ($P \geq 0.86$) among development groups.

Final Copper, Manganese, and Zinc Status

No previous development × mineral treatment interaction was observed ($P > 0.40$) for Cu, Mn, or Zn. Unexpectedly, CON heifers had a significantly greater ($P < 0.01$, Table 4) final Cu status than HD heifers. This contradicts Spears et al. (2004) in which tribasic Cu chloride was more bioavailable in growing steers than $CuSO_4$ when added to a high Mo and S diet. Steers were stratified by BW and randomly assigned to 0, 5, or 10 mg supplemental Cu/kg diet DM from Cu chloride or Cu sulfate, resulting in 5 different treatments. Corn silage diets were supplemented with 5 mg Mo/kg and 0.15% S in addition to the 6.9 mg Mo/kg and 3.0 g S/kg analyzed in the corn silage diet. In the present study, dietary S was low (0.23%) while Mo was considered high (1.46 mg/kg). Zezeski et al. (2016) utilized 37 bulls of mixed breeds ranging from 2 to 4 yr of age to assess trace mineral source on liver mineral status. Bulls were blocked by length of time

without trace mineral supplementation and stratified by initial liver Cu status into 1 of 3 treatments: supplement without Cu, Mn, and Zn; supplement with Cu, Mn, and Zn sulfate; and supplement with basic Cu chloride, Zn and Mn hydroxychloride. Liver Cu concentrations were greater in bulls receiving the hydroxy supplement when compared to the sulfate source. Arthington and Spears (2007) reported similar availability between hydroxy and sulfate Cu sources in non-pregnant, growing beef heifers. Three Cu treatments were assigned to heifers for 90-d in the form of a corn- or molasses-based supplement: 1) 100 mg of Cu/d from $CuSO_4$, 2) 100 mg of Cu/d from tribasic Cu chloride, or 3) 0 mg of Cu/d. Heifers provided supplemental Cu had increased liver Cu concentration; however, no differences were observed between Cu sources.

The presence of Cu antagonists can alter how Cu sources are metabolized, which may explain the variation in Cu status from previous literature. Absorption of Cu can be inhibited by the ruminal interaction of S and Mo to form thiomolybdates. These insoluble complexes will bind ruminally available Cu and be excreted (Suttle, 1991). However, thiomolybdates can be absorbed in the presence of insoluble ruminal Cu, thereby inhibiting Cu-dependent enzymes within the body (Kelleher et al., 1983). Genther and Hansen (2014) found Cu from the hydroxy trace mineral source to be less soluble in the higher pH of the rumen when compared with a sulfate source. Due to a more acidic environment in the abomasum and small intestine, hydroxy trace minerals will solubilize and absorption will occur (Spears et al., 2004). Therefore, in the presence of hydroxy Cu, thiomolybdates could have been absorbed and reduced hepatic Cu stores, resulting in a decreased final Cu status for the HD heifers (Hartman et al., 2017).

Diet type variation may also explain liver Cu differences in the current study. Molasses-based supplements generally contain greater S concentrations compared with corn-based supplements. Arthington and Pate (2002) reported heifers provided molasses-based supplements to have decreased liver Cu concentrations than heifers receiving a similar amount of Cu in a corn-based supplement. The high S content in the molasses-based supplement was presumed to be the reason for the Cu reduction. Due to a lower liver Cu content in cattle fed molasses-based supplements, Arthington et al. (2003) fed steers a molasses-cottonseed meal supplement with 1 of 4 Cu treatments: 1) 10 ppm of Cu from an organic source, 2) 10 ppm Cu from tri-basic Cu chloride (TBCC), 3) 30 ppm of Cu from TBCC, or 4) 30 ppm of a 50:50 TBCC and organic Cu. Liver Cu was greater for steers consuming 30 vs. 10 ppm of Cu. Therefore, a dietary Cu concentration greater than 10 ppm may be necessary for adequate absorption in cattle fed molassess-based supplements (Arthington et al., 2003). In feedlot cattle fed high-concentrate diets, Cu requirements are not distinct (Engle and Spears, 2000). Kowalczyk et al. (1964) suggested Cu was more available in concentrate diets vs. forage-based diets due to Cu reports of toxicity in lambs fed concentrate diets. Engle and Spears (2000) indicate as little as 20 mg/kg of supplemental Cu can reduce finishing steer performance. Interestingly, consulting nutritionists may formulate feedlot diets to contain 3 times the NRC (2000) recommendation for certain trace minerals (Vasconcelos and Galyean, 2007). Caldera et al. (2017) compared 4 treatments consisting of various concentrations (10 to 17.5 mg/kg) of supplemental basic Cu chloride. No differences in liver Cu concentrations, feedlot performance, or carcass merit were observed, thereby indicating

yearling steers can be fed at a reduced rate compared with current industry feeding practices (Caldera et al., 2017).

Final Mn and Zn did not differ ($P > 0.42$) between trace mineral sources in the current study. Hartman et al. (2017) utilized a 2 × 2 factorial to assess trace mineral sources fed within a low- or high-S diet. Angus, crossbred steers were blocked by BW and assigned to low-S (0.27%) or high-S (0.54%) diets and supplemented trace minerals from hydroxy or inorganic sources. No differences were observed in liver Zn concentrations in steers receiving either a hydroxy or inorganic trace mineral during the growing and finishing phase. However, liver Mn concentrations were affected. In the growing phase, steers supplemented with hydroxy in a low S diet experienced greater liver Mn concentrations compared with steers supplemented with inorganic trace minerals or those supplemented with hydroxy or inorganic trace minerals in a high S diet (Hartman et al., 2017).

Mineral Source on Gain and Reproductive Performance

Initial and final BW prior to and following mineral source treatment did not differ ($P \geq 0.90$, Table 5) between CON and HD heifers. Average daily gain during the 68-d period was not different ($P \geq 0.79$) between treatments. Limited work has been conducted comparing hydroxy and traditional sources of trace minerals on gain in beef heifers. However, previous literature in calves and steers has studied these effects. Caramalac et al. (2017) observed no differences in final BW or gain in calves supplemented with a hydroxy or sulfate mineral source at a rate of 114 g/calf daily for 84 d prior to weaning. However, total supplement intake was greater for calves consuming the hydroxy source of Cu, Mn, and Zn. Postweaning BW gain was less in calves supplemented with sulfate

forms of trace minerals than hydroxy-supplemented calves in yr 1 and 2 of the experiment (Caramalac et al. 2017). Hartman et al. (2017) observed overall feed efficiency in a high S diet to be greater in steers supplemented with inorganic trace minerals when compared with steers receiving hydroxy. However, Hilscher et al. (2015) reported no differences in feed efficiency and carcass traits in steers receiving either a sulfate or hydroxy supplement. In the current study, percent of mature BW was similar ($P = 0.85$) in heifers on both mineral treatments. Furthermore, no differences ($P \geq 0.83$) were observed for prebreeding BW or BW recorded at AI and final pregnancy diagnosis. Average daily gain during the breeding season and from mineral trial completion to first pregnancy diagnosis did not differ ($P \geq 0.62$). Pregnancy rate to AI and overall pregnancy rates were similar ($P \geq 0.89$) for CON and HD-treated heifers. Burnett et al. (2017) also observed no impact of a sulfate or hydroxychloride source of Cu and Zn on reproductive performance in crossbred-Angus beef heifers.

Results from this study imply Cu status was less in heifers supplemented with a hydroxy mineral source when receiving a low S and high Mo diet. Thiomolybdate absorption due to the presence of ruminal hydroxy Cu may have reduced hepatic Cu stores, resulting in decreased Cu status. Heifer gain and reproductive performance was not affected by mineral source.

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Table 1. Ingredient composition and nutrient profile of diets containing sulfate sources (CON) or hydroxy sources (HD) of Cu, Mn, and Zn of heifers during 68-d mineral trial

Item	CON	HD
Ingredient, kg/d (DM basis)		
Grass hay	5.5	5.5
Wet corn gluten feed	2.1	2.1
Mineral Supplement	0.41	0.41
Nutrient profile (DM basis)		
CP, %	12.3	12.3
TDN, %	75.9	75.9
S, %	0.23	0.23
Cu, mg/kg	15.3	15.5
Fe, mg/kg	166.8	166.8
Mn, mg/kg	81.5	81.4
Mo, mg/kg	1.45	1.46
Zn, mg/kg	49.2	45.3

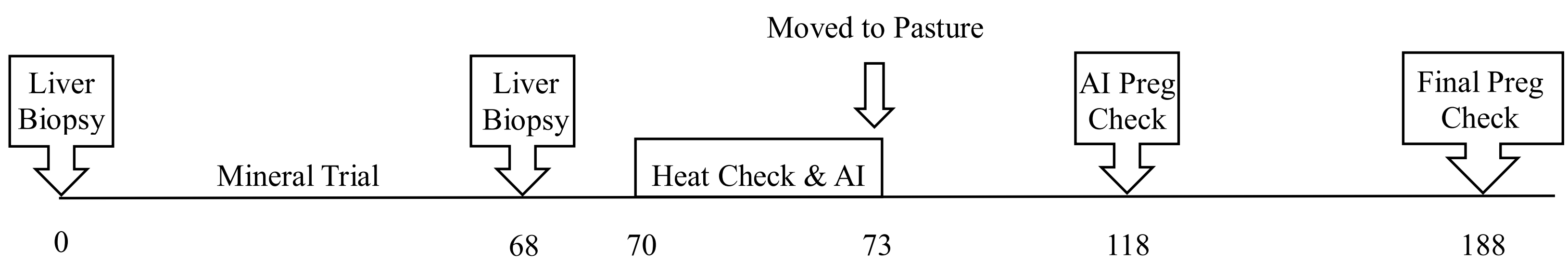
Moved to Pasture
Liver Biopsy
Liver Biopsy
AI Preg Check
Final Preg Check
Mineral Trial
Heat Check & AI
0
68
70
73
118
188

Figure 1. Experimental timeline for heifers receiving two different trace mineral sources. A liver biopsy was performed on randomly selected heifers at d 0 to determine initial mineral status prior to mineral trial. During the 68-d mineral trial, heifers received 0.41 kg (DM basis) of a hydroxy or sulfate supplement. On d 68, a second liver biopsy was conducted to evaluate heifer mineral status after the treatment period. Heifers were heat-checked and AI from d 70 to 73. Following AI, heifers grazed native range. Pregnancy diagnosis via transrectal ultrasonography occurred on d 118 and 188.

Table 2. Liver concentrations of Cu, Mn, and Zn prior to mineral source trial in yearling heifers previously developed on range (RG), corn residue (CR), or within the drylot (DL)

	CON			**HD**			**SEM**	***P*-value**		
	RG	CR	DL	RG	CR	DL		Development treatment	Mineral treatment	Interaction
n	8	8	8	8	8	8				
Trace mineral										
Cu, PPM	94	136	318[a]	93	141	223[b]	16.3	<0.01	0.04	<0.01
Mn, PPM	10.6	10.7	9.3	10.5	10.6	9.9	0.37	<0.01	0.74	0.49
Zn, PPM	98	94	144[a]	98	100	106[b]	6.9	<0.01	0.11	<0.01

[a,b] Means in a row with different superscripts are different ($P \leq 0.05$).

Table 3. Gain and reproductive performance of beef heifers developed on range (RG), corn residue (CR), or within the drylot (DL)

	Development Treatment[1]				
Item	RG	CR	DL	SEM	*P*-value
n	2	2	2		
Initial development BW, kg	246	254	254	7.1	0.72
Final development BW, kg	280^{b}	265^{b}	332^{a}	7.2	0.01
Development ADG, kg	0.30^{b,x}	0.10^{c,y}	0.69^{a}	0.054	0.01
Prebreeding BW, kg	329^{b}	317^{b}	371^{a}	4.7	<0.01
Percent of mature BW[2], %	58^{x,y}	56^{y}	66^{x}	1.8	0.06
Breeding ADG[3], kg	0.87^{x,z}	0.98^{y,z}	0.66^{x}	0.072	0.10
AI pregnancy diagnosis BW, kg	375^{b}	368^{b}	406^{a}	5.3	0.03
Final pregnancy diagnosis BW, kg	427^{b,y}	419^{b}	448^{a,x}	4.2	0.04
AI pregnancy, %	65	61	58	9.6	0.86
Final pregnancy, %	86	83	79	15.7	0.94

[1] RG = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing winter range for 114 d before entering the drylot for estrus synchronization and AI; CR = each heifer received the equivalent of 0.45 kg/d of a distillers-based supplement while grazing corn residue for 83 d and winter range for 30 d before entering the drylot for estrus synchronization and AI; DL = heifers were developed on a high-energy diet in the drylot for 114 d and through estrus synchronization and AI.

[2]Percent of mature BW at breeding based on mature cow size of 552 kg.

[3]ADG between prebreeding and first pregnancy diagnosis.

^{a,b,c} Means in a row with different superscripts are different ($P \leq 0.05$).

^{x,y,z} Means in a row with different superscripts tended to be different ($0.05 < P \leq 0.1$).

Table 4. Final liver concentrations[1] of Cu, Mn, and Zn in beef heifers following a 68-d mineral source trial

Item	Mineral Treatment[2] CON	HD	SEM	*P*- value
n	24	23		
Trace Mineral				
Cu, PPM	208	123	6.1	<0.01
Mn, PPM	10.6	10.8	0.32	0.53
Zn, PPM	152	134	15.2	0.42

[1]Initial mineral status used as a covariate (Cu *P*-value < 0.01, Mn *P*-value < 0.01, Zn *P*-value = 0.15).
[2]CON heifers received a high-energy diet with a sulfate-based supplement for 68 d; HD heifers received a high-energy diet with a hydroxy-based supplement for 68 d.

Table 5. Effect of hydroxy (HD) or sulfate (CON) mineral source on gain and reproductive performance in beef heifers fed for 68 d

	Mineral Treatment			
Item	CON	HD	SEM	*P*-value
n	8	8		
Initial BW, kg	293	292	2.4	0.90
Final BW, kg	339	339	2.7	0.98
Mineral treatment ADG, kg	0.68	0.69	0.027	0.79
Prebreeding BW, kg	339	339	2.7	0.97
Percent of mature BW[1], %	60	60	0.5	0.85
Breeding ADG[2], kg	0.83	0.84	0.021	0.64
AI pregnancy diagnosis BW[3], kg	382	383	2.7	0.83
Mineral treatment to first pregnancy ADG[4], kg	0.75	0.76	0.017	0.62
Final pregnancy diagnosis BW[5], kg	433	430	2.8	0.38
AI pregnancy, %	61	62	5.4	0.89
Final pregnancy, %	84	84	4.0	0.95

[1]Percent of mature BW at breeding based on mature cow size of 552.5 kg.
[2]ADG between prebreeding and first pregnancy diagnosis.
[3]July 14 or approximately 45 d post-AI.
[4]ADG between start of mineral treatment and first pregnancy diagnosis.
[5]September 23 or approximately 115 d post-AI.

Appendix A

The Nebraska Ranch Practicum: A holistic approach to beef and forage systems

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Abstract

Initiated in 1999, the Nebraska Ranch Practicum continues today with the goal to strengthen beef cattle operations by providing hands-on learning experiences and direct participation in beef systems. The primary objectives are to improve decision-making skills, enhance stewardship of natural resources, and improve critical evaluation skills of alternative production enterprises. The Practicum is taught by an interdisciplinary team for 8 days over an 8-month period. The hands-on teaching enables students to actively participate and witness outcomes of management decisions from holistic beef systems, including reproductive management, calving and weaning date decisions, heifer development, yearling and calf-fed production systems, and cull cow management and marketing. Additions to the practicum over time have focused on biosecurity, wildlife and pest management, and marketing concepts in a systems-based approach. The learning experience has provided an opportunity to create a production database covering 15 yr from the practicum cow herd. The database includes precipitation records, nutrient content of grazed diets, cow and calf performance traits, and yearling gain. Students critically analyze individual production components in a systems approach and applied this approach to their unique operation. An identical pre- and post-test revealed

participants increased their working knowledge of holistic systems. In 17 years, over 600 individuals from 13 states have participated. Course attendees include producers (73%), graduate students (11%), allied industry (8%), extension (5%), and veterinarians (3%). Collectively, participants reported direct impacts on over 290,000 cattle, 3.8 million acres of land with an average of 740 beef animals/ranch and a $15,000 impact/ranch for a total direct impact of $3.4 million. Participants reported they have extended information received from the Practicum to more than 19,000 people, thereby influencing over 1.6 million cattle and nearly 8 million acres. The Nebraska Ranch Practicum indirectly impacted over $6 million to the beef industry.

Key words: experiential learning, forage systems, holistic beef systems, Ranch Practicum

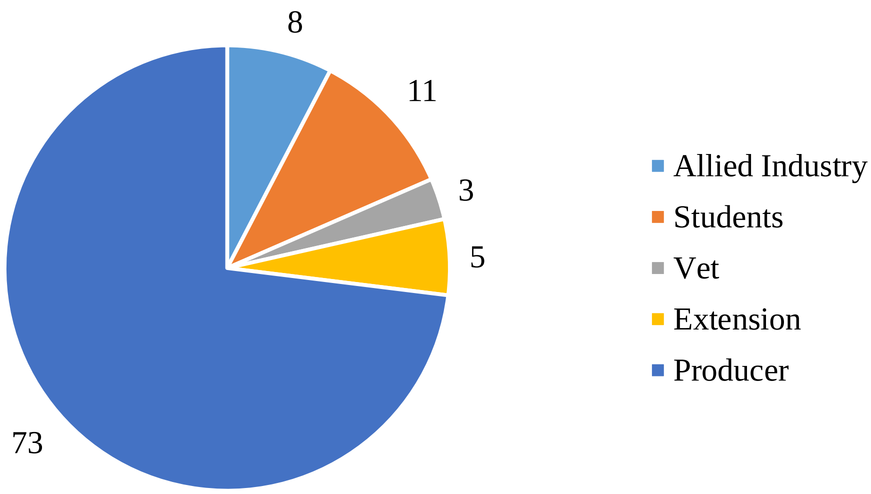

Figure 1. Categorization of professions represented in the Nebraska Ranch Practicum.

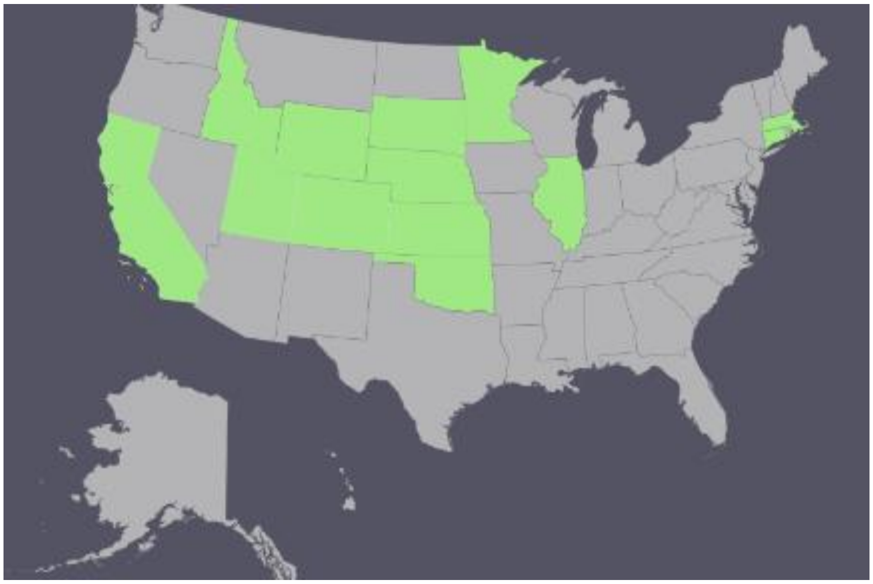

Figure 2. Ranch Practicum participants represented 13 states since course initiation.

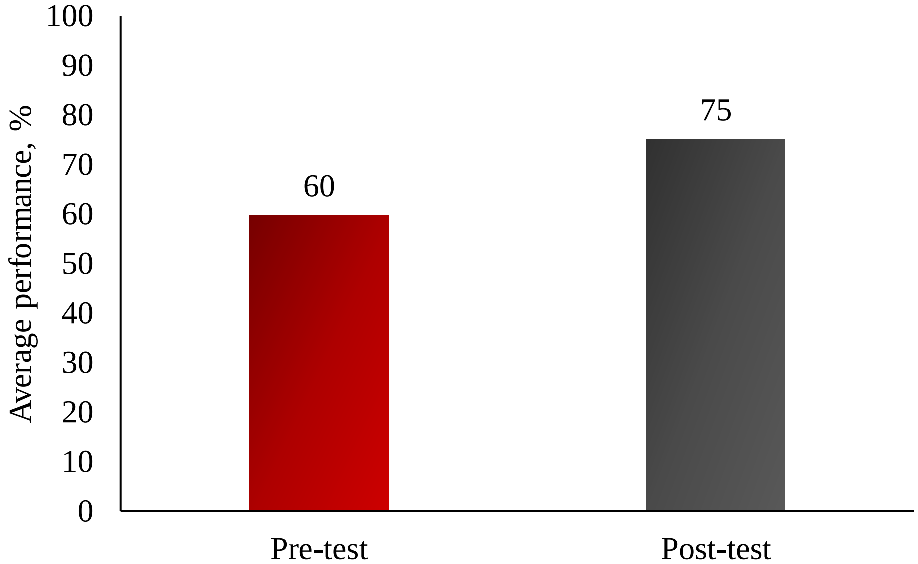

Table 1. Ranch Practicum post-test scores revealed a 15% average improvement rate from pre-test.

Pre Subject Matter Assessment

Nebraska Ranch Practicum

Name: ____

Circle the correct answer:

1.) Research has shown that sub-irrigated meadows will have an increasing yield response with application of which fertilizer nutrient(s).

  a. Nitrogen
  b. Phosphorus
  c. Sulfur
  d. All of the above

2.) Which of the following is not true about applying more nitrogen to a sub-irrigated meadow?

  a. It may provide forage needed for future use
  b. It is always cost effective
  c. It increases the productivity of the meadow
  d. It may pay when forage prices are high

List “ECONOMIC” factors that should be considered when making the choice to apply fertilizer to a sub-irrigated meadow?

  a) _______________________________________
  b) _______________________________________

3.) What is the primary factor determining the quality of range diets selected by cattle?

4.) What time of the year are grasses most resistant to heavy grazing?

5.) What is a key indicator of the nutrient status of a cow? ______________________
What production trait is it closely related to? _____________________________

6.) Heavy defoliation of mid- or tall grasses during the growing season reduces the length of roots ___________.

  a. primarily in the first foot of rooting depth
  b. primarily at the mid-rooting depth

c. primarily at deep rooting depth
d. uniformly throughout rooting depth

7.) What are 3 management factors that a producer may use to influence the nutritional quality of sub-irrigated meadow hay?

1. ______________________________
2. ______________________________
3. ______________________________

8.) What are 3 things that a producer can do to manage milk production in the cowherd?

1. ______________________________
2. ______________________________
3. ______________________________

9.) Which 2 of these factors would have a positive influence on the range condition or health score of upland Sandhills range?

a. A high proportion of warm-season grasses
b. A high proportion of cool-season grasses
c. High plant species diversity
d. A high proportion of forbs
e. A high proportion of annual grasses

10.) When environmental conditions are favorable for plant growth, individual shoots (tillers) of grass continue to grow after grazing if ___________.

a. 50% or more of the leaf material is left
b. the growing point has not been removed
c. they have been grazed only once
d. the plants have headed before grazing

11.) List 5 natural events or processes, not including livestock, that can significantly reduce the amount of herbage on upland range sites.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

12.) What effect does milk production have on cow nutrient requirements?

13.) List 3 management factors that could contribute to the lowering of range condition or plant health.

1.
2.
3.

14.) When are the nutrient requirements the greatest during the annual production cycle of a cow?

15.) T or F Grazing management directly affects infiltration of rain water and snow melt into the soil and the uptake of soil water by plants.

16.) Which of the following will generally be the first limiting nutrient for beef cattle in dormant Sandhills range forages?

a. Water
b. Energy
c. Vitamins
d. Minerals
e. Protein

17.) What 2 environmental variables must be simultaneously favorable before plants can grow rapidly?

1.
2.

18.) List 5 common or important upland range grasses in the Sandhills.

1.
2.
3.
4.
5.

19.) Forage **quality** of grasses is most affected by which of the following factors?

a. soils and rainfall
b. stage of maturity and tiller age

c. tiller age and plant species
d. rainfall and stage of plant maturity

20.) When grazing sub-irrigated meadows, grazing during which month would be most favorable to increasing the proportion of warm-season grasses in that meadow?

a. January
b. May
c. July
d. September

21.) In the Sandhills, tall warm-season grasses are likely to be most vigorous when pastures are grazed primarily _______.

a. in June
b. in July
c. in August
d. after killing frost

22.) What is the best way to select a grazing system for your ranch?

a. Go to a grazing school
b. Select one based on your objectives
c. Follow the lead of the previous manager
d. Use the most popular system

23.) Generally the most limiting habitat factor for upland game bird species in western Nebraska is _______.

a. Predators
b. Winter food and shelter
c. Safe nesting cover
d. Water

24.) The best time to retain cattle through the feedlot is when you think the potential for ___________ is high relative to the risk you are taking on.

25.) Changes in the futures contract price relative to changes in my local cash price is referred to as a change in my ___________.

26.) T or F When taking a position in the futures market, I am locking in a futures cash price for when I sell my cattle.

27.) When making decisions, you may sometimes over rely on your first thoughts. This is called the

a. anchoring trap
b. confirming evidence trap
c. framing trap
d. recallability trap
e. status quo trap

28.) If your primary business objective is to maximize profit, then the most economical feed would be:

a. The least expensive.
b. The one that produces the best rate of gain.
c. The one that results in the lowest cost of gain.
d. None of the above.

29.) Which one of the following is <u>NOT</u> one of the eight key elements of effective decision making?

a. Problem definition
b. Identify Alternatives
c. Risk Tolerance
d. Make the Decision
e. Consequences

30.) Why is a marketing plan important?

a. Helps avoid crisis selling
b. Helps remove emotion from the decision process
c. Changes the time when the decision is made
d. All the above
e. None of the above

31.) Mentoring is about all of the following except:

a. a partnership in two-way learning.
b. enhancing skill sets and expanding networks.
c. learning to value differences in approach and philosophy.
d. passing on knowledge in a meaningful way.
e. sponsoring young producers.

Appendix B

The Nebraska Ranch Practicum: An insight into cow and calf production from varying precipitation and two weaning dates

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Abstract

Data from the Nebraska Ranch Practicum teaching herd (Red Angus × Simmental) were analyzed to determine if spring precipitation and weaning date affected cow-calf performance at the Gudmundsen Sandhills Laboratory, Whitman, NE. April, May, and June precipitation records for each yr from 2000 to 2014 were used to calculate annual average precipitation. When annual precipitation was compared with the 15 yr precipitation average, each year's cow-calf data were classified into 1 of 3 categories: below-average (**DRY**, n = 79), average (**AVG**, n = 82), or above-average (**WET**, n = 80). Crude protein and TDN were determined from diets of esophageally fistulated cows collected during the same 15 yr period. Although forage quality was impacted by precipitation, stocking rate was adjusted so forage quantity was not limited for grazing cows each yr. Calves were either weaned in September or November. Calves weaned in September grazed subirrigated meadow, whereas the unweaned calf and cow grazed native range. Calf BW was greater ($P \leq 0.01$) in DRY yr compared with AVG and WET yr. Cow BW did not differ ($P \geq 0.20$) in June, July, and November; however cows in DRY yr tended to weigh more ($P = 0.06$) in September than AVG-yr cows. In addition, DRY-yr cows weighed more ($P < 0.01$) in January than cows managed in AVG or WET

yr. Above-average precipitation in August and September during the DRY yr resulted in new plant growth and higher CP in fall diets, likely explaining increased cow BW. Cows classified in the WET yr had greater ($P < 0.01$) BCS in July and September than AVG or DRY cows. Body condition score, however, did not differ ($P \geq 0.17$) among precipitation levels in November and January (5.3 ± 0.07). In September, DRY-yr cows had increased ($P = 0.04$; 5.5 vs 4.6 ± 0.28 kg, DRY vs WET) milk production compared with WET-yr cows. Precipitation level did not affect ($P = 0.95$) pregnancy rates (94 ± 3%). Calves weaned in November weighed more ($P < 0.01$; 222 vs 189 ± 3 kg, Nov. vs Sept.) than September-weaned calves at the November weaning date. However, the September weaning date resulted in greater ($P \leq 0.01$) cow BW and BCS in November and January than November weaning. In summary, cow production traits were not negatively impacted in a below-average precipitation yr, and calves weighed more in below-average than average or above-average precipitation yr.

Key words: cow-calf, precipitation, Ranch Practicum, weaning date

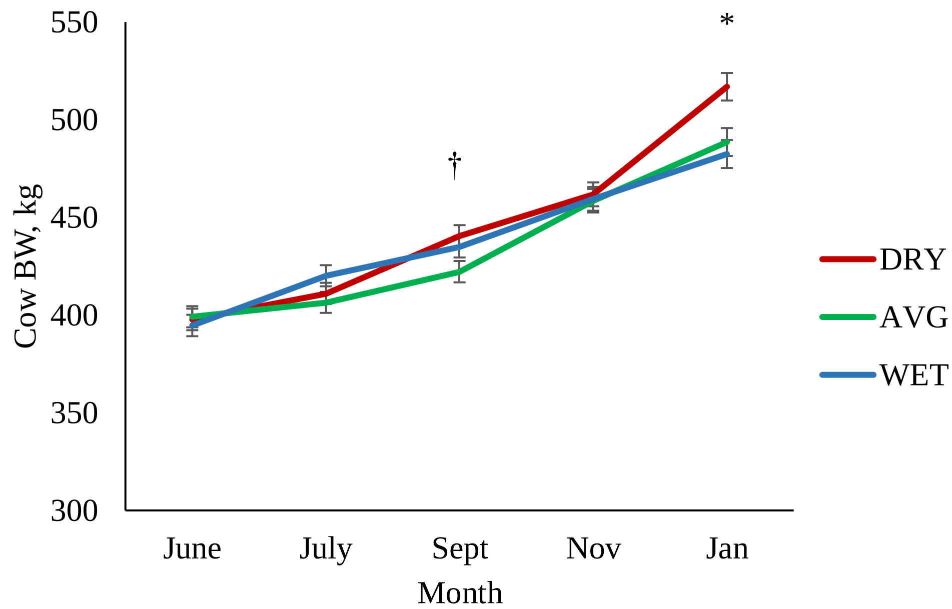

Figure 1. The effects of precipitation level on Practicum cow herd BW from 2000 to 2014. Within month, † $0.05 < P \leq 0.10$, * $P < 0.01$.

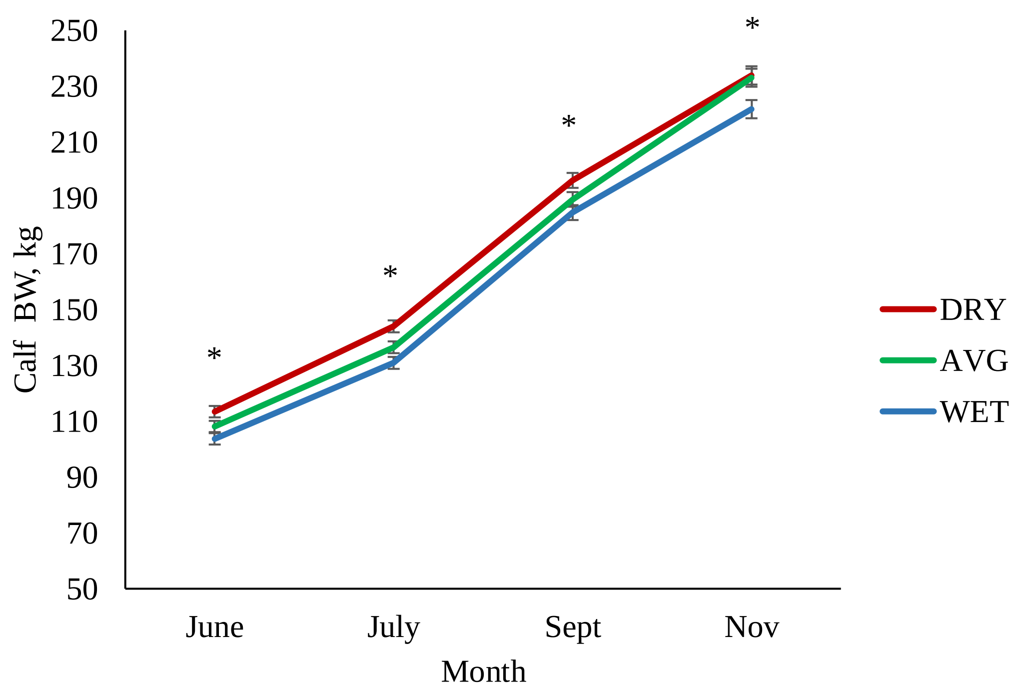

Figure 2. The effects of precipitation level on calf BW from 2000 to 2014. Within month, * $P \leq 0.01$.

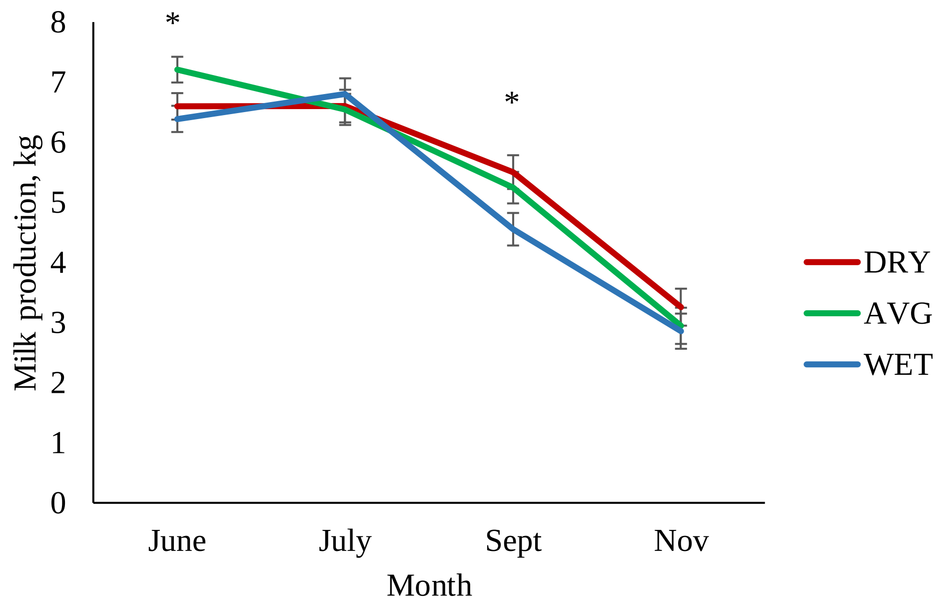

Figure 3. The effects of precipitation level on cow milk production from 2000 to 2014. Within month, * $P < 0.05$.

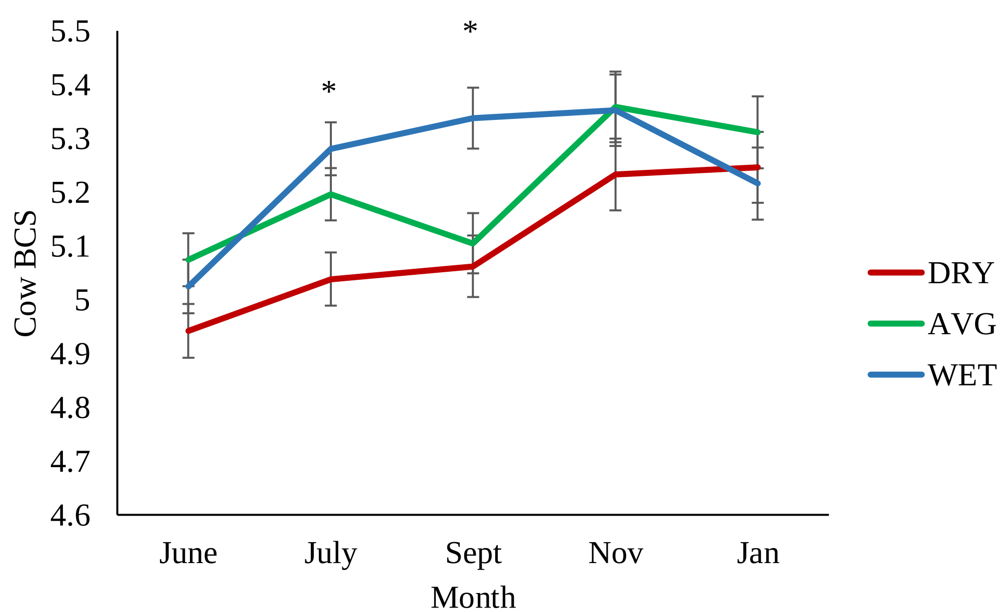

Figure 4. The effects of precipitation level on cow BCS from 2000 to 2014. Within month, * $P < 0.01$.

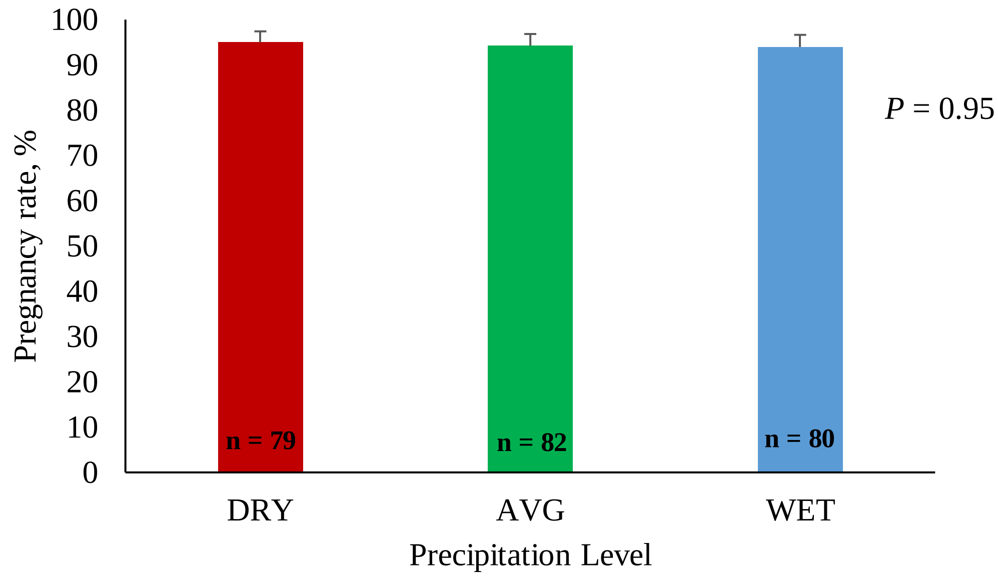

Figure 5. The effects of precipitation level on overall pregnancy rates from 2000 to 2014.

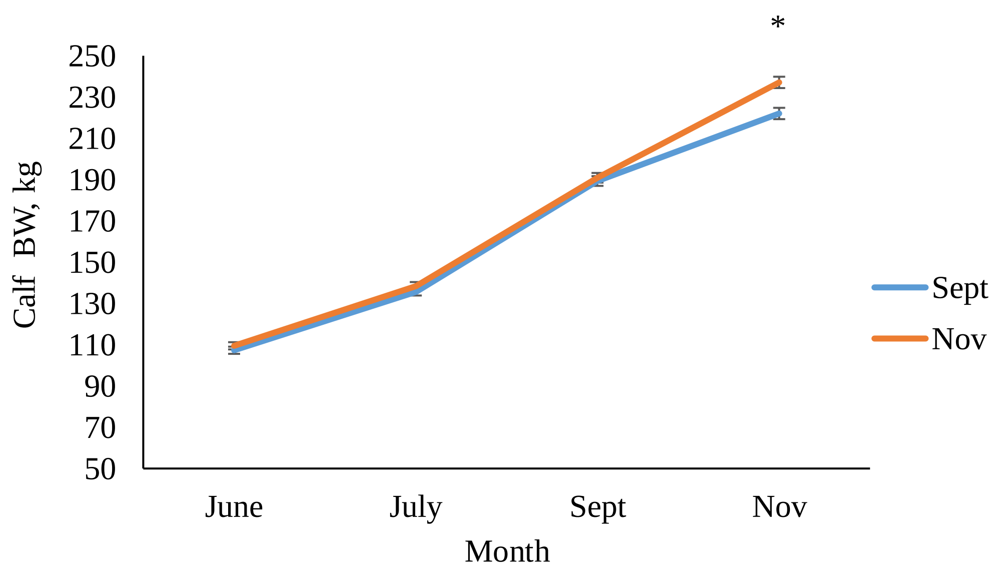

Figure 6. The effects of weaning date on calf BW from 2000 to 2014. Within month, * $P < 0.01$.

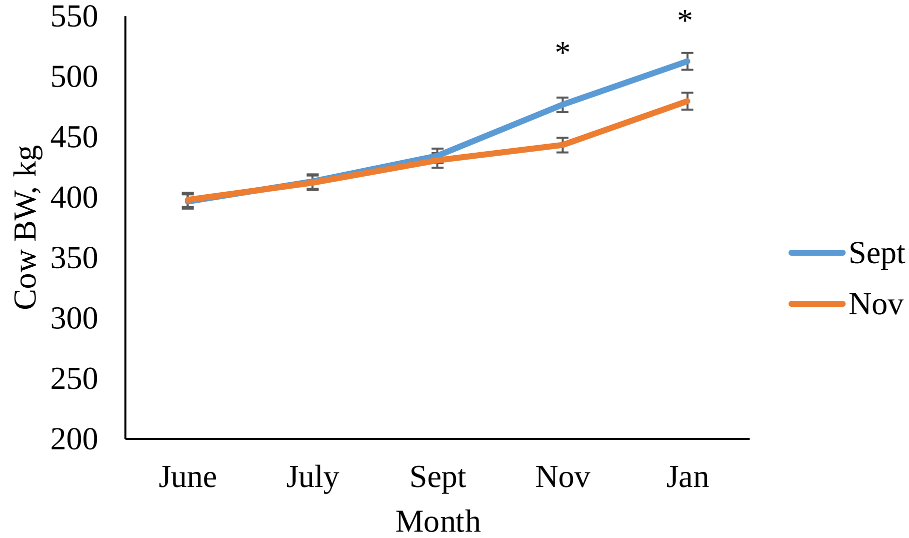

Figure 7. The effects of weaning date on cow BW from 2000 to 2014. Within month, * $P \leq 0.01$.

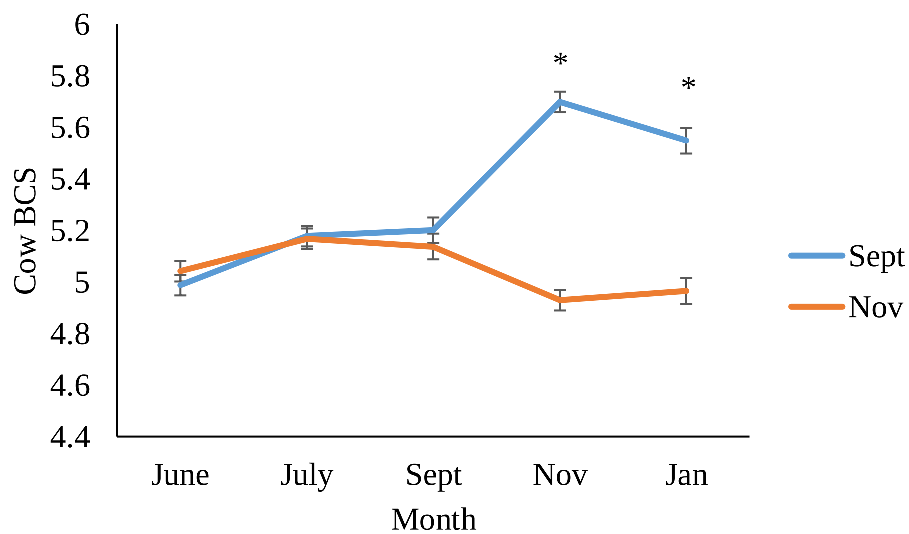

Figure 8. The effects of weaning date on cow BCS from 2000 to 2014. Within month, * $P < 0.01$.

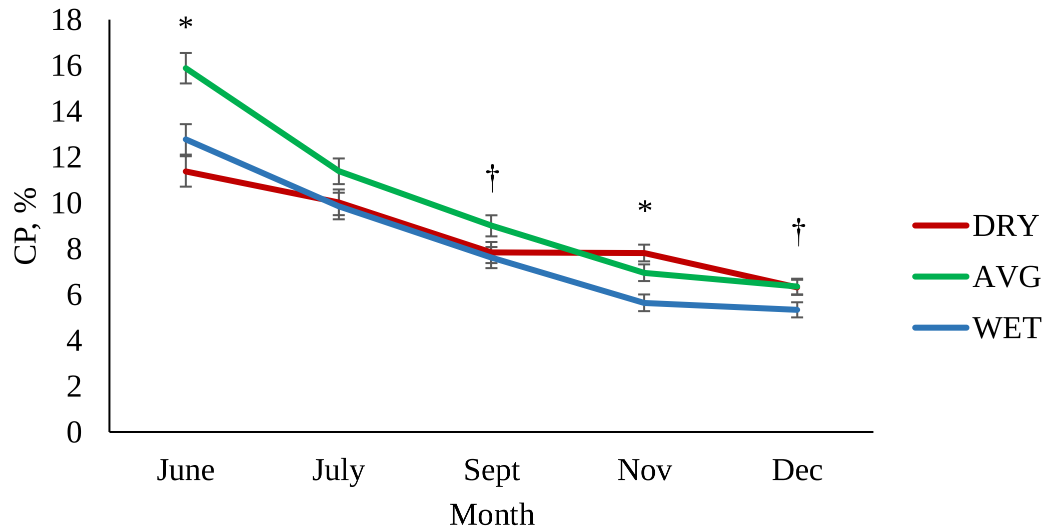

Figure 9. The effects of precipitation level on diet CP collected from esophageally fistulated cows grazing native range from 2000-2014. Within month, † $0.05 < P \leq 0.10$, * $P < 0.01$.

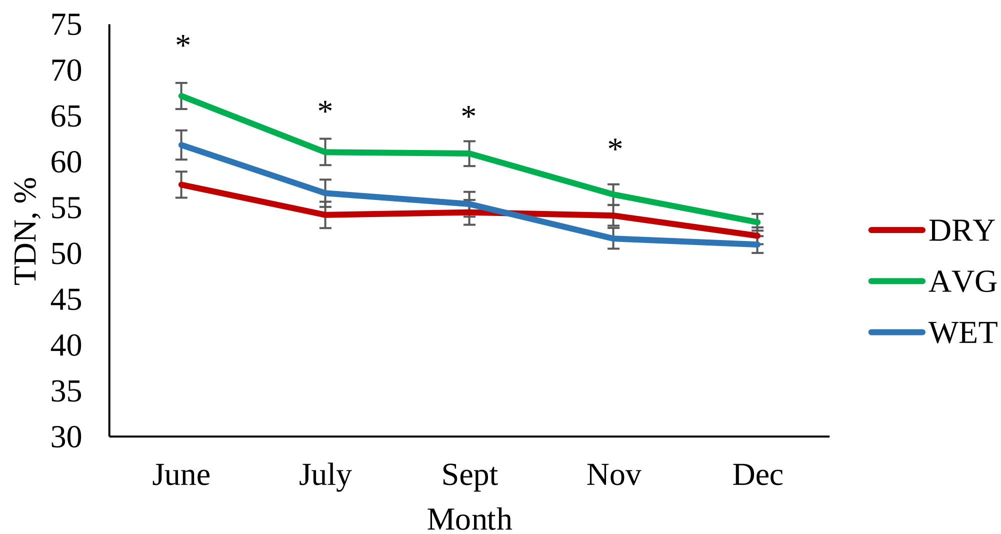

Figure 10. The effects of precipitation level on diet TDN collected from esophageally fistulated cows grazing native range from 2000-2014. Within month, * $P < 0.01$.