ENERGY AND MINERAL SUPPLEMENTATION STRATEGIES FOR BEEF CATTLE GRAZING THE NORTHERN GREAT PLAINS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Four experiments were conducted to evaluate different technologies and supplementation strategies that may impact beef cattle production in the Northern Great Plains. Our overarching hypothesis was that we can enhance beef cattle performance and production through strategic supplementation of energy and minerals. In experiment 1, steers were fitted with transmission beacons on collars to determine effects of preweaning creep feeder attendance influences on post-weaning performance, feeding behavior, and carcass characteristics. Calves that visited creep feeders more frequently spent more time eating and ate more meals during the first 28 d of the finishing period. In experiment 2, we utilized electronic feeders to monitor mineral intake of cow-calf pairs and found that HIGH (>90 g/d; average 125.4 g/d) intake cows and calves spent more time at the mineral feeder than their LOW (<90 g/d; average 33.5 g/d) intake counterparts. Furthermore, we noted greater concentrations of Se, Cu, and Co in livers of HIGH intake cows compared to LOW intake cows. In experiment 3, we evaluated a slow-release vitamin and mineral bolus in feedlot heifers which failed to influence heifer performance, liver mineral concentrations or carcass characteristics. Overall, heifers performed as expected while on a finishing diet from feeds sourced in the Northern Great Plains. In experiment 4, we further utilized the SmartFeed system to control intake of individual heifers assigned to different treatments in a group pasture scenario. Our results clearly show that the feed controlling portion can be used for precision feeding of individuals in extensive group managed scenarios. Though heifers had similar BW and ADG among treatment groups, treatments that provided supplemental mineral enhanced liver concentrations of Se, Fe, Cu, and Co. Furthermore, the CowManager system was able to detect divergence in highly active behavior among treatment groups, but also reported many false health and estrus-related alerts. Overall, we were able to successfully monitor individual mineral intakes in cow-calf pairs and report differences in energy and mineral supplement intakes in heifers grazing native range. We were also able to corroborate differences in supplement intakes with changes in concentrations of mineral in the liver of animals.

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DEDICATION

To my grandma, Melodye Tuttle. You are such a strong and beautiful person. I admire your strength while battling breast cancer for the second time. Thank you listening and encouraging me during my PhD program.

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LIST OF ABBREVIATIONS

°C	Degrees Celsius.
µg	Microgram or micrograms.
µg/mL	Microgram per milliliter.
µmol/L	Micromole per liter.
ADF	Acid detergent fiber.
ADG	Average daily gain.
AI	Artificial insemination.
AMP	Adenosine monophosphate.
ATP	Adenosine triphosphate.
AUM	Animal unit month.
BCS	Body condition score.
BW	Body weight.
Ca	Calcium.
CIDR	Control internal drug release.
Cl	Choline.
cm	Centimeter.
Co	Cobalt.
CON	Control treatment.
CP	Crude protein.
Cr	Chromium.
Cu	Copper.
d	Day or days.

DDGS	Dried distillers grains plus solubles.
DM	Dry matter.
DMI	Dry matter intake.
EE	Ether extract.
Fe	Iron.
g	Gram or grams.
g/d	Gram per day.
g/min	Gram per minute.
G:F	Gain to feed.
GnRH	Gonadotropin releasing hormone.
GPS	Global positioning system.
GSH-Px	Glutathione peroxidase.
h	Hour.
h/d	Hour per day.
ha	Hectares.
HCW	Hot carcass weight.
I	Iodine.
IGF-1	Insulin-like growth factor-1.
K	Potassium.
kg	Kilogram or kilograms.
KPH	Kidney, pelvic, and heart fat.
LSMEANS	Least square means.
m	Meter or meters.

Mg	Magnesium.
mg	Milligram or milligrams.
mg/d	Milligram per day.
mg/dL	Milligram per deciliter.
mg/kg	Milligrams per kilogram.
MIN	Mineral supplement treatment.
min	Minute or minutes.
min/d	Minutes per day.
mL	Milliliter.
mm	Millimeter.
Mn	Manganese.
Mn-SOD	Manganese superoxide dismutase.
Mo	Molybdenum.
MP	Metabolizable protein.
MP/d	Metabolizable protein per day.
N	Nitrogen.
n	Sample size.
Na	Sodium.
NaCl	Salt.
NADPH	Nicotinamide adenine dinucleotide phosphate.
NDF	Neutral detergent fiber.
NEFA	Non-esterified fatty acid.
Ni	Nickel.

NRG	Energy supplement treatment.
P	Potassium.
$PGF_{2\alpha}$	Prostaglandin F2 alpha.
r	Correlation coefficient.
RBCL	Red blood cell lysate.
RDP	Rumen degradable protein.
RFID	Radio-frequency identification.
s	Second or seconds.
S	Sulfur.
Se	Selenium.
SeCys	Selenocysteine.
SEM	Standard error of the means.
SeMet	Selenomethionine.
TCA	Tricarboxylic acid cycle.
TDN	Total digestible nutrients.
times/d	Times per day.
TMR	Total mixed ration.
Zn	Zinc.

CHAPTER 1: LITERATURE REVIEW

Introduction

Rangeland quality in the Northern Great Plains is very dynamic and provides high quality forage in May and June, when temperature and precipitation conditions are optimal for native cool-season forage growth (Grings et al., 2005). Therefore, as precipitation decreases and temperature increases in late summer, forage quality rapidly declines and stays low through autumn and winter (Adams et al., 1996; Grings et al., 2005). Nutritional requirements for beef cows vary with physiological states such as lactation and gestation, at the same time, the forage quality in the Northern Great Plains will vary depending on the season; therefore, meeting beef cow nutrient requirements may depend on season of calving (Grings et al., 2005). Calving season in this region may vary depending on goals of an operation as well as an appropriate time of weaning for optimal production of the cow herd. If native range is ready for grazing in early May, then corresponding calving season to match when cow nutrient requirements are highest, then calving would occur late April to early June to match the highest nutrient density of range and pasture forage (Adams et al., 1996).

Producers in the Northern Great Plains depend largely on range vegetation as the major feed resource for cattle. Warm- and cool-season native species make up much of the native range in the Northern Great Plains (Lardy et al., 2004). The vegetation in central North Dakota near the Central Grasslands Research and Extension Center is classified as mixed-grass prairie dominated by western wheatgrass (*Pascopyrum smithii* [Rydb.] À. Löve), green needlegrass (*Nassella viridula* [Trin.] Barkworth) and blue grama (*Bouteloua graciles* [Willd. ex Kunth] Lag. ex Griffiths). Other important species include sedges (*Carex* spp.), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), sages (*Artemisia* spp.), and goldenrods (*Solidago* spp.). Kentucky bluegrass (*Poa pratensis* L.) a non-native grass and western snowberry (*Symphoricarpos occidentalis* Hook.) a native shrub, are important drivers in biodiversity changes in the region (Limb et al., 2018).

The nutrient availability of grazed forages fluctuates by environmental conditions, forage species, soil type, and stage of maturity (NASEM, 2016). Providing nutrients to offset deficiencies or to meet production demands is more often practiced during periods of summer dormancy or during the fall and winter months (Caton and Dhuyvetter, 1997). Generally, producers implement a supplementation program at a time when livestock are grazing dormant forage low in nitrogen (N) and low in digestibility (Caton and Dhuyvetter, 1997). A decrease in the forage nutritive value is typical in diets of grazing cattle during the advancing season (Bedell, 1971; Johnson et al., 1998; Cline et al., 2009).

Forage intake reductions have been attributed to starch from corn supplementation (Caton and Dhuyvetter, 1997). These reductions are typically attributed to a carbohydrate effect or depression in ruminal pH (Mould et al., 1983). The depression in ruminal pH is generally associated with increasing dietary starch which affects the ruminal bacteria shifting toward greater amylolytic and lower cellulolytic populations. This results in bacterial shifts that reduce fiber digestion and can negatively affect grazed forage intakes (Caton and Dhuyvetter, 1997). Generally, total intake is increased when energy supplements are provided as readily digestible fiber that has fewer negative effects on forage intake than starch-based supplements (Caton and Dhuyvetter, 1997). However, substitution effects need to be considered when using energy or protein supplementation in grazing cattle scenarios. The amount of basal forage that is exchanged for supplemented nutrients has been termed substitution coefficients, which is the amount of decrease in basal forage divided by the amount of supplement provided (Caton and

Dhuyvetter, 1997). However, numerous studies have shown that cattle consuming low-to moderate-quality forages and supplied supplemental protein and (or) energy can increase body weight (BW) gains and forage organic matter intake and increase forage digestibility (Krysl and Hess, 1993). Typically, providing energy supplement to grazing ruminants often improves production when measuring body condition score or weight change (Caton and Dhuyvetter, 1997).

Suppplement Strategies

Success of supplementation programs relies on the assumption that animals are consuming a targeted quantity of supplement. Usually supplement intake is measured by dividing the disappearance of supplement by the number of animal days (Bowman and Sowell, 1997). However, this method of measuring intake does not account for the variation among animals or if animals are not meeting targeted amounts of recommended intakes. Variation in individual consumption has been known to vary depending on feeder number and placement, individual animal preference, weather, individual and herd behavior, characteristics of the feedstuff, and feed additives that may be included (Tait and Fisher, 1996; Bowman and Sowell, 1997; Smith et al., 2016). For example, changes in trough space per animal can influence competitiveness among animals and lead to variation in supplement consumption (Bowman and Sowell, 1997). Additionally, supplements classified as self-fed (found in the form of either liquid or block supplements), are generally thought of as providing unlimited trough space per animal; which in theory, should allow the animal to consume the supplement or at least reduce the incidence of non-feeders (Bowman and Sowell, 1997). There is also the potential for animals to exhibit neophobia with new feedstuffs or equipment. Neophobia is the cautious sampling or rejection of the feed that is not related to palatability (Launchbaugh et al., 1997). Generally, neophobia is characterized by a period of low feed intake, followed by increased consumption, which leads to a relatively stable level of intake (Bowman and Sowell, 1997). Furthermore, variation in consumption can also be attributed to dominant animals, which consume large amounts of supplement and therefore prevent other animals from consuming the desired amounts (Bowman and Sowell, 1997). Inexperienced sheep commonly increase supplement intake in the presence of more experienced sheep (Bowman and Sowell, 1997).

Nursing Calf Supplementation Strategies

Creep feeding traditionally consists of allowing unlimited access to a grain- or grain by-product-based mix as a supplementation source to nursing calves (Faulkner et al., 1994; Soto-Navarro et al., 2004). Nursing calves can be given supplements to increase preweaning weight gains (Tarr et al., 1994; Loy et al., 2002), reduce grazing pressure and improve intake at weaning (Reed et al., 2006). Increased weaning weights of calves can increase the gross income of many cow-calf production systems that sell calves at weaning (Martin et al., 1981; Tarr et al., 1994). Furthermore, creep feeding early-weaned calves can be used to increase starch intake (Shike et al., 2007). Marbling development can be influenced early in the life of the animal (Faulkner et al., 1994). Starch fermentation in the rumen results in greater propionate and less acetate production, and therefore a greater supply of glucose to the animal, which suggests that high-starch supplements may enhance marbling development (Sharman et al., 2013). Additionally, creep feeding has been found to alter behavior by training calves to recognize milled feed and availability of feed from mechanical devices (Pritchard, 2013). Utilization of such devices can help producers understand feeding behavior and monitor calf performance in grazing settings.

Faulkner et al. (1994) reported that steer calves that received corn creep feed had greater quality grades at harvest compared to calves that were provided the soy-hull creep feed. Faulkner et al. (1994) provided steer calves corn creep feed and calves consumed more (1.77 kg/d) supplement than calves provided soy-hull creep feed (1.53 kg/d). However, final BW was similar among creep fed calves (Faulkner et al., 1994). Additionally, all other carcass measurements (yield grade, fat thickness, longissimus muscle area, and internal fat percentage) were not different between the two sources of creep feed (Faulkner et al., 1994). Work from Tarr et al. (1994) reported that overall gain increased in calves the longer they were exposed to creep feed. In the first year of their study, Tarr et al. (1994) reported that calved fed creep for 84 d gained 0.53 kg/d more than controls. Whereas in year 2, the calves added gain on creep feed for 84 d was 0.46 kg/d (Tarr et al., 1994).

Ralston et al. (2005) from Calgary, AB used electronic identification tags to monitor individual free choice creep feed intake by suckling calves on range. Calves (n = 51) were monitored for a 36 d period where calves had access to one circular tub creep feeder (52.5 cm diameter) that limited feeding to one calf at time. Calves attended the creep feeder an average of 21 ± 10.3% of the 36 d monitoring period with a range of 2 to 42% (Ralston et al., 2005). Towards the later half of the study, attendance was more frequent with 30% or greater attendance occurring among the calves (Ralston et al., 2005). Ralston et al. (2005) reported that only 62.7% of calves consumed creep feed at least once with individual intake ranging from 67 to 3424 g/calf. The mean daily creep feed intake over the 36 d period from calves that attended the feeder ranged from 224 to 1,845 g/d (Ralston et al., 2005). The variation among the calves was suggested to have been caused by the limited access to one calf at a time, and calf attendance observed occurring mostly when their dams came to water nearby; which could have caused competition for the creep feeder and therefore the high variability among calf intakes (Ralston et al., 2005).

Energy Supplement Strategies

Energy supplementation is often provided in cow-calf production systems, particularly in systems based on low-quality forages (Schillo et al., 1992). According to Ciccioli et al. (2005), feeding starch-based supplements has hastened puberty attainment in beef heifers independent of BW gains. Furthermore, Cooke et al. (2008) demonstrated that replacement heifers consuming low-quality forages and receiving a low-starch energy supplement daily had greater growth rates, hastened puberty attainment, and improved pregnancy rates compared to heifers supplemented 3 times weekly. Thus, inclusion of energy ingredients into supplements, such as starch, may further benefit reproductive development of heifers consuming low-quality cool season forages by influencing circulating concentrations of nutritional mediators of puberty (Cappellozza et al., 2014). However, energy supplementation can significantly increase production costs and become unattractive to cow-calf producers (Moriel et al., 2012). A typical approach to help reduce costs is to change the frequency of supplementation, such as 3 times weekly instead of daily, reducing costs associated with fuel, equipment, and labor (Moriel et al., 2012).

Moriel et al. (2012) evaluated the concentrations of hormones and metabolites associated with energy metabolism, DMI, growth rates, puberty attainment, and pregnancy rates of replacement heifers consuming low-quality hay (8% CP, DM basis) or medium-quality hay (12% CP, DM basis), and receiving a low-starch energy supplement daily or 3 times weekly. Moriel et al. (2012) detected supplementation by day interactions for plasma concentrations of glucose, NEFA, and IGF-1. Previous research (Cooke et al., 2008) also reported that plasma glucose concentrations in heifers supplemented infrequently were increased during non-supplementation days, and attributed this outcome to the time required for synthesis and activation of gluconeogenic enzymes to substantially change the magnitude of glucose synthesis and release by the liver. Additionally, heifers that were supplemented daily had similar plasma NEFA concentrations compared to heifers only supplemented 3 times per week (Moriel et al., 2012). These outcomes suggest that heifers only supplemented 3 times weekly may have been mobilizing fat tissue during non-supplemented days (Ellenberger et al., 1989). Furthermore, Moriel et al. (2012) suggested that increased NEFA concentrations noted in heifers supplemented 3 times weekly may have been attributed to the differences in plasma glucose concentrations as well as differences in reproductive performance between heifers supplemented daily or 3 times weekly. Circulating NEFA are nutritional modulators of cattle reproduction and may directly impair synthesis and release of gonadotropins (DiCostanzo et al., 1999; Hess et al., 2005).

Work from Cappellozza et al. (2014) compared the effects of supplements based on protein or energy ingredients on performance, plasma metabolites and hormones, expression of hepatic genes associated with nutritional metabolism, and puberty attainment of beef heifers consuming a low-quality cool-season forage. Forage DMI was similar among control, energy, or protein (Cappellozza et al., 2014). Cappellozza et al. (2014) noted that average daily gain (ADG) was greater for energy and protein supplemented heifers compared with control heifers and similar between energy and protein. In previous work from Cappellozza et al. (2014), they reported that pregnant heifers receiving energy and protein supplement had similar ADG, which were greater compared with control cohorts. Collectively, these results provide evidence that to support BW gains, beef heifers consuming low-quality cool-season forages can equally utilize nutrients provided by supplements based on protein or energy ingredients. Furthermore, differences in CP and RDP intakes between energy and protein in the study were minimal and did not impact heifer ADG (Cappellozza et al., 2014).

Additionally, beef cattle grazing low-quality forages and provided protein supplement have been reported to increase forage intake and improve cow BW gain and may increase pregnancy rate (reviewed by DelCurto et al., 2000). A 3-yr study was conducted by Summers et al. (2015) to determine the effect of supplemental protein source on ADG, feed intake, calf birth BW, and subsequent pregnancy rate in pregnant beef heifers. Forage intake declines when CP values are below 7% (Mathis, 2000). Summers et al. (2015) noted that forage CP content was greater than 7% and subsequently protein supplement replaced forage intake in high and low protein supplement heifers. Forage-only DMI was greater in control heifers compared to high or low protein supplement heifers. Summers et al. (2015) reported that protein supplementation increased ADG in pregnant heifers; however, calf birth BW, resumption of estrus, and subsequent pregnancy rates were similar, regardless of supplementation or supplemental protein source.

Glucose Metabolism

Ruminants eating high-forage, low-starch diets depend on liver synthesis of glucose to meet their metabolic requirements (Huntington, 1997). Organic acids from fermentation (mainly propionate and lactate), carbon skeletons from deaminated amino acids, and glycerol from the breakdown of triglycerides are the principal substrates or carbon sources for glucose synthesis (Huntington, 1997). Glucose is important in the generation of ATP through glycolysis and the tricarboxylic acid (TCA) cycle, reducing equivalents (NADPH) through the hexose monophosphate shunt, functions of the nervous system and associated with metabolism of amino acids and lipids (Huntington, 1997). The amount and rate of glucose also changes depending on nutritional or physiological state (fasting, rapid growth, pregnancy, lactation) (Huntington, 1997). Blood glucose concentrations are inversely related to energy intake (Yelich et al., 1996).

Hence, glucose is one of the most important metabolic substrates required for proper function of reproductive processes in beef cattle (Hess et al., 2005). Glucose is the primary metabolic fuel utilized by the neural system, since the neural-endocrine system is intimately involved in controlling reproduction and hormone secretion (Short and Adams, 1988). Thus, Short and Adams (1988) hypothesized that blood glucose concentration is the specific mediator for the effects of energy intake on reproduction.

Mineral Supplement Strategies

Supplementation of minerals is provided through a variety of means, including free choice mineral mixtures, blocks, and trace mineral fortified energy/protein supplements. Research has clearly documented that intake of mineral is variable between animals with some cattle over-consuming or under-consuming the supplement (Greene, 2000). Additionally, variation of mineral intake has been found to be dependent on a number of factors which include: season of year, individual animal requirements, animal preference, availability of fresh minerals, mineral palatability, physical form of minerals, salt content of water, mineral delivery method, soil fertility, forage type, forage availability, and animal social interactions (Bowman and Sowell, 1997; McDowell, 1996).

For grazing cattle, forages can be the primary source of trace minerals. Forage mineral composition is dependent on many factors, including soil characteristics, stage of plant growth, climatic conditions, and fertilization practices (Greene, 2000). Therefore, when developing or “fine-tuning” a mineral supplement, a forage sampling and analysis plan for the specific production environment is recommended (Greene, 2000). This will identify minerals not being supplied in adequate quantities by the diet (Greene, 2000). These considerations make meeting mineral requirements for grazing cattle a challenge.

Mineral Requirements

Macrominerals are dietary minerals that are required in gram quantities and include calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), chlorine (Cl), sodium (Na), and sulfur (S; NASEM, 2016; Table 1.1). Macrominerals are essential for structural components in bones, other tissues and bodily fluids. The major factors dictating the dietary requirement include mineral utilization from forages, mineral interactions, and stage and level of production (Greene, 2000). The Ca and P requirements of grazing cattle are dependent on stage and level of production, with major changes occurring in Ca requirements during the transition from gestation to lactation (NRC, 1996). Phosphorous is the mineral that provides the greatest return on investment when supplemented and plays an intimate role in energy metabolism, causing an energy deficiency in phosphorous-deficient animals (McDowell, 1996). Magnesium is essential, as the complex Mg-ATP, for all biosynthetic processes including glycolysis, energy-dependent membrane transport, formation of cyclic-AMP, and transmission of the genetic code (NRC, 1996). Potassium deficiency is not likely to occur in cattle grazing actively growing forages, but it can create a problem if it is too high (> 2.5%; Greene, 2000).

Trace minerals are required for normal growth and development in animals; however, trace minerals are generally present in minute quantities in the body and are required in low concentrations in the diet (Hostetler et al., 2003). Microminerals or “trace minerals” are required in microgram or milligram amounts and include copper (Cu), cobalt (Co), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), chromium (Cr), selenium (Se), and zinc (Zn; NASEM, 2016). Micromineral requirements do not change with stage or level of production (NRC, 1996), with the exception of Mn, for which the requirement doubles from growing calves to gestating and lactating cows and heifers.

Table 1.1. Mineral requirements of beef cattle[a]

			Cows/heifers	
Mineral	Unit	Growing Cattle	Gestating	Lactating
Calcium[b]	%	0.40-0.80	0.16-0.27	0.28-0.58
Phosphorus[b]	%	0.22-0.50	0.17-0.22	0.22-0.39
Magnesium	%	0.10	0.12	0.20
Potassium	%	0.60	0.60	0.70
Sodium	%	0.06-0.08	0.06-0.08	0.10
Sulfur	%	0.15	0.15	0.15
Cobalt	mg/kg	0.15	0.15	0.15
Copper	mg/kg	10	10	10
Iodine	mg/kg	0.50	0.50	0.50
Iron	mg/kg	50	50	50
Manganese	mg/kg	20	40	40
Selenium	mg/kg	0.10	0.10	0.10
Zinc	mg/kg	30	30	30

[a] Adapted from NRC, 1996 and NASEM, 2016

[b] Calcium and P requirement (% of DM intake) decreases with increasing weight, increases with rate of gain and increases with level of milk production

Inadequate trace mineral consumption can compromise reproduction, animal health and animal growth (NRC, 2005; NASEM, 2016). Furthermore, dietary requirements for trace minerals are essential for both the immediate and long-term well-being of the embryo, fetus and neonate (Ashworth and Antipatis, 2001). Trace minerals play key roles in vitamin synthesis, hormone production, enzyme activity, tissue synthesis, oxygen transport, and energy production (Underwood, 1999). Therefore, supplementation at different stages of production may have greater impacts on reproduction and animal performance, which may affect fetal development.

Trace elements are integral components of certain enzymes and other biologically important compounds, such as Se in glutathione peroxidase (GSH-Px), Fe in hemoglobin, and I in the thyroid hormones thyroxine and triiodothyronine (McDowell, 2003). In the thyroid, GSH-Px is thought to be the main antioxidant system for neutralizing cytotoxic hydrogen peroxide and its oxidative by-products (McDowell, 2003). Liver and plasma GSH-Px activities increase and decrease rapidly during Se repletion or depletion; therefore, concentrations of the enzyme serve as an accurate indicator of Se sufficiency (McDowell, 2003). Manganese superoxide dismutase (Mn-SOD) is an enzyme that functions in the mitochondria to detoxify superoxide radicals (Kuratko, 1999). Recent studies have utilized an injectable trace mineral as means for mineral administration and supplementation that has been shown to improve liver Cu and Se concentrations (Pogge et al., 2012). Moreover, steers treated with injectable trace minerals have reported greater Mn-SOD activity compared to steers that received saline (Genther and Hansen, 2014).

The minerals that seem to have the greatest impact on reproduction include Cu, I, Mn, Se, Zn (Hostetler et al., 2003), along with Fe and the antioxidant vitamins A and E (Ashworth and Antipatis, 2001). The mineral requirements for reproduction in mammals are usually equated to the mineral content of the fetus and products of conception (placenta, uterus, and fetal fluids). Trace minerals also affect development by modifying changes in hormones, growth factors and cell signaling pathways that affect both nutrient uptake by the conceptus and the environment in which prenatal development proceeds (Ashworth and Antipatis, 2001). Grace et al. (1986) indicated that there is an exponential increase of mineral accumulation of ovine fetuses in mid to late stages of gestation, which eventually peak at late gestation. Trace minerals may have direct effect on growth and development of the conceptus, thereby influencing their development and survival in the uterine environment (Hostetler et al., 2003). However, we do not know if we have a similar accumulation of minerals in the first stage of gestation in a bovine model.

Copper

Copper (Cu) is an essential component to a number of enzymes including cytochrome oxidase, superoxide dismutase, ceruloplasmin, as well as having a role in pigmentation (tyrosinase) and connective tissue development (lysyl oxidases; Suttle, 2010; NASEM, 2016). Requirements of Cu can vary from 4 to more than 15 mg/kg dietary DM, with the variation due largely in part to concentrations of dietary Mo and S (NASEM, 2016). The recommended concentration for Cu in beef cattle diets is 10 mg/kg; however, less than 10 mg/kg may meet requirements in feedlot diets because Cu is more available in concentrates than forage diets (NASEM, 2016). Grings et al. (1996) reported Cu concentrations in western wheatgrass (cool-season perennial grass) in the Northern Great Plains to average 2 mg/kg; whereas, cool-season grasses averaged 7 mg/kg, 4 mg/kg for warm-season grasses, and 13 mg/kg for forbs. Most Cu deficiencies in ruminants can occur through low Cu concentrations in pastures or due to Mo and S in the forage, which forms thiomolybdates in the rumen resulting in decreased availability of Cu (Hostetler et al., 2003; NASEM, 2016). Considerable storage of Cu occurs in the liver (NASEM, 2016).

Abdelrahman and Kincaid (1993) quantified Cu levels in fetal liver and kidney tissues in pregnant cattle late in gestation, and found that stage of gestation did not affect Cu concentrations in the fetal liver or kidney. In contrast, Grace et al. (1986) determined that there is an accumulation of Cu by ovine fetal liver as stage of gestation advances. Additionally, Gooneratne and Christensen (1989) reported that Cu concentrations are normally greater in fetal tissue compared to maternal liver Cu concentrations.

Selenium

Forages produced in certain geographical regions are extremely low in Se; whereas, forages produced in other regions can act as Se accumulators (Greene, 2000). Due to the variation, current recommendations for Se requirements in beef cattle can be met by 0.1 mg Se/kg dietary DM (NASEM, 2016). Absorption of dietary Se occurs in the small intestine

(Suttle, 2010) then it is transported to the liver, kidney, and muscle (Hostetler et al., 2003). In mammalian tissues, Se is found in protein pools, which include specific amino acids that contain Se such as selenocysteine (SeCys) and selenomethionine (SeMet; NASEM, 2016). Well known selenoproteins include glutathione peroxidase, diodinases, and thioredoxin reductases (Hostetler et al., 2003; NASEM, 2016). Selenium plays an important role in maintaining cell integrity and the organelles within the cell, and may act through this mechanism to protect the early fetus from oxidative stress which may result in early fetal mortality (Hostetler et al., 2003).

Van Saun et al. (1989) found that maternal and fetal Se concentrations in liver, whole blood, and serum were highly correlated. Abdelrahman and Kincaid (1993) quantified Se levels in bovine fetal liver and noted that Se concentrations increased from d 120 to 220 of gestation and then decreased from d 221 to 270 of gestation. Abdelrahman and Kincaid (1995) treated Holstein cows approximately 60 d prepartum with one intraruminal bolus of Se that was designed to release 3 mg/d of supplemental Se as sodium selenite for 120 d or received no bolus (control). Cows that were provided the Se bolus were in adequate nutritional status with Se concentrations in whole blood of 0.15 μg of Se/ml; whereas, the cows that did not receive the Se bolus had significantly reduced concentrations in both their whole blood and plasma at parturition (Abdelrahman and Kincaid, 1995). At birth, calves of cows that received the Se bolus had significantly greater Se concentrations in whole blood and plasma compared to calves that cows did not receive the Se bolus (Abdelrahman and Kincaid, 1995). Furthermore, Abdelrahman and Kincaid (1995) noted that supplementing Se to cows during the dry period also increased liver Se concentrations in calves at birth and at 42 d of age. Therefore, supplementation of 3 mg/d of Se provided enough for calves to be born with adequate Se concentrations.

Manganese

Typical functions of Mn include being a component of the enzymes pyruvate carboxylase, arginase, and superoxide dismutase as well as being an activator in hydrolases, kinases, transferases, and decarboxylases (NASEM, 2016). Manganese deficiency results in poor growth and impaired reproduction, testicular atrophy in males, impaired ovulation in females, and small weak piglets (Hostetler et al., 2003). The requirement for Mn in growing and finishing diets is approximately 20 mg/kg (NASEM, 2016); whereas, the recommended concentration for breeding cattle is 40 mg/kg (NASEM, 2016). Grings et al. (1996) noted that western wheatgrass, common forage found in the Northern Great Plains, averaged 57 mg/kg Mn on silty clay soil and 37 mg/kg Mn on loam soil.

Abdelrahman and Kincaid (1993) quantified Mn levels in fetal liver and kidney tissues and reported no changes with gestational age from d 120 to 270. Genther and Hansen (2014) reported that steers treated with Multimin90 (Multimin USA, Fort Collins, CO) after a 89 d depletion period had greater manganese-superoxide dismutase (Mn-SOD) activity, measured in red blood cell lysate (RBCL), compared to steers receiving saline. However, there were no differences in liver Mn concentrations between steers provided Multimin90 or saline (Genther and Hansen, 2014).

Iron

Iron is an essential component in oxygen transport or utilization through a number of different proteins (NASEM, 2016). These proteins include myoglobin, hemoglobin, cytochromes and Fe-S proteins involved in the electron transport chain (NASEM, 2016). Iron content in forages is highly variable (NRC, 1996; Greene, 2000), with most sources of forages containing 70 to 500 mg Fe/kg (NASEM, 2016). Much of the variation in forage Fe concentrations is due to soil contamination (NASEM, 2016). Additionally, Fe requirement for beef cattle is approximately 50 mg/kg (NASEM, 2016). A deficiency results in anemia, decreased feed intake, listlessness, weight gain, pale mucus membranes, and atrophy (NASEM, 2016). Generally, Fe is supplemented as ferrous sulfate, ferrous carbonate, or ferric oxide in the diet (NASEM, 2016).

Zinc

Zinc is an essential component of a number of different metalloenzymes including Cu-Zn superoxide dismutase, alcohol dehydrogenase, carboxypeptidase, carbonic anhydrase, alkaline phosphatase, and RNA polymerase (NASEM, 2016). In addition, Zn is important for normal development and immune function. The recommended Zn requirements are 30 mg/kg DM in beef cattle diets (NASEM (2016). Grings et al. (1996) reported average Zn concentrations at 18 mg/kg for western wheatgrass, 20 mg/kg for brome, and 31 mg/kg for forbs in the Northern Great Plains. Deficiency normally presents as decreased growth, feed intake, and feed efficiency; listlessness; parakeratosis; decreased testicular growth; and alopecia (NASEM, 2016). Zinc absorption occurs primarily in the abomasum and small intestine (NASEM, 2016).

Abdelrahman and Kincaid (1993) quantified Zn levels in fetal liver and kidney tissues and reported no changes with gestational age from d 120 to 270. Calves fed supplemental Zn gained more weight each season compared to calves in the basal group (Mayland et al., 1980). Spears and Kegley (2002) noted that zinc supplementation during the finishing phase increased quality grade and marbling in steers, compared with nonsupplemented steers.

Cobalt

Cobalt functions as a component of vitamin B_{12}. Ruminal microorganisms utilize the dietary Co to produce vitamin B_{12} (Spears and Weiss, 2014). Generally, when dietary Co is sufficient in the diet, ruminal synthesis of vitamin B_{12} will meet the requirement in the animal.

The requirements for Co in the diet are recommended at 0.15 mg/kg DM (NASEM, 2016). Deficiency exhibits signs of rapid weight loss, unthriftiness, fatty degeneration of the liver, pale skin and mucus membranes, decreased appetite (NASEM, 2016). Liver vitamin B_{12} concentrations of 0.10 μg/g wet weight or less are indicative of a deficiency (NASEM, 2016).

Vitamin B_{12} (also known as cobalamin) is a water-soluble molecule that functions as an essential coenzyme for cytoplasmic methionine synthase, which catalyzes methylation of homocysteine to methionine; and methylmalonyl-CoA mutase, which catalyzes the conversion of methylmalonyl-CoA to succinyl-CoA in the mitochondria (Nielsen et al., 2012). The reaction of methionine synthase also involves folate (vitamin B_9), which is essential for a number of methyl-transfer reactions and therefore indirectly involved in nucleotide synthesis (Nielsen et al., 2012). Furthermore, methylmalonyl-CoA mutase reactions are involved in digestion of different compounds such as branched amino acids and odd-chain fatty acids (Nielsen et al., 2012).

Mineral Status in Cattle

The collection of natural resources (forage, soil, and water) is one such way to measure mineral status of available resources and provides producers knowledge and a way to evaluate the mineral status of their resources. Furthermore, measuring animal mineral status is another technique that helps answer mineral supplementation program questions in terms of meeting grazing cattle mineral requirements. A common collection method for determining baseline mineral status in cattle is through the collection of blood serum. Additionally, techniques have been established to collect liver biopsy samples that also provide baseline mineral status in cattle. Liver biopsy samples from live animals may provide a more reliable indicator for diagnosing sub-clinical trace mineral deficiencies (Greene et al., 1998). The liver is a metabolically active organ responsible for many vital life functions such as bile production and excretion; excretion of bilirubin, cholesterol, hormones; metabolism of fats, proteins, and carbohydrates; enzyme activation; storage of glycogen and gluconeogenesis (Huntington and Eisemann, 1988); status of vitamins and minerals (Kincaid, 2000); synthesis of plasma proteins, such as albumin, and clotting factors; and blood detoxification and purification. Blood measures for mineral assessment are less invasive than liver samples (Kincaid, 2000). Trace mineral status is best described by concentrations in the liver and usually should be taken before and after treatments are applied (Kincaid, 2000).

Suggested adequate liver Cu concentrations have been defined as 125 to 600 μg/g DM (Kincaid, 2000; Table 1.2) or greater than 100 μg/g DM (Radostits et al., 2007). According to guidelines published by Kincaid (2000), liver mineral concentrations for Zn are adequate at 25 to 200 μg/g DM, whereas deficient levels are considered anywhere from < 20 to 40 μg/g DM (Table 1.3). Selenium liver concentrations in cattle are considered adequate (1.25 to 2.50 μg/g DM; Kincaid, 2000), whereas Radostits (2007) classified adequate levels at 0.9 to 1.75 μg/g DM (Table 1.4). Liver Co levels at 0.08 to 0.12 μg/g DM or more indicate satisfactory Co status (McNaught, 1948). According to Kincaid (2000), adequate classification for liver manganese status is > 13 μg/g DM or normal levels are classified as 12 mg/kg (Radostits, 2007; Table 1.5). Levels of iron in tissues have been reported by Kincaid (2000) to be adequate at 45 to 300 μg/g wet weight (Table 1.6). Iodine has also been classified in cattle tissues with adequate levels in serum to be 10 to 40 μg/ 100 mL (Kincaid, 2000; Table 1.7).

Littledike et al. (1995) analyzed the effects of breed, intake and carcass composition on the status of several macro and trace minerals of 118 adult beef cattle of nine different cattle breeds. The objective of this study was to compare liver and (or) serum Cu, Zn, Fe, Ca, and Mg among these nine breeds fed four levels of dietary energy over an extended time. Free choice mineral mix was continuously available in each pen. Average daily consumption of the mineral mix was 58.5 g/cow estimated from total mineral mix consumed by all cows during the experimental period (Littledike et al., 1995). Moreover, regardless of treatment, Pogge et al. (2012) reported that Simmental steers had lower plasma concentrations of Cu, Zn, and Se when compared with Angus steers. These differences in breed suggest that cattle of differing breeds may have differing trace mineral requirements, and producers may benefit from specialized mineral supplementation programs (Pogge et al., 2012). Blood serum and liver biopsy samples provide techniques to understanding cattle mineral status and provide information that help producers and nutritionists develop programs for mineral supplementation. To establish mineral supplementation programs, numerous considerations and factors contribute to decisions on how to provide and meet cattle mineral requirements.

Table 1.2. Criteria for classification of cattle on copper in liver and plasma

Diet	Cu in liver, µg/g DM	Cu in plasma, µg/mL
Clinically deficient	< 20	< .2
Deficient	< 33	.2 to .5
Marginal	33 to 125	.5 to .7
Adequate	125 to 600	.7 to .9
High	600 to 1250	.9 to 1.1
Toxic	> 1250	> 1.2

Adapted from Kincaid, 1999

Table 1.3. Criteria for classification of cattle on zinc in plasma and liver

Status	Zn in liver, µg/g DM	Zn in plasma, µg/mL
Deficient	<20 to 40	.2 to .4
Marginal	25 to 40	.5 to .8
Adequate	25 to 200	.8 to 1.4
High	300 to 600	2 to 5
Toxic	> 1000	3 to 15

Adapted from Kincaid, 1999

Table 1.4. Criteria for classification of cattle on selenium in blood and liver

Classification	Se in whole blood, ng/mL	Se in liver of adults, µg/g DM	Se in liver of newborns, µg/g DM
Severely deficient	< 60	.1 to .5	< 1.1
Marginally deficient	60 to 200	.6 to 1.25	1.1 to 2.2
Adequate	210 to 1200	1.25 to 2.5	2.3 to 8.0
High Adequate	> 1200	> 2.5	
Adequate		.9 to 1.75	

Adapted from Kincaid, 1999 and Radostits, 2007

Table 1.5. Criteria for classification of cattle on manganese in blood, serum, and liver

Status	Mn in whole blood ng/mL	Mn in serum ng/mL	Mn in liver µg/g, DM
Deficient	<20	< 5	< 7
Marginal	20 to 60	5 to 6	7 to 15
Adequate	70 to 200	6 to 70	> 13
Normal			12 mg/kg

Adapted from Kincaid, 1999 and Radostits, 2007

Table 1.6. Criteria for classification of cattle on iron and ferritin in tissues

Status	Fe in liver, µg/g wet wt	Fe in Kidney, µg/g wet wt	Fe in serum, µg/100 mL	Serum ferritin, ng/mL
Deficient	< 40	< 20	12 -120	2 to 10
Adequate	45 - 300	30 - 150	130-250	30-50
High	53 - 700	49- 300	400-600	>80

Adapted from Kincaid, 1999

Table 1.7. Criteria for classification of cattle on Iodine in tissues

Status	Total I in serum, µg/100 mL	Protein bound I, µg/100 mL	Milk I, µg/L	Urinary I, µg/100 mL	Serum T4, ng/mL
Deficient	1 to 5	3-5.3	8 to 25	NA	< 7 to 30
Adequate	10-40	4.6 - 12.8	30 to 300	10 to 25	20 to 100
Excessive	70-300	20-100	500 to 3500	>50	34 to 120

Adapted from Kincaid, 1999

Regional Mineral Status

Utilization of mineral is an area that can also be dependent on geographical area and animal requirements with regard to deficiency or excess of particular minerals in forages and water. One such area of interest is the North Central Region and the variability of mineral status in natural resources and meeting beef cattle mineral requirements. Furthermore, areas of previous research on selenium status of North Dakota range forages throughout grazing seasons have been analyzed as well as areas with high concentrations of selenium in the soil and forage have been analyzed to determine connections with selenium concentrations in beef. Hintze et al. (2001) reported that areas within the state that did not have high-Se geological features consistently produced animals with the lowest tissue Se concentrations and found similar results for the high-Se areas. Understanding that different regions within the country can have variable levels of particular minerals dictates how mineral supplements are formulated for cattle in that area. Additionally, researchers from several states provided liver biopsy data, which showed that liver Cu concentrations are generally deficient in grazing beef cattle for optimum performance and immune response (Greene et al., 1998). Moreover, these data indicated that North and South Dakota had the lowest averages for liver Cu (Greene et al., 1998). Additionally, Zinc concentrations in the liver did not appear to be as negatively affected as the Cu levels provided from approximately 1,100 cows from the several states (Greene et al., 1998).

Further research from Hintze et al. (2002) was focused on determining the effect of dietary selenium and geographical area of animal origin on the selenium accumulation in beef steers. Sixteen crossbred, yearling steers were purchased from two geographic areas: seleniferous area of South Dakota (n = 8) and from the North Dakota State University herd (n = 8). Animals were assigned to individual pens and fed a diet based on alfalfa hay and wheat that contained either normal or high concentrations of Se. Animals were also allowed access to a Se-free mineral supplement. Diet and background Se status did not significantly affect feed intake, average daily gain, or final weight. The final Se concentration in all retail cuts of beef was significantly affected by diet and Se background, and Se concentrations were similar for all cuts (Hintze et al., 2002). Additionally, Hintze et al. (2002) observed Se concentrations of all organs except liver were significantly affected by Se background and dietary Se intake. Interestingly, the greatest concentrations of Se in the kidney and liver were found in the animals from the nonseleniferous area fed the high Se diet compared to the animals from the seleniferous area fed the high Se diet (Hintze et al., 2002). This could imply that the animals from the seleniferous area have developed physiologic adaptations that allow them to reach a much lower percentage of dietary Se. Authors suggested that perhaps cattle from seleniferous areas adapt to high Se intakes by upregulation of Se methylation through increased S-adenosylmethionine (SAM) biosynthesis (Hintze et al., 2002).

Mineral Supplementation in Cow-Calf Phase

There have been several experiments that have focused on trace mineral supplementation during the cow-calf phase. Very few have evaluated the effects of lifetime (pre-natal through harvest) trace mineral supplementation and source on feedlots performance. Ahola et al. (2004) evaluated the effects of trace mineral supplementation and source on grazing beef cow and calf performance over a 2 yr span. Approximately 80 d prior to the average calving date of the cowherd, dams were assigned to one of three treatments: 1) control (no supplemental Cu, Zn, or Mn), 2) organic (ORG; 50% organicly bound and 50% inorganic Cu, Zn, and Mn); and 3) inorganic (ING; 100% inorganic $CuSO_4$, Zn SO_4, and Mn SO_4) trace minerals. Organic trace minerals were provided from a commercially available mineral proteinate source; whereas, inorganic supplements were provided as $CuSO_4$, $ZnSO_4$, and $MnSO_4$. The authors had formulated the ad libitum ORG and ING supplements to supply 10 ppm Cu, 30 ppm Zn, and 40 ppm Mn daily. When calves reached an average age of 90 d, they were provided access to the same mineral supplement as their dams via creep feeders in each pasture. Calves continued to have access to mineral treatments until weaning. Ahola et al. (2004) noted that liver status of cows was affected by trace mineral supplementation and source. Liver Cu was greater in supplemented compared to control cows (Ahola et al., 2004). However, mean BW and BCS were similar among treatments (Ahola et al., 2004).

Calves from Ahola et al. (2004) were then transitioned to a feedlot where they received feedlot treatments of either 1) control (no supplemental Cu, Zn, or Mn), 2) ORG (33% organic and 67% inorganic Cu, Zn, and Mn), and 3) ING (100% inorganic $CuSO_4$, $ZnSO_4$, and $MnSO_4$) trace minerals. Treatments were fed during the growing and feedlot phases. Animal performance, mineral status, immune response and health status, and carcass data were evaluated on calves. During the initial growing phase (56 d), no treatment by time interactions were present with calves exhibiting similar initial BW across treatments. Prior to the growing phase when calf weaning weights were evaluated, Ahola et al. (2004) reported differences for both trace mineral supplementation and source. However, at the end of the growing phase, no BW differences were observed. Similarly, Ahola et al. (2005) reported that neither ADG nor DMI were affected by either trace mineral supplementation or source. Once calves moved to the finishing phase, similar results were observed with neither initial nor final BW differed between treatments. Additionally, Ahola et al. (2005) reported no differences in ADG and saw a tendency for great DMI in supplemented compared to non-supplemented controls during the finishing phase. Furthermore, plasma Cu concentrations were not affected by trace mineral supplementation or source during the feeding period (Ahola et al., 2005). Moreover, plasma Zn concentrations tended to be greater at the end of the feeding period in cattle that were supplemented (Ahola et al., 2005). All treatments, including the non-supplemented controls, were able to maintain plasma concentrations of Cu and Zn that were considered above deficient levels (Ahola et al., 2005). It appears that the cattle on the control diet were able to consume enough Cu and Zn via the basal diet. Throughout the growing and finishing phase, cattle that were supplemented compared to controls had greater liver Cu concentrations (Ahola et al., 2005). However, Zn liver concentrations were not affected by either source or supplementation of trace minerals (Ahola et al., 2005). Ahola et al. (2005) noted that liver Mn was affected by trace mineral supplementation at the end of the feeding period with ORG and ING treatments (7.24 and 6.49 mg/kg DM) having greater concentrations than controls (5.35 mg/kg DM), respectively.

Due to challenges with rugged topography in some rangelands and limited vehicle access to some areas, delivery of traditional mineral supplements can be problematic. A long-acting means of trace mineral delivery may be advantageous for beef production in extensively managed systems. A company in the United Kingdom (Cosecure; Telsol Ltd., Leeds, UK) developed a long-acting (6 mo) reticulorumen trace mineral bolus containing Cu, Se, and Co. Researchers in Arizona evaluated this long-acting trace mineral bolus in range cows over a 3-yr study. Sprinkle et al. (2006) found that liver Cu for control cows were deficient (71 ± 6.6 ppm); whereas, cows that received the long-acting bolus had liver Cu values at 120 ± 7.5 ppm, which were within adequate levels (>75 to 90 ppm; Corah and Dargatz, 1996). However, Sprinkle et al. (2006) reported no differences in liver Zn concentrations in control and bolus cows.

There are numerous supplementation delivery strategies and products that can be utilized to provide mineral, energy or protein to cattle in confinement or grazing systems. However, understanding if individual animals are consuming mineral or supplement at recommended feeding rates is typically unknown. However, we know that meeting mineral requirements in beef cattle is critical for optimal production and health of cows and their offspring. Therefore, gaining an understanding of cattle feeding behavior of mineral and energy supplements in grazing scenarios can help producers make management decisions pertaining to supplementation strategies and how those decisions can potentially impact animal performance and reproduction.

Technologies and Delivery Mechanisms

Techniques Used to Determine Supplement Intakes

Efficiency of converting feed consumed into energy for maintenance, growth, or lactation in cattle is a trait that drives profit in every sector of the beef industry. Therefore, efforts that improve efficiency and optimize productivity are key to the long-term sustainability of the beef industry. Technology can play a role in collecting and determining how efficient and productive cattle may be while grazing. Several technological advances have changed management paradigms and impacted the efficiency of production. One such technology is the use of electronic ID systems that have been used largely to manage calves in feedlot scenarios and to qualify calves for export programs. However, systems that integrate electronic identification on a ranch level into future decisions about cattle management are not currently available.

Electronic identification of individual animals, combined with computer recording software, provide a means of addressing some of the questions related to the consumption of supplements (Tait and Fisher, 1996). Recent development with feeders that utilize electronic identification can allow researchers and producers to analyze intake of supplements and feed consumption in cattle in various production settings. One such unit that is newly available is the SmartFeed (C-Lock Inc., Rapid City, SD) unit, which is a self-contained and portable unit that has an RFID reader, weigh scales, access control gate, and stainless steel feed bin which continuously logs data to determine the feed intake per visit per animal. Researchers in Oklahoma conducted a pilot study to characterize the daily variation in salt supplement intake by group-housed, self-fed grazing steers. Salt inclusion to the supplement over a 14 d period, which was a subset of 61 d, was analyzed for supplement intake, visit behavior, and salt intake. Over the 14 d period with a 45% salt inclusion, steer intakes averaged 1.21 kg/d (Reuter et al., 2017). A visit to the SmartFeed unit was defined as a period when the RFID was repeatedly observed in the SmartFeed with no gaps between successive observations greater than 300 s (Reuter et al., 2017), which is similar to how Cockwill et al. (2000) defined a visit with a GrowSafe unit. Over the 14 d period, steers visited the feeders 5.1 ± 1.3 times/d; which over the course of the whole study, steers visited 5.4 ± 2.1 times/d and visited more during the middle of the day (Reuter et al., 2017). With the one feeder in the pasture, the interval between different RFID readings (animals exchanging places at the feeder) was less than 1 s, which indicated to the researchers that competition for use of the feeder was occurring. Over the course of the 61 d period, steers consumed 0.43 kg/d of salt or 0.17% of BW per d (which mean BW was 256 kg), which was supplied at a feed rate of 0.56 kg/d or 0.18% of BW per d (Reuter et al., 2017).

Research has been conducted utilizing multiplex radio frequency mineral feeders (GrowSafe Systems Ltd.) to monitor feeder attendance and mineral intake by individual pastured cattle. One such study was conducted in Canada, where Cockwill et al. (2000) utilized two GrowSafe feeders that were equipped with a load cell that was tared to zero in readiness for an animal's attendance at the feeder. Data were collected including transponder number (i.e., animal identification), date and time of the feeder visit, and amount of supplement removed from the feeder during the animal's attendance (Cockwill et al., 2000). The commercial mineral mix used in this particular study was designed to meet the trace mineral needs of cattle when consumed at 100 g/d. Different levels of salt were also provided with low salt (9.8% NaCl) or high salt (22.5% NaCl) as the treatment (Cockwill et al., 2000). Variability in daily intake of mineral mix by individual animals was high according to Cockwill et al. (2000) with intakes ranging from 0 to 974 g/d for cows and they also looked at calf intake and found ranges of 0 to 181 g/d. Interestingly, increasing the salt in the mineral reduced the average intake by cows from 241.6 to 183.5 g/d (Cockwill et al., 2000). Additionally, increasing the salt content also increased the frequency of visits (Cockwill et al., 2000). Along with changing salt content, Cockwill et al (2000) compared intake and feeder attendance by cow-calf pairs with free access to trace mineralized salt containing 0% or 0.486% fenbendazole and reported higher visitation in cows and calves fed the fenbendazole compared to cows and calves not provided the fenbendazole. Furthermore, Cockwill et al. (2000) took individual intakes and body weights and found that average total doses for cows and calves over the 5 d period were 4.44 and 3.16 mg/kg BW, respectively. Unfortunately, no other performance changes or data were presented. These findings support others who have reported that intake among animals is variable (Bowman and Sowell, 1997; McDowell, 1996; Greene, 2000). Interestingly, when free choice mineral mixture was provided to Holstein steers, they visited the feeder every hour of the day with the highest incidence of visits occurring in the late evening (Tait and Fisher, 1996). These provide insight in the variation and frequency of cattle at a mineral source. Being able to individually monitor intake can help answer some of these questions regarding intake, as data is variable between cows.

Additionally, cow distribution and behavior on range can be analyzed through the utilization of global positioning system (GPS) collars. Schauer et al. (2005) utilized GPS collars that recorded head forward/backward and left/right movement sensors, a temperature sensor, and a GPS unit. These collars were programmed to take readings at 10-min intervals for a three 6-d periods to estimate grazing time (h/d), distance traveled (m/d), maximum distance from water (m/d), cow distribution (% of ha occupied * pasture^{-1} * yr^{-1}), and percentage of supplementation events frequented (Schauer et al., 2005). As a comparison to mineral intake, this study utilized protein supplementation on grazing cows. They found that grazing time was greater for controls compared to supplemented treatments, with no differences observed due to supplementation frequency (Schauer et al., 2005). Changes in BW and BCS were greater for supplemented treatments compared to controls (Schauer et al., 2005). Additionally, Schauer et al. (2005) reported distance traveled (5,881 ± 160 m/d) and maximum distance from water (1,864 ± 105 m/d) was not affected by protein supplementation or supplementation frequency. Moreover, collared cows were dosed with intraruminal n-alkane controlled-release devices on d 28 for estimation of DMI, DM digestibility, and harvest efficiency. Fecal output and DMI were unaffected by protein supplementation or supplementation frequency; however, DMI tended to decrease for supplemented treatments compared to controls, which is consistent with responses reported for grazing time (Schauer et al., 2005). Schauer et al. (2005) suggested that the inability to detect a treatment affect might have been due to the innate variability associated with the use of alkanes to determine DMI combined with the limited replications due to logistical constraints. Furthermore, Schauer et al. (2005) observed that dry matter digestibility and harvest efficiency were not affected by protein supplementation or supplementation frequency.

Behavior Monitoring Technologies

Individual technologies have been used to measure rumination and feeding time, health status of dairy cows (Bikker et al., 2014), and activity of estrus detection. However, much of the work conducted with behavior and rumination technologies have been in confinement systems for dairy cattle (Bikker et al., 2014; Dolecheck et al., 2015) and feedlot steers (Wolfger et al., 2015). Validation of the CowManager ear tag sensor (CowManager B.V., the Netherlands) in a grazing dairy herd was conducted by Pereira et al. (2018) and compared direct visual observations and sensor data for rumination, eating, not active, and active cow behavior. The CowManager ear tag is mounted over a radio frequency identification tag and the sensor detects and identifies ear and head movements and then classifies data as ruminating, eating, not active, active and high active behavior through algorithms (Pereira et al., 2018). The accelerometer continuously registers movements from the cow's ear and the data is sent through a wireless connection, via routers and coordinators, to a computer (Bikker et al., 2014). Raw data is continuously collected with a proprietary model and subsequently expressed as percentage of behavior per hour as well as per day, and data is available through a web-based application (Bikker et al., 2014). The dairy cows observed in Pereira et al. (2018) were offered pasture for 22 h/d and were milked twice per day at 0600 and 1700 h in a swing-9 parabone milking parlor. A single trained observer throughout the study recorded all direct visual observations and terms were defined prior to initiation of the study. Bikker et al. (2014) and Pereira et al. (2018) defined rumination as a cow either standing, walking or lying and the cow has regurgitated a bolus and chewed the cud while moving her head and jaw in a circular motion and then swallowing the masticated cud. Eating was defined when the muzzle was in close contact with the ground and the cow was making a licking or chewing movement (Bikker et al., 2014). Active was defined as the cow standing on all 4 legs and only moving her head slightly; whereas, high active as defined as a cow walking or moving her body and head (Bikker et al., 2014). Pereira et al. (2018) reported that direct visual observations for eating and the sensor data were highly correlated (r =

0.88); whereas, active behavior had the lowest correlation with the sensor data and direct visual observations (r = 0.20). Pereira et al. (2018) found an association between not active sensor data and visual observations (r = 0.88).

Another measure that the CowManager ear tag provides is ear surface temperature. Dolecheck et al. (2015) compared multiple technologies on dairy cows and compared the DVM reticulorumen bolus (DVM systems, LLC, Greeley, CO) and the CowManager ear tag. The reticulorumen bolus increased 0.43°C during estrus, whereas the ear surface temperature increased 1.20°C during estrus (Dolecheck et al., 2015). The ear surface temperature is influenced by ambient temperature and core body temperature, whereas the reticulorumen bolus does not fluctuate as much because it is only measured from core body temperature alone (Dolecheck et al., 2015). Therefore, the variation in temperature increase was expected to be less in the bolus compared to the ear tag temperature.

Other technologies such as the GrowSafe System (GrowSafe Systems Ltd. Airdrie, AB, Canada) and the Insentec monitoring system (Insentec, Marknesse, the Netherlands) have been validated for feeding behavior in beef cattle. These systems are highly accurate and allow researchers to monitor intake; however, they are designed for single-animal access to a limited number of bunks (Wolfger et al., 2015). However, these systems can be used in conjunction with other technologies to validate rumination and eating behavior. Wolfger et al. (2015) recorded 10,252 min of observed behavior on 18 steers over a 13 d monitoring period during daylight hours. Of the total observation times, steers were observed to be eating for 26% of the time (2,692 min) and ruminating for 23% of the time (2,359 min; Wolfger et al., 2015). Across all steers, Wolfger et al. (2015) observed steers eating time was 10. 8 ± 15.0 min/h, and an average rumination time was 9.5 ± 13.9 min/h.

Using the GrowSafe technology, Gibb et al. (1998) found that steers on a 55% (DM basis) concentrate diet spent 55.6 min/d at the bunk. Steers were then stepped up to a 95% (DM basis) concentrate diet and spent an average of 33.6 min/d at the bunk with a range of 7.7 to 89.2 min (Gibb et al., 1998). Furthermore, Schwartzkopf-Genswein et al. (1999) found that steers using the GrowSafe technology averaged 87.2 ± 2.0 min/d at the feed bunk with a range of 36.9 to 116.3 min/d. Schwartzkopf-Genswein et al. (1999) found that steers made an average of 29 ± 11.8 visits/d to the feed bunk. Therefore, suggesting that the duration of bunk attendance may be a better indicator of feed intake by the animal compared to frequency of attendance (Schwartzkopf-Genswein et al., 1999). Steers fed a barley-based finishing diet during a 54 d finishing period reported eating rates at 5.52 kg feed per min (Schwartzkopf-Genswein et al., 2002). Additionally, Schwartzkopf-Genswein et al. (2002) observed a significant correlation between the duration of bunk attendance and average intake per d, which suggests that the longer animals spent at the bunk, the more feed they consumed.

There are numerous technologies available that have provided information pertaining to feeding behavior, estrus activity, physical activity, and health statuses of individual animals. However, the adaptions of such technologies are slow in beef production systems. Although individual animal variation exists, and animal needs change throughout the year, implementing technologies into production systems may provide information and alternative means for management decisions for progressive producers.

Summary and Research Needs

Our overarching hypothesis is that we can enhance beef cattle performance and production through strategic supplementation of energy and mineral. The specific objective for chapter two is to evaluate the effect of preweaning creep feeding behavior on postweaning feeding behavior, performance, and carcass characteristics. Objectives for chapter three are to evaluate an electronic feeder to monitor individual cow and calf mineral intake and feeding behavior, and their relationship with growth performance and concentrations of minerals in liver. Objectives for chapter four are to evaluate effects of a vitamin and mineral bolus on heifer feedlot performance, feeding behavior, carcass characteristics, and liver mineral concentrations. Objectives for chapter five are to develop a Mobile Cow Command Center (MCCC) for use in, 1) examining the relationship between mineral and energy supplementation on intake, liver mineral concentrations, and metabolites in heifers being managed on native range and 2) examining activity and reproductive behavior of heifers on native range.

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CHAPTER 2: THE RELATIONSHIP BETWEEN STEER CREEP FEEDER APPEARANCE PREWEANING AND POST-WEANING FEEDING BEHAVIOR AND CARCASS CHARACTERISTICS

Abstract

Suckling crossbred Angus steers (n = 24) at the Central Grasslands Research Extension Center (Streeter, ND) were fitted with transmission beacons on collars to determine the effect of preweaning creep feeding behavior on post-weaning feeding behavior, performance, and carcass characteristics. Preweaning data was recorded for 24 d and included the number of days the steers visited creep feeders and total minutes at the feeder. Calves then were weaned and acclimated to finishing diets and the Insentec feeding system (which recorded feed intake and behavior) during a 24 d transition period, followed by a 172 d finishing period. Steer attendance at creep feeders was categorized as FREQUENT (attending greater than 80 percent of days) or INFREQUENT (attending less than 80 percent of days). During the 24 d transition period, frequent creep feeder visitors ate more meals ($P = 0.05$) but had reduced ($P \leq 0.03$) time per meal, intake per meal and DMI compared with infrequent visitors. During the first 28 days of finishing, frequent creep feeder visitors spent more time eating and ate more meals, compared with infrequent visitors ($P \leq 0.01$), but infrequent visitors ate more DMI per meal and ate faster ($P \leq 0.04$). The frequency of creep feeder attendance had no impact on DMI, average daily gain (ADG) or gain-to-feed ratio (G:F) during the feeding period, or on carcass weight, marbling or longissimus muscle area ($P \geq 0.19$). Overall, data indicate that preweaning creep feeder attendance influenced post-weaning feeding behavior and carcass characteristics.

Introduction

Nursing calves have been given supplements to increase preweaning weight gains (Tarr et al., 1994; Loy et al., 2002), reduce grazing pressure and improve intake at weaning (Reed et al., 2006). Increased weaning weights of calves can increase the gross income of many cow-calf production systems that sell calves at weaning (Martin et al., 1981; Tarr et al., 1994). Additionally, creep feeding has been found to alter behavior by training calves to recognize milled feed and availability of feed from mechanical devices (Pritchard, 2013). Utilization of electronic feeders or equipment can help producers understand feeding behavior and monitor calf performance in grazing settings.

Electronic ID systems have been used largely to qualify calves for export programs and, to a lesser extent, manage calves in feedlot scenarios. However, systems that integrate electronic identification on a ranch level into future decisions about cattle management are not widely utilized. Development of such systems could result in many improvements in management of cattle and management or feeding approaches to improve the efficiency of production of calves and beef. The use of electronic monitoring systems in the beef industry has been limited; these systems primarily have been used in research settings to examine the effects on feed intake in relation to cattle growth performance (Islas et al., 2014), health status (Wolfger et al., 2015) or animal movement in extensive pasture settings (Schauer et al., 2005).

Tremendous potential exists for utilizing these types of technologies to predict cattle performance that will allow for the development of precision management programs. Therefore, the objectives of this study were to evaluate an electronic system of monitoring preweaning creep feeding behavior and its subsequent effects on postweaning feeding behavior, performance and carcass characteristics.

Materials and Methods

All procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University (A16063).

Animal Procedures

Suckling crossbred Angus steers (n = 24) at the Central Grasslands Research Extension Center (Streeter, ND) were fitted with transmission beacons equipped with radio-frequency identification and accelerometers (Remote Insights Inc., Minneapolis, MN) on collars. Each beacon contained an accelerometer, and upon movement, transmitted data to receiver gateways placed at the feeders. All calves had access to creep feeders equipped with beacon gateways that detected RFIDs within ~30 cm and subsequently sent data through a cellular network to a cloud platform. Further, creep feeder bunks were surrounded by a steel cage that only allowed calves to enter directly from the front of the feeder, and steel construction of the creep feeders resulted in a RFID reading plane that was directed toward the front of the feeder. Preweaning data included total minutes spent at the feeder on each day visited. Data were summarized to include number of days beacon was functioning, number of days visiting creep feeders, total minutes per day visiting creep feeders, and minutes per day beacon was functioning. Initial data from 32 beacons were recorded and then beacon function was evaluated. We had 8 beacons that did not function for at least 7 d, thus the remaining functioning beacons (n = 24) were used for the preweaning data.

At weaning, weights were recorded and calves were shipped to the NDSU Beef Cattle Research Complex (BCRC) in Fargo, ND. Steers (initial BW = 298 ± 3.1 kg) received a radio frequency identification (RFID) tag in the right ear before the experiment. Steers were adapted to a 90% concentrate finishing diet consisting primarily of corn, corn silage, wheat straw, and premix and was formulated to an average predicted MP requirement of 880 g MP/d (Sitorski et al., 2019). Steers were acclimated to a Insentec feeding system (Hokofarm Group B.V., the Netherlands), which recorded feed intake and behavior during a 24 d transition period, followed by a 172 d finishing period.

On completion of the trial, data from the Insentec feed system were combined with the creep feeder beacon data. Feed intake and behavior were summarized by day for each individual steer (Montanholi et al., 2010; Swanson et al., 2014) as follows: events (number of bunk visits and meals daily), eating time (minutes; per visit, per meal, and per day), and feed intake (kg; per visit, per meal, and per minute) and summarized for the 172 d feeding period. A visit was defined as each time the Insentec system (Hokofarm Group B.V., the Netherlands detected a steer at a bunk. A meal was defined as eating periods that might include short breaks separated by intervals not longer than 7 min (Montanholi et al., 2010; Swanson et al., 2014). The median value for the percentage of creep feeder attendance was used as an inflection point to categorize steers into groups. Steer attendance at creep feeders was categorized as FREQUENT (n = 13; attending greater than 80 percent of days) or INFREQUENT (n = 11; attending less than 80 percent of days). Postweaning feeding behavior data were summarized by 1) ration transition period (24 d) and 2) first 28 days on the finishing ration.

Steers were fed until they achieved an average BW of 598 ± 3.1 kg. Final 2 d body weights were recorded prior to steers being transported to a commercial abattoir. Hot carcass weight data were obtained following steers being slaughtered; whereas, marbling score; back fat; longissimus muscle area; kidney, pelvic and heart fat (KPH); and yield grade were taken after carcasses were chilled in the cooler for 24 h. Dressing percentages were calculated using hot carcass weight and final weights.

Statistical Analysis

All data were analyzed for the effects of creep feeder attendance on postweaning feeding behavior, and carcass characteristics were analyzed using the GLM procedure of SAS (9.4; SAS Institute Inc., Cary, N.C.). Differences were considered significant at $P < 0.05$.

Results and Discussion

During October, beacons were recording the appearance or number of visits per calf at the creep feeders (Figure 2.1). Overall, the creep feeders were visited at least 5 minutes per d throughout the month. The maximum number of time spent at the creep feeder was 28 min in one day. Steers in the frequent category attended feeders an average of 90.6% of days; whereas, steers in the infrequent category attended feeders an average of 62.5% of days. Ralston et al. (2005) utilized electronic identification tags to monitor individual free choice creep feed intake by suckling calves on range. Calves attended one circular tub creep feeder an average of 21 ± 10.3% of the 36 d monitoring period with a range of 2 to 42% (Ralston et al., 2005). The steers reported herein only had a 24 d monitoring period, but attended the creep feeder more frequently than steers from Ralston et al. (2005); however, our current study was unable to record individual creep feed intake among our calves.

During the 24 d transition period (Table 2.1), FREQUENT creep feeder visitors ate more meals ($P = 0.05$) but had reduced time per meal, intake per meal and DMI ($P \leq 0.03$), compared with INFREQUENT visitors. Steers that attended the creep feeder more frequently attended the feedlot bunks within the first seven days upon arrival to the BCRC a greater percentage of time, compared with infrequent visitors (59 vs. 37%, respectively). These data may suggest that calves that frequented the creep feeder were more familiar with mechanical devices and milled feed such as the devices they attended while on pasture.

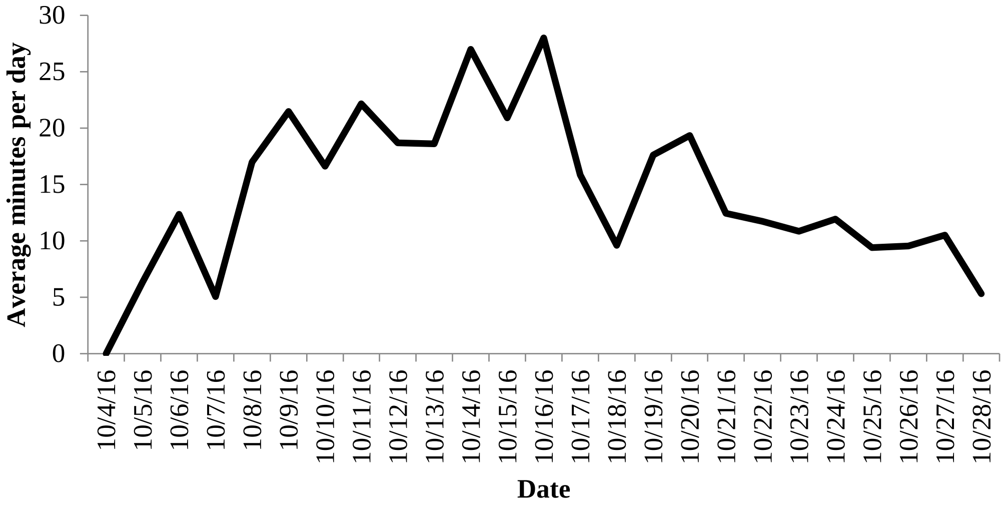

Figure 2.1. Average minutes per day suckling crossbred Angus steers (n = 24) fitted with transmission beacons on collars visited creep feeders during a 24 d creep feeding period.

Using the GrowSafe technology, Gibb et al. (1998) found that steers on a 55% (DM basis) concentrate diet spent 55.6 min per d at the bunk. Steers were then stepped up to a 95% (DM basis) concentrate diet and spent an average of 33.6 min per d at the bunk with a range of 7.7 to 89.2 min (Gibb et al., 1998). Furthermore, Schwartzkopf-Genswein et al. (1999) found that steers using the GrowSafe technology averaged 87.2 ± 2.0 min per d at the feed bunk with a range of 36.9 to 116.3 min per d. During the transition period, steers reported herein fall within range of other studies looking at bunk attendance. Moreover, Schwartzkopf-Genswein et al. (1999) found that steers made an average of 29 ± 11.8 visits per day to the feed bunk. Our steers visited the bunks more than the studies reported herein but consumed less for DMI. Therefore suggesting that the duration of bunk attendance may be a better indicator of feed intake by the animal compared to frequency of attendance (Schwartzkopf-Genswein et al., 1999). Steers in our current study spent more time at the feed bunks during the transition period than steers from Gibb et al. (1998) and Schwartzkopf-Genswein et al. (1999).

Table 2.1. Impact of frequency of creep feeder visits on transition period (24 d) feeding behavior of crossbred Angus steers

	Visiting frequency category[1]			
Item	Frequent	Infrequent	SEM	*P*-Value
No. of steers	13	11		
DMI, kg	5.29^a	6.15^b	0.26	0.03
Events, per d				
Visits[2]	39.3	33.4	3.07	0.20
Meals[3]	13.97^a	12.43^b	0.52	0.05
Time eating, min				
Per visit	2.34^a	3.47^b	0.29	0.01
Per meal	6.55^a	8.33^b	0.54	0.03
Per day	93	102	7	0.38
Eating rate, kg				
Per visit	0.14^a	0.22^b	0.02	0.02
Per meal	0.37^a	0.51^b	0.02	0.001
Per min	5.65	3.26	1.58	0.29

[ab]Means with uncommon superscripts differ ($P < 0.05$)

[1] Steers in the Frequent category attended creep feeders an average of 90.6% of days, whereas steers in the Infrequent category attended creep feeders an average of 62.5 % of days.

[2] A visit was defined as each time the Insentec system (Insentec B. V., Marknesse, The Netherlands) detected a steer at a bunk.

[3] A meal was defined as eating periods that might include short breaks separated by intervals not longer than 7 min (Montanholi et al., 2010; Swanson et al., 2014).

During the first 28 days of finishing both groups had similar DMI (Table 2.2). Interestingly, FREQUENT creep feeder visitors spent more time eating and ate more meals, compared with INFREQUENT visitors ($P \leq 0.01$), but infrequent visitors ate more DMI per meal and ate faster ($P \leq 0.04$). Similar eating rates (5.52 kg feed per min) have been reported from steers fed a barley-based finishing diet during a 54 d finishing period (Schwartzkopf-Genswein et al., 2002). Additionally, Schwartzkopf-Genswein et al. (2002) observed a correlation between the duration of bunk attendance and average intake per d, which suggests that the longer animals spent at the bunk, the more feed they consumed. Although FREQUENT creep feed visitors spent more time eating, we reported no differences in DMI per d between categories. Furthermore, our

FREQUENT and INFREQUENT steers reported 33.8 and 27.2 visits per d, respectively. Which is within range for what Schwartzkopf-Genswein et al. (1999) reported for steers using the GrowSafe technology. Frequency of creep feeder attendance had no influence on DMI, ADG or G:F during the feeding period ($P \geq 0.45$). Studies of creep feeding calves for 28 days showed no advantage in feedlot performance and carcass characteristics, compared with longer time on creep feed (Tarr, 1994).

Table 2.2. Impact of frequency of creep feeder visits on growth performance and feeding behavior in crossbred Angus steers during the first 28 d on feed

	Visiting frequency category[1]			
Item	Frequent	Infrequent	SEM	*P*-Value
No. of steers	13	11		
DMI[2], kg/d	6.41	6.53	0.30	0.77
ADG[3], kg/d	0.99	0.90	0.15	0.66
G:F	0.15	0.13	0.15	0.45
Events, per d				
Visits[4]	33.8	27.2	3.17	0.15
Meals[5]	12.7^{a}	10.7^{b}	0.52	0.01
Time eating, min				
Per visit	5.86	6.83	0.80	0.41
Per meal	13.31	12.61	1.03	0.64
Per day	158^{a}	126^{b}	7.91	0.01
Eating rate, kg				
Per visit	0.25^{a}	0.37^{b}	0.04	0.03
Per meal	0.85^{a}	1.05^{b}	0.06	0.04
Per min	0.066^{a}	0.086^{b}	0.003	<0.001

[ab] Means with uncommon superscripts differ ($P < 0.05$)

[1] Steers in the Frequent category attended creep feeders an average of 90.6% of days, whereas steers in the Infrequent category attended creep feeders an average of 62.5 % of days.

[2] DMI = dry mater intake

[3] ADG = average daily gain

[4] A visit was defined as each time the Insentec system (Insentec B. V., Marknesse, The Netherlands) detected a steer at a bunk.

[5] A meal was defined as eating periods that might include short breaks separated by intervals not longer than 7 min (Montanholi et al., 2010; Swanson et al., 2014).

Back fat and calculated yield grade were greater for frequent visitors (*P* ≥ 0.03), compared with infrequent visitors (Table 2.3). Frequency of creep feeder attendance had no influence on carcass weight, marbling or longissimus muscle area (*P* ≥ 0.19). Studies of calves gaining similarly to the calves in this study have shown mixed results regarding back fat thickness, with increased time on creep feed resulting in greater fat thickness (Tarr, 1994). Faulkner et al. (1994) reported that steers fed corn creep feed had greater quality grades than steers consuming soy-hull creep feed; however, both sources of creep had no influence on adjusted fat thickness, hot carcass weight, internal fat, longissimus muscle area, and yield grade. Marbling development can be influenced early in the life of the animal (Faulkner et al., 1994). Creep feeding has been utilized to increase starch intake in young calves. Which starch fermentation in the rumen results in greater propionate and less acetate production, and therefore a greater supply of glucose to the animal, which suggests that high-starch supplements may enhance marbling development (Sharman et al., 2013).

Table 2.3. Impact of frequency of creep feeder visits on carcass characteristics of crossbred Angus steers

	Visiting frequency category[1]			
Item	Frequent	Infrequent	SEM	*P*-Value
No. of steers	13	11		
HCW[2], kg	367	356	9	0.39
Marbling score	487	445	22	0.19
Backfat, cm	1.40[a]	1.02[b]	0.09	0.01
Longissimus area, cm^2	84.13	84.83	1.93	0.80
KPH, %	2.02	1.88	0.05	0.07
Calculated yield grade	3.24[a]	2.66[b]	0.18	0.03

[ab] Means with uncommon superscripts differ (*P* < 0.05).

[1] Steers in the Frequent category attended creep feeders an average of 90.6% of days, whereas steers in the Infrequent category attended creep feeders an average of 62.5 % of days.

[2] HCW = hot carcass weight.

Conclusions

Overall, data indicate that frequency of preweaning creep feeder attendance influenced postweaning feeding behavior and carcass characteristics. Steers reported herein that frequently attended a creep feeder attended the feedlot bunks a greater percentage of time upon feedlot arrival. Additionally, greater responses to backfat and yield grade were found in steers that frequently attended creep feeders with a tendency for percent KPH to be greater in those frequent creep feed attending steers. These data support behavioral changes found when training calves to recognize milled feed from mechanical devices (Pritchard, 2013). Utilization of such devices, as reported herein, can help producers understand feeding behavior and monitor calf performance in grazing settings. With changes in feeding behavior prior to entry into the feedlot, producers that choose to retain calves through finishing, may have opportunities to improve carcass characteristics with preweaning creep feeding attendance as reported herein.

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CHAPTER 3: TECHNICAL NOTE: UTILIZING AN ELECTRONIC FEEDER TO MEASURE INDIVIDUAL MINERAL INTAKE, FEEDING BEHAVIOR, AND GROWTH PERFORMANCE OF COW-CALF PAIRS GRAZING NATIVE RANGE

Abstract

Crossbred Angus cow-calf pairs (n = 28 pairs) at the Central Grasslands Research Extension Center (Streeter, ND) were used to evaluate an electronic feeder to monitor individual mineral intake and feeding behavior and their relationship with growth performance and liver mineral concentrations. Cows and calves were fitted with radio frequency identification (RFID) ear tags that allowed access to an electronic feeder (SmartFeed system; C-Lock Inc., Rapid City, SD) and were provided ad libitum mineral (Purina Wind and Rain Storm, Land O’Lakes, Inc., Arden Hills, MN). Mineral intake, number of visits, and duration at the feeder were recorded over a 95 d monitoring period while pairs were grazing native range. Liver biopsies were collected from a subset of cows on the final day of monitoring and analyzed for mineral concentrations. Data were analyzed with the GLM procedure in SAS for mineral intake and feeding behavior with age class (cows vs. calves), intake category (high vs. low), and the interaction between class and category in the model. Correlations were calculated among cow feeding behavior and calf intake and growth performance with the CORR procedure, and a comparison of liver mineral concentrations among cows of HIGH (>90 g/d; average 125.4 g/d) and LOW (<90 g/d; average 33.5 g/d) mineral intake with the GLM procedure. HIGH intake calves (>50 g/d; average 72.2 g/d) consumed greater ($P < 0.001$) amounts of mineral than LOW intake calves (<50 g/d; average 22.2 g/d) intake calves. Cows and calves attended the mineral feeder a similar ($P = 0.71$) proportion of the days during the experiment (overall mean of 20%, or once every 5 days). On days calves visited the feeder, they consumed less ($P < 0.01$) mineral than cows (222 ± 27 vs 356 ± 26 g/d, respectively). Over the grazing period, calves gained 1.17 ± 0.02 kg/d whereas cows lost 0.35 ± 0.02 kg/d. Calf mineral intake was correlated with cow duration at the mineral feeder (r = 0.403, P = 0.05). Cows with HIGH mineral intake had greater (*P* < 0.01) concentrations of Se (2.92 vs. 2.41 ug/g), Cu (247 vs. 116 ug/g), and Co (0.51 vs. 0.27 ug/g) compared with LOW mineral intake cows, but liver concentrations of Fe, Zn, Mo, and Mn did not differ (*P* ≥ 0.22). We were able to successfully monitor individual mineral intake and feeding behavior with the electronic feeder evaluated, and the divergence in mineral intake observed with the feeder was corroborated by concentrations of mineral in the liver.

Introduction

Mineral requirements of grazing cattle are not always satisfied by forages (McDowell, 1996), thus mineral supplementation is often necessary to optimize animal health and performance (NASEM, 2016). Supplementing mineral to cattle grazing poor-quality range vegetation can improve forage utilization and animal performance (Köster et al., 1996; Caton and Dhuyvetter, 1997). An issue with providing mineral supplements to cattle; however, is the high degree of intake variability associated with free choice mineral supplements (Greene, 2000; Cockwill et al., 2000). Mineral intake variability is influenced by season, individual animal requirements, animal preference, availability of fresh minerals, mineral palatability, physical form of minerals, salt content of water, mineral delivery method, soil fertility, forage type, forage availability, animal social interactions, and likely other unknown factors (Bowman and Sowell, 1997; McDowell, 2003).

Providing free choice mineral supplements to pasture-based cattle does not allow measurement of individual animal mineral intake; as a result, mineral intake is measured on a group basis. Measurement of individual animals' mineral supplement intake allows specific animal responses to be evaluated. The use of electronic monitoring systems in the beef industry has been limited to systems primarily used in research settings to examine the effects on feed intake in relation to cattle growth performance (Islas et al., 2014), daily intake of salt-limited supplements (Reuter et al., 2017), health status (Wolfger et al., 2015), or animal movement in extensive pasture settings (Schauer et al., 2005). These technologies could be adapted easily for use in beef cattle production systems to monitor activity, feeding or drinking behavior, or as tools for monitoring inventories in intensive or extensive production systems. Therefore, our objective was to evaluate an electronic feeder to monitor individual cow and calf mineral intake and feeding behavior, and their relationship with growth performance and concentrations of mineral in the liver.

Materials and Methods

All animal procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University (A17064).

Study Area

Research was conducted at the Central Grasslands Research Extension Center, located near Streeter, ND from May 22, 2017 to September 27, 2017. This area is characterized by a continental climate with warm summers and cold winters with a majority (72%) of precipitation occurring between May and September (Limb et al., 2018). August is the warmest month with a mean temperature of 18.6°C and January is the coldest month with an average low temperature of -15.3°C (Figure 3.1; NDAWN, 2017).

The pasture was 62 ha with a stocking rate of 2.1 Animal Unit Months (AUMs)/ha. The vegetation is classified as mixed-grass prairie dominated by western wheatgrass (*Pascopyrum smithii* [Rydb.] À. Löve), green needlegrass (*Nassella viridula* [Trin.] Barkworth) and blue grama (*Bouteloua graciles* [Willd. ex Kunth] Lag. ex Griffiths). Other important species include sedges (*Carex* spp.), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), sages (*Artemisia* spp.), and goldenrods (*Solidago* spp.). Kentucky bluegrass (*Poa pratensis* L.) a non-native grass and western snowberry (*Symphoricarpos occidentalis* Hook.) native shrub, are important drivers in biodiversity changes in the region (Limb et al., 2018).

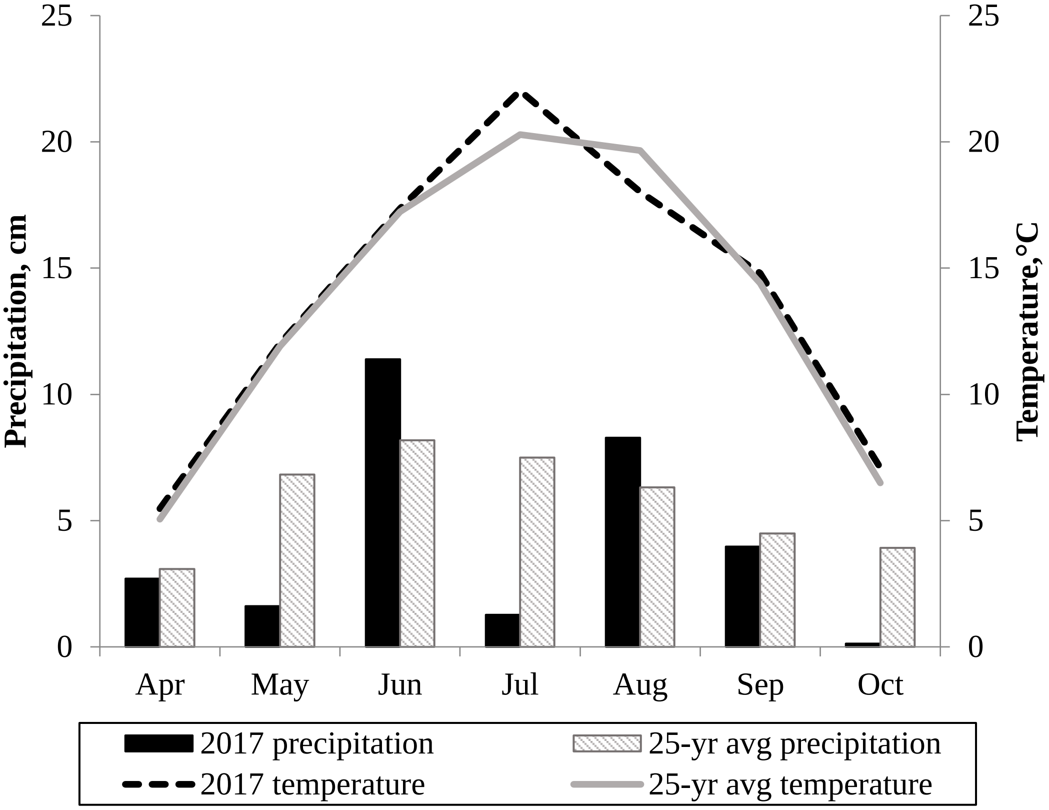

Figure 3.1. Temperature and precipitation data from April to October 2017 compared with 25-yr average. Data from North Dakota Agricultural Weather Network Station located in Streeter, ND (NDAWN, 2017).

Electronic Feeder Device

The SmartFeed system (C-Lock, Inc., Rapid City, SD) was used to deliver mineral supplement and measure intake. The system features a stainless steel feed bin suspended on two load cells, a radio frequency (RFID) tag reader and antenna, an adjustable framework to allow access to one animal at a time, and a data acquisition system that records RFID tags and feed bin weights (Reuter et al., 2017). The electronic feeder was fastened securely to the fence line to allow animal access to feeder and restrict access to electrical components and solar power source. The mineral feeder was located down the fence line in a corner of the pasture away from the water source. The feeder was covered with a plywood shell to protect the feed bin and equipment from wind and rain. Mineral disappearance in the feeder was monitored visually and through the online portal where intake and monitoring of the device were done remotely.

Animal Measurements

Twenty-eight crossbred Angus based primiparous cows (initial BW 586 ± 52 kg) and their suckling calves (initial BW 113 ± 19 kg; 66 ± 8 d of age) were used to evaluate an electronic feeder to monitor mineral intake and feeding behavior and their relationship with growth performance and concentrations of mineral in the liver. The mean value of consecutive day weights of cows and calves were used as initial and final body weights, with single day body weights collected at 28 d intervals. Body condition score was assessed on cows at the initiation and completion of the 95 d monitoring period. Cows and calves were fitted with RFID ear tags that allowed access to the electronic feeder, which contained free choice loose mineral (Purina Wind and Rain Storm, Land O'Lakes, Inc., Arden Hills, MN; Table 3.1).

The SmartFeed unit was set in training mode (lowest locked setting to allow for ad libitum access to the feeder) and training cattle to the feeders started from initial pasture turn out (May 22, 2017) to June 22, 2017. Mineral intake, number of visits, time of visits, and duration at the feeder were recorded continuously during a 95 d monitoring period while pairs were grazing native range. Daily mineral intake was calculated as the sum of individual feeding events in each 24 h period and overall mineral intake was the sum of all feeding events during the 95 d monitoring period. The median value for overall intake was used as an inflection point to categorize cattle into mineral intake groups. Cows and calves were categorized into one of two mineral intake classifications: HIGH (>90 or >50 g/d for cows and calves, respectively) and LOW (<90 or <50 g/d for cows and calves, respectively) mineral intake during the 95 d monitoring period.

Liver Sample Collection and Analysis

Samples of liver were collected on d 95 via biopsy from a subset of cows (n = 18) with the greatest and least attendance at the mineral feeder throughout the grazing period. Cows were restrained in a squeeze chute and the hair between the 10th and 12th ribs was clipped with size 40 blades (Oster; Sunbeam Products Inc., Boca Raton, FL). Liver biopsy samples (approximately 20 mg) were collected using the method of Engle and Spears (2000) with the modifications that all heifers were given an intradermal 3 mL injection of Lidocaine Injectable-2% (MWI, Boise, ID) at the target biopsy site. An imaginary line is drawn from the tuber coxae (hook) to the elbow. At the intersection with a line drawn horizontally from the greater trochanter, a stab incision was then made between the 10th intercostal space. A core sample of liver was taken via the Tru-Cut biopsy trochar (14 g; Merit Medical, South Jordan, UT). The liver sample was placed on ashless filter paper (Whatman 541 Hardened Ashless Filter Papers, GE Healthcare Bio-Sciences, Pittsburg, PA) and then stored in tubes designed for trace mineral analysis (potassium EDTA; Becton Dickinson Co., Franklin Lakes, NJ) and stored at -20°C until further analysis. After obtaining liver biopsies, a staple (Disposable Skin Staple 35 Wide; Amerisource Bergen, Chesterbrook, PA) and topical antibiotic (Aluspray; Neogen Animal Safety, Lexington, KY) was applied to the surgical site and an injectable NSAID (Banamine; Merck Animal Health, Madison, NJ) was given intravenously at 1.1 mg/kg of body weight. Liver samples were sent to the Veterinary Diagnostic Laboratory at Michigan State University and were evaluated for concentrations of minerals using inductively coupled plasma mass spectrometry.

Forage Collection and Analysis

Forage samples were obtained every two weeks from ten different locations in the pasture in a diagonal line across the pasture. The forage samples were hand clipped to a height of 3.75 cm above ground. Forage samples were dried in a forced-air oven at 60˚C for at least 48 h and then ground to pass through a 2-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Clipped forage samples for each location reported herein are composite over all locations within the representative sampling date. Forage samples were analyzed at the North Dakota State University Nutrition Laboratory for dry matter (DM), crude protein (CP), ash, N (Kjehldahl method), Ca, P and ether extract (EE) by standard procedures (AOAC, 1990). Multiplying N by 6.25 determined crude protein calculation. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined by the modified method of Van Soest et al. (1991) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). Samples were also analyzed for Cu, Zn, Co, Mo, Fe, S, and Se using inductively coupled plasma optical emission spectroscopy by the Veterinary Diagnostic Laboratory at Michigan State University.

Statistical Analysis

Data were analyzed using SAS (SAS 9.4; SAS Inst. Inc., Cary, NC) with mineral intake and feeding behavior compared among cows and calves via PROC GLM with significance at $P < 0.05$. Mineral intake and feeding behavior were analyzed by age class (cows vs. calves), intake category (high vs. low), and the interaction between class and category. Correlations were generated among cows and calves with the variables; cow duration at the feeder, intake, and BW; and calf ADG, intake, duration at the feeder using the CORR procedure of SAS. Comparisons of liver mineral concentrations among cows of HIGH (>90 g/d) and LOW (<90 g/d) mineral intake were analyzed with PROC GLM.

Table 3.1. Composition of Purina Wind and Rain Storm Mineral (Land O'Lakes, Inc., Arden Hills, MN) with company guaranteed analysis

	%		mg/kg	
Item	min	max	min	max
Minerals[1]				
Ca	13.5	16.2	-	-
P	7.5	-	-	-
NaCl	18.0	21.6	-	-
Mg	1.0	-	-	-
K	1.0	-	-	-
Mn	-	-	3,600	-
Co	-	-	12	-
Cu	-	-	1,200	-
I	-	-	60	--
Se	-	-	27	-
Zn	-	-	3,600	-
	IU per kg			
Vitamins[2]				
Vitamin A	661,500	-	-	-
Vitamin D	66,150	-	-	-
Vitamin E	661.5	-	-	-

[1] Ingredients: Dicalcium Phosphate, Monocalcium Phosphate, Calcium Carbonate, Salt, Processed Grain By-Products, Vegetable Fat, Plant Protein Products, Potassium Chloride, Magnesium Oxide, Natural and Artificial Flavors, Calcium Lignin Sulfonate, Ethoxyquin (a Preservative), Manganese Sulfate, Zinc Sulfate, Basic Copper Chloride, Ethylenediamine Dihydroiodide, Cobalt Carbonate

[2] Ingredients: Vitamin A Supplement (proprietary), Vitamin E Supplement (proprietary), Vitamin D3 Supplement (proprietary)

Results and Discussion

Mineral Intake and Feeding Behavior

Over the duration of the 95 d grazing period cows consumed more ($P < 0.001$; Table 3.2) mineral than calves. An age class × mineral intake category interaction ($P = 0.005$) was detected for intake over the 95 d monitoring period, with HIGH intake cows having greater mineral consumption (125.4 g; $P < 0.001$) compared with HIGH intake calves (72.2 g), which were greater ($P < 0.001$) than LOW intake cows and calves (33.5 g vs. 22.2 g, respectively). Generally, cattle mineral formulations are designed to fall within the targeted intake of between 56 and 114 g/d per animal for free-choice mineral supplementation (Greene, 2000). Research groups have reported on feeder attendance and daily mineral intake by individual cattle utilizing other electronic feeders (Cockwill et al., 2000; Manzano et al, 2012; Patterson et al., 2013). Furthermore, Patterson et al. (2013) evaluated cows and their calves using a Calan gate feeder system and provided 3 different supplemental sources of Se during a year-long production regimen and also reported variability with intakes ranging from 27.9 to 97.3 g/d with a mean mineral consumption of 54 g/d. However, calf intake was not evaluated in Patterson et al. (2013). Compared to utilizing electronic feeders, Pehrson et al. (1999) provided mineral supplement in a wooden box to grazing cows for an 80 d period and calculated the mean daily supplement consumption by dividing the total amount of fed by the number of animals consuming it, with the assumption that calves did not consume any significant amount. Thus, Pehrson et al. (1999) estimated daily consumption for Se yeast mineral supplement was 110 g/cow; whereas, cows supplemented with selenite consumed 107 g/cow. Although Pehrson et al. (1999) assumed calves did not consume any significant amount, our results show that calves in fact can consume more than some LOW consuming cows and may need to be considered when providing mineral supplement to a group on pasture. Nevertheless, our group was able to use the SmartFeed system to evaluate mineral intake of cow-calf pairs on pasture and record individual intakes of calves that the aforementioned groups were unable to evaluate.

No class × category interactions ($P > 0.14$) were present in the proportion of days cattle consumed mineral, time spent at the feeder, and eating rate. Further, no differences were observed for age class (*P* = 0.83); however, HIGH intake cattle spent a greater proportion of days consuming mineral compared to LOW intake cattle (*P* < 0.001). Overall, calves spent more time at the feeder compared to cows (*P* < 0.001). With HIGH intake cows and calves spending more time at the mineral feeder than their LOW intake counterparts (*P* = 0.02). Calves spent more time at the feeders and consumed less mineral that resulted in an overall slower eating rate. However, cows ate faster (*P* < 0.001) than calves and HIGH intake animals ate faster (*P* < 0.006) than LOW intake animals. It is important to note that both classes of cattle attended the mineral feeders for similar (*P* = 0.71) proportion of days during the experiment (overall mean of only 20 percent, or once every 5 days). Interestingly, though mean intake values for cows and calves over the course of the experiment did not meet manufacturers feeding recommendation (113.4 g) for the mineral used, because cattle did not visit feeders every day the mineral intake of both cows and calves exceeded the manufacturers feeding recommendation on days they did visit the feeders.

Table 3.2. Mineral intake and feeding behavior of grazing cow-calf pairs on native range utilizing an electronic feeder

	Calves[1]		Cows[2]			*P*-Value		
Item	High	Low	High	Low	SEM	Age Class	Intake Category	Class × Category
95 d intake[3], g/d	72.2^{b}	22.2^{c}	125.4^{a}	33.5^{c}	5.7	< 0.001	< 0.001	0.005
Days eating, %	27.5^{a}	14.5^{b}	27.5^{a}	14.5^{b}	1.4	0.83	< 0.001	0.64
Intake[4], g/d	300.1^{b}	161.2^{c}	461.8^{a}	242.5^{b}	28.1	< 0.001	< 0.001	0.005
Time, min	147.3^{a}	57.2^{c}	118.4^{b}	39.4^{c}	9.3	0.02	< 0.001	0.56
Eating rate, g/min	49.4^{c}	39.2^{c}	106.6^{a}	74.8^{b}	7.3	< 0.001	< 0.006	0.14

^{abc}Means within row lacking common superscript differ ($P < 0.05$).

[1] Calf divergent mineral intake classified calves as HIGH (> 50 g/d) or LOW (< 50 g/d) mineral intake.

[2] Cow divergent mineral intake classified cows as HIGH (> 90 g/d) or LOW (< 90 g/d) mineral intake.

[3] Represents average daily intake over the course of the 95 d monitoring period.

[4] Represents daily intake on the days cows and calves attended the electronic feeder.

On the days cows and calves visited the mineral feeders, HIGH intake cows consumed more ($P < 0.001$) mineral (461.8 kg/d) compared to LOW intake cows 242.5 kg/d and consumed more mineral than calves. Further, HIGH intake calves consumed more mineral (300.1 kg/d) than LOW intake calves (161.2 kg/d; $P < 0.001$). In addition, HIGH intake calves consumed more mineral than LOW intake cows ($P = 0.005$). Cockwill et al. (2000) reported high variability of mineral intake over a 6 d grazing period with individual intakes among cows and calves ranging from 0 to 974 and 0 to 181 g/d, respectively. Unfortunately, little field data exist for individual free-choice mineral intake by cows and calves managed under forage based cow-calf regimens (Patterson et al., 2013). The current offers a glimpse of mineral intake variability over a 3-month period in cows and calves grazing native range.

With the proportion of days during the experiment that cattle were consuming mineral, location of the mineral feeder and grazing behavior may explain variation in intake over the grazing period. It is probable that such distances from the water source could also alter patterns of electronic feeder attendance. Likewise, Smith et al. (2016) reported that individual steers visited a mineral feeder an average of 44.3% of the days monitored (90 d monitoring period) when the mineral feeder was in immediate proximity to the water source. Therefore, additional observations of cattle movements would need to be made to better understand frequency of attendance at the mineral feeder.

Cow and Calf Performance

Final body weight for cows and calves were 568 ± 53 kg and 245 ± 28 kg, respectively. Suckling calf weight increased over the grazing period and gained 1.17 ± 0.02 kg/d; whereas, cows lost 0.35 ± 0.02 kg/d as season advanced which was likely due to declining forage nutrient content combined and demands of lactation. The variation in nutrient requirements that come from changes in forage nutritive value and availability results in cows increasing and decreasing in body weight and body condition in a cyclic pattern throughout the production year (NASEM, 2016). Additionally, primiparous cows require additional nutrient requirements for their own growth and meeting nutrient requirements for lactation to support an existing offspring, and overall maintenance (Short et al., 1990; Meek et al., 1999; NASEM, 2016), which makes it hard to gain weight.

Table 3.3. Correlation coefficient (*r*) and associated *P*-values between cow-calf pairs intake and duration at mineral feeder while grazing native range for 95 d monitoring period and utilizing an electronic feeder for mineral intake

	Cow Duration	Cow Intake	Calf Duration	Calf Intake
Cow Duration	——	0.923 ($P < 0.01$)	0.306 ($P = 0.13$)	0.403 ($P = 0.05$)
Cow Intake		——	0.185 ($P = 0.36$)	0.279 ($P = 0.19$)
Calf Duration			——	0.948 ($P < 0.01$)
Calf Intake				——

Amount of time cows spent at the mineral feeder was positively correlated with cow mineral intake (r = 0.923; $P < 0.01$; Table 3.3). Additionally, the amount of time calves spent at the feeder was positively correlated with calf mineral intake (r = 0.948; $P < 0.01$). The time cows spent at the feeder was also positively correlated with calf mineral intake (r = 0.403; $P = 0.05$). Similar findings have been reported with inexperienced sheep increasing supplement intake in the presence of more experienced sheep (Bowman and Sowell, 1997). Furthermore, cow starting body weight was negatively correlated with the duration the calf spent at the feeder and calf intake (r = -0.631 and -0.553, respectively; $P < 0.01$; Table 3.4). This could suggest that as the grazing season progressed, the cow's milk production was declining because of the normal lactation curve and the decreasing quality of the forages available. It has been reported that suckling calves increase forage intake to compensate for reduced milk intake (Boggs et al., 1980). Therefore, calves in the current study could be accounting for the variation in cow milk production and in turn, compensating with available forage and mineral supplementation.

Table 3.4. Correlation coefficient (*r*) and associated *P*-values between cow BW and calf performance while grazing native range for 95 d monitoring period and utilizing an electronic feeder for mineral intake

	Cow BW	Cow Intake	Calf ADG	Calf Duration	Calf Intake
Cow BW	——	0.048 (*P* = 0.81)	0.204 (*P* = 0.23)	-0.631 (*P* < 0.01)	-0.553 (*P* < 0.01)
Cow Intake		——	-0.134 (*P* = 0.51)	0.185 (*P* = 0.36)	0.279 (*P* = 0.19)
Calf ADG			——	-0.166 (*P* = 0.42)	-0.212 (*P* = 0.32)
Calf Duration				——	0.948 (*P* < 0.01)
Calf Intake					——

Forage Analysis

Forage nutrient content appeared to decrease over the course of the mineral intake grazing period (Table 3.5) as noted with decreasing CP and increasing values for NDF. A decrease in the forage nutritive value is typical in diets of grazing cattle during the advancing season (Bedell, 1971; Schauer et al., 2004; Cline et al., 2009). The nutrient availability of grazed forages fluctuates by environmental conditions, forage species, soil type, and stage of maturity (NASEM, 2016). Recommended allowance for Se, Fe, Cu, Zn, and Mn are 0.10, 50, 10, 30, and 40 mg/kg dietary DM, respectively (NASEM, 2016). Selenium in forage can range widely within and between different types of feedstuffs (Suttle, 2010). However, the current pasture Se concentrations are below detectable levels. Iron in pastures has been shown to have seasonal fluctuations with peaks in spring and autumn (Suttle, 2010), where our current forage Fe concentrations are adequate over the course of the grazing season. According to Corah and Dargatz (1996), forage Fe is within adequate levels at 50 to 200 mg/kg. Concentrations of Cu in forage were marginal to deficient (4 to 7 vs. < 4 mg/kg, respectively; Corah and Dargatz, 1996). According to Corah and Dargatz (1996), concentrations of Zn were deficient (< 20 mg/kg) over the course of the grazing period. Whereas, according to Corah and Dargatz (1996) Mo, Co, and Mn were adequate (< 1, 0.1 to 0.25, > 40 mg/kg, respectively). Grings et al. (1996) found that Mo content ranged from 1 to 2 mg/kg in forages from the Northern Great Plains, which our pastures fall within this similar range.

Liver Mineral Concentrations

Cows with HIGH mineral intake had greater ($P < 0.01$) liver concentrations of Se, Cu, and Co compared with LOW mineral intake cows, but liver concentrations of Fe, Zn, Mo, and Mn did not differ ($P \geq 0.22$; Table 3.6) among cows in respective mineral intake categories. Selenium concentrations in the liver for HIGH cows were classified as high adequate (>2.50 µg/g DM; Kincaid, 2000) and LOW mineral intake cows were adequate (1.25 to 2.50 µg/g DM; Kincaid, 2000). Adequate liver Cu concentrations are defined as 125 to 600 µg/g DM (Kincaid, 2000) or normal > 100 µg/g DM (Radostits et al., 2007). Therefore, HIGH and LOW cows would be considered adequate to normal for liver Cu concentrations. Liver Co levels at 0.08 to 0.12 µg/g DM or more indicate satisfactory Co status (McNaught, 1948), which HIGH and LOW cows were above satisfactory levels. According to Kincaid (2000), liver mineral concentrations for Fe, Zn, Mo, and Mn are considered adequate for HIGH and LOW groups. Overall, cows in the HIGH and LOW mineral intake groups had adequate liver mineral concentrations.

Table 3.5. Forage analysis of pasture grazed by cow-calf pairs from May to September 2017[1].

Item	Grazing Period[2]				
	May	June	July	August	September
TDN[3]	63.9	63.25	62.05	61.45	60.23
CP, %	9.08	8.30	6.47	5.82	6.67
Ash	10.27	9.42	9.31	9.79	10.09
NDF, %	58.98	60.88	62.48	62.04	65.22
ADF, %	31.65	32.46	33.97	34.75	36.27
Ca, %	0.36	0.37	0.40	0.40	0.44
P, %	0.19	0.16	0.14	0.12	0.14
S, mg/kg	1,259	1,285	1,107	1,160	1,257
Se, mg/kg	<10.0	<10.0	<10.0	<10.0	<10.0
Fe, mg/kg	144	90.50	92.50	77.50	193.67
Cu, mg/kg	4.4	4.20	3.20	2.95	3.70
Zn, mg/kg	18.3	17.85	14.35	15.10	17.23
Mo, mg/kg	1.2	0.95	1.30	1.25	1.37
Mn, mg/kg	86.3	67.30	72.10	84.40	99.77
Co, mg/kg	<1.00	<1.00	<1.00	<1.00	<1.00

[1] Clipped forage samples from 10 different locations reported herein are composite over all locations within the representative sampling dates.

[2] Values presented are mean values of the representative sampling dates within the given month: May (n = 1), June (n = 2), July (n = 2), August (n = 2) and September (n = 3).

[3] TDN = 88.9 – (0.79 × ADF%); Lardy, 2018

Conclusions

The use of an electronic feeder in the pasture enabled the measurement of individual ad libitum intake of free-choice mineral by individual cows and calves. In this system, all cow-calf pairs had equal ad libitum access to native range forage and access to mineral. Overall, calves spent more time at the feeder compared to cows. Additionally, HIGH intake cows and calves spent more time at the mineral feeder than their LOW intake counterparts. Furthermore, we noted greater concentrations of Se, Cu, and Co in livers of HIGH intake cows compared to LOW intake cows. In conclusion, we were able to successfully monitor mineral intake and feeding behavior with the electronic feeder evaluated, and the divergence in mineral intake observed with the feeder was corroborated by concentrations of mineral in the liver.

Table 3.6. Liver mineral concentrations of cows with divergent mineral intake from an electronic feeder

	Intake Category[1]			
Item, µg/g	High	Low	SEM	*P*-Value
n	9	9		
Se	2.92^a	2.41^b	0.10	< 0.01
Fe	202	220	22	0.58
Cu	247^a	116^b	22	< 0.01
Zn	111	119	17	0.74
Mo	3.98	3.75	0.29	0.59
Mn	9.74	8.84	0.50	0.22
Co	0.51^a	0.27^b	0.05	< 0.01

[ab]Means within row lacking common superscript differ ($P < 0.05$)

[1] Cow divergent mineral intake classified cows as HIGH (> 90 g/d) or LOW (< 90 g/d) mineral intake.

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CHAPTER 4: EFFECTS OF A VITAMIN AND MINERAL BOLUS ON BEEF HEIFER FEEDLOT PERFORMANCE, FEEDING BEHAVIOR, CARCASS CHARACTERISTICS, AND LIVER MINERAL CONCENTRATIONS

Abstract

Crossbred beef heifers (n = 23; initial BW= 370 ± 12 kg) housed at the NDSU Beef Cattle Research Complex (BCRC) in Fargo, ND, were used to evaluate the effects of a 250 d slow-release vitamin and mineral bolus on feedlot performance, feeding behavior, carcass characteristics, and liver mineral concentrations. Heifers were assigned to one of two treatments: 1) received no supplemental mineral or vitamin (**CON**, n = 12) or 2) received two boluses on day 0 (Ca, Mg, Na, Cu, I, Mn, Se, Zn, Co, vitamin A, vitamin D3 and vitamin E; Reloader 250 Mineral Bolus, Cargill Inc., Minneapolis, MN; **MIN**, n = 11). Heifers were fed a total mixed ration (TMR) containing corn silage, grass hay, dried distillers grains with solubles (DDGS), and corn (16.05% CP, 1.44 Mcal/kg NEg) with no added vitamin or mineral supplement. Feed intake, and number and time of visits were recorded for each heifer using the Insentec feeding system (Hokofarm Group B.V., the Netherlands) during the 150-day feeding period. Liver biopsies were collected from heifers on day 0, 69 and 134 of the feeding period for analysis of mineral concentrations. Heifers were slaughtered after 150 days on feed and carcass characteristics were determined. Final BW, ADG, DMI, G:F and carcass characteristics were not influenced ($P > 0.19$) by treatment. Control heifers visited feeders more but spent less time per visit and ate less per visit, compared with MIN heifers ($P < 0.03$). No differences ($P > 0.06$) in liver mineral concentrations were observed between treatments, and concentrations of Se, Cu, Mo, Mn, and Co decreased ($P < 0.05$) over the feeding period. In this experiment, the slow-

release vitamin and mineral bolus evaluated failed to increase liver mineral concentrations during the finishing period or influence heifer performance and carcass characteristics.

Introduction

Diet alone often does not supply sufficient amounts of trace minerals; therefore, supplementation is necessary to optimize animal health and performance (NASEM, 2016). Research clearly has documented that intakes of free-choice minerals are variable among animals, with some cattle over or underconsuming supplements (Greene, 2000). Furthermore, inadequate trace mineral consumption can compromise reproduction, animal health and animal growth (NRC, 2005; NASEM, 2016).

In confinement scenarios, liquid, loose dry, and pelleted dry supplements are used as an ingredient in finishing diets (Samuelson et al., 2016). With trace minerals being formulated into the basal diet as a combination of organic and inorganic sources (Samuelson et al., 2016). Moreover, feedlot nutritionists provide greater concentrations of vitamins in receiving diets compared to finishing diets (Samuelson et al., 2016). However, in range or pasture settings, range pellets can be delivered to cattle, but the inconvenience of transporting large quantities of feed to remote grazing sites often has producers providing mineral and protein supplements on a free-choice basis. Free-choice supplementation assumes that cattle will consume the quantities that are recommended and satisfy requirements.

A long-acting (six-month) reticulorumen trace mineral bolus developed in the United Kingdom (Cosecure; Telsol Ltd., Leeds, UK) containing Cu, Se and Co has shown promise in increasing liver copper and blood selenium levels in range cows (Sprinkle et al., 2006). A recently developed bolus product was released in the U.S. (Reloader 250 Mineral Bolus, Cargill Inc., Minneapolis, MN) that targets a slow release over 250 d. A long-acting delivery of trace minerals could be advantageous for beef production in extensively managed systems. Therefore, this study was a model to evaluate the slow-release bolus in a confinement scenario prior to testing the bolus in extensive environments. The objectives of this study were to evaluate effects of a vitamin and mineral bolus on heifer feedlot performance, feeding behavior, carcass characteristics and liver mineral concentrations.

Materials and Methods

All animal procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University (A18021).

Animals, Diet, Body Weights, and Intake Measurements

Twenty-three crossbred beef heifers (initial BW= 370 ± 12 kg) were housed at the NDSU Beef Cattle Research Complex (BCRC) in Fargo, N.D. Heifers were weighed before feed delivery for 2 consecutive days at the beginning of the experiment and every 28 d throughout the 150 d feeding period. Heifers were assigned to one of two treatments: 1) received no supplemental mineral or vitamin bolus (**CON**, n = 12), or 2) received two boluses on day 0 (Ca, Mg, Na, Cu, I, Mn, Se, Zn, Co, vitamin A, vitamin D3 and vitamin E; Reloader 250 Mineral Bolus, Cargill Inc., Minneapolis, MN (Table 4.1); **MIN**, n = 11). Heifers were fed a total mixed ration (TMR) that consisted of corn silage, grass hay, dried distillers grain plus solubles (DDGS), and corn (Table 4.2; 1.44 Mcal/kg NEg) with no added vitamin or mineral supplement.

Heifers received a radio frequency identification (RFID) tag in the right ear before the experiment that allowed access to the Insentec feeding system (Hokofarm Group B.V., the Netherlands). Feed intake and behavior were summarized by day for each individual heifer (Montanholi et al., 2010; Swanson et al., 2014) as follows: events (number of bunk visits and meals daily), eating time (minutes; per visit, per meal, and per day), and feed intake (kg; per visit, per meal, and per minute). A visit was defined as each time the Insentec feeding system detected a heifer at a bunk. A meal was defined as eating periods that might include short breaks separated by intervals not longer than 7 min (Montanholi et al., 2010; Swanson et al., 2014).

Table 4.1. Chemical composition of Reloader 250 slow release bolus with company guaranteed analysis[1]

	%		mg/kg	
Item	min	max	min	max
Minerals[2]				
Ca	2.0	2.5	20,000	25,000
Mg	8.8	-	88,000	-
Na	0.06	0.20	600	2,000
Cu	6.0	-	60,000	-
I	1.58	-	15,800	-
Mn	1.5	-	15,000	-
Se	0.27	-	2,700	-
Zn	26.0	-	260,000	-
Co	0.25	-	2,500	-
	IU per kg			
Vitamins[3]				
Vitamin A	4,410,000	-	-	-
Vitamin D3	926,100	-	-	-
Vitamin E	22,050	-	-	-

[1] Reloader 250 Mineral Bolus, Cargill Inc., Minneapolis, MN. Each heifer received 2 boluses with a recommended payout rate of 250 d. One bolus weighs approximately 93.5 g.

[2] Ingredients: Zinc Oxide, Copper Sulfate, Magnesium Oxide, Sodium Selenite, Manganous Oxide, Calcium Iodate, Zinc Amino Acid Chelate, Cobalt Carbonate, Calcium Carbonate

[3] Ingredients: Vitamin A Acetate, Vitamin E Supplement (proprietary), Vitamin D3 Supplement (proprietary)

Table 4.2. Dietary ingredient and nutrient composition of TMR diet provided to finishing heifers.

Item	% DM basis
Ingredient	
Corn silage	10
Grass hay	5
Corn	60
Dried distillers grains with solubles	20
Premix	5
Nutrient Analysis	
DM	72.59
Ash	4.69
CP	16.05
N	2.57
NDF	24.78
ADF	9.35
Ether extract	3.25
Ca	0.65
P	0.45
Mineral Analysis, mg/kg	
Se	< 10.0
Fe	130
Cu	4.4
Zn	32.7
Mo	0.6
Mn	23.7
Co	< 1.00

Feed Analysis

Diet TMR samples were collected weekly throughout the experiment and composited over the 150 d feeding period. Weekly samples were dried in a 55°C oven and ground to pass a 2-mm screen. The sample was analyzed at the North Dakota State University Nutrition Laboratory for dry matter (DM), crude protein (CP), ash, N (Kjehldahl method), Ca, P and ether extract (EE) by standard procedures (AOAC, 1990). Multiplying N by 6.25 determined crude protein calculation. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined by the modified method of Van Soest et al. (1991) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). The TMR diet was also analyzed for Cu, Zn, Co, Mo, Fe, S, and Se using inductively coupled plasma optical emission spectroscopy by the Veterinary Diagnostic Laboratory at Michigan State University.

Liver Mineral Collections

Liver biopsies were collected from heifers on days 0, 69, and 134 of the feeding period to measure concentrations of trace minerals. Heifers were restrained in a squeeze chute and the hair between the 10th and 12th ribs was clipped with size 40 blades (Oster; Sunbeam Products Inc., Boca Raton, FL). Liver biopsy samples (approximately 20 mg) were collected using the method of Engle and Spears (2000) with the modifications that all heifers were given a subcutaneous 3 mL injection of Lidocaine Injectable-2% (MWI, Boise, ID) at the target biopsy site. An imaginary line is drawn from the tuber coxae (hook) to the elbow. At the intersection with a line drawn horizontally from the greater trochanter, a stab incision was then made between the 10th intercostal space. A core sample of liver was taken via the Tru-Cut biopsy trochar (14 g; Merit Medical, South Jordan, UT).

The liver sample was placed on ashless filter paper (Whatman 541 Hardened Ashless filter paper, GE Healthcare Bio-Sciences, Pittsburg, PA) and then stored in tubes designed for trace mineral analysis (potassium EDTA; Becton Dickinson Co., Franklin Lakes, NJ) and stored at -20°C until further analysis. After obtaining liver biopsies, a staple (Disposable Skin Staple 35 Wide; Amerisource Bergen, Chesterbrook, PA) and topical antibiotic (Aluspray; Neogen Animal Safety, Lexington, KY) was applied to the surgical site and an injectable NSAID (Banamine;

Merck Animal Health, Madison, NJ) was given intravenously at 1.1 mg/kg of body weight. Liver samples were shipped frozen on ice packs to the Veterinary Diagnostic Laboratory at Michigan State University and were evaluated for concentrations of minerals using inductively coupled plasma mass spectrometry.

Carcass Characteristics

Heifers were fed until visually observed to be finished (approximately 12 mm subcutaneous [s.c.] fat thickness at the 12th rib). Final 2 d body weights were recorded prior to heifers being transported approximately 534 km to Dakota City, NE to a commercial abattoir. Carcass characteristics were collected at slaughter and provided by the commercial abattoir. Hot carcass weight (HCW) data were obtained following animal slaughter; whereas, marbling score, back fat, longissimus muscle area and yield grade were taken after carcasses were chilled for 24 h. Dressing percentages were calculated using hot carcass weight and final weights.

Statistical Analysis

Data were analyzed as a completely randomized design using the MIXED procedure of SAS (9.4, SAS Inst. Inc., Cary, N.C.) for effects of treatment on intake, behavior and carcass characteristics. The Kenward-Roger approximation was used to determine the denominator degrees of freedom for the tests of fixed effects. Concentrations of mineral in the liver were also analyzed using the MIXED procedure and Kenward-Roger approximation to determine the denominator degrees of freedom for the tests of fixed effects. The model statement used contained the effects of treatment, time and all interactions. Values from the d 0 liver sample were used as covariates in the respective models. The specified term for the repeated statement was time, and heifer was included as the subject. The covariance structure used was variance components by providing the smallest Akaike information criterion for all variables analyzed.

For all analysis, individual heifer was the experimental unit and results are reported as least square means with significance set at $P \leq 0.05$.

Results and Discussion

Final body weight did not differ between treatments (Table 4.3; *P* = 0.77). We found no differences (*P* = 0.93) in ADG between treatments, with heifers gaining 1.23 kg/d. No differences (*P* = 0.23) were observed in DMI between treatments, with heifers consuming 9.71 kg/d. Feed efficiency (G:F) also was not influenced (*P* = 0.41) by treatment and averaged 0.127 kg/kg. Heifers performed as expected over the course of the experiment. In mineral studies, performance responses have been variable relative to trace mineral or Cu and Zn supplementation on finishing steer performance with no effect on ADG, DMI or G:F (Spears and Kegley, 2002; Ahola et al., 2005) versus nonsupplemented controls; whereas, DMI has been shown to decrease as Zn supplementation has increased (Malcolm-Callis et al., 2000). Additionally, ADG was not affected in finishing beef steers when fed either zinc sulfate, zinc amino acid complex or zinc-organic polysaccharide complex (Malcolm-Callis et al., 2000). Furthermore, Greene et al. (1988) found that steers fed either a control, zinc methionine, or zinc oxide diet reported no differences in gains and had similar daily feed intakes for a 112 d trial.

Control heifers visited the feeders more frequently (*P* = 0.01), compared with heifers receiving the mineral bolus. However, the number of meals per day was not influenced (*P* = 0.96) by treatment. Heifers receiving the mineral bolus ate longer (*P* = 0.01) per visit than control heifers. However, the amount of time heifers spent eating per meal and per day was not different (*P* > 0.49) between treatments. Heifers receiving the mineral bolus ate more per visit (*P* = 0.03), compared with control heifers, but we found no differences (*P* > 0.08) in eating rate per meal and eating rate per minute between treatments. It is not clear why mineral bolus heifers ate more per visit, nor is it clear why mineral bolus heifers ate longer than control heifers. There may be no biological relevance to these differences since heifers were eating the same amount of feed and at the same rate.

Table 4.3. Feed intake and feeding behavior of heifers receiving vitamin and mineral bolus.

	Treatment[1]			
Item	CON	MIN	SEM	*P*-value
Initial BW, kg	372	367	12	0.77
Final BW, kg	557	551	14	0.77
ADG, kg	1.23	1.23	0.05	0.93
DMI, kg	9.93	9.48	0.25	0.23
G:F[2], kg gain/kg feed	0.125	0.129	0.004	0.41
Events, per d				
Visits[3]	39.24	31.43	1.75	0.01
Meals[4]	8.24	8.22	0.29	0.96
Time eating, min				
Per visit	1.64	2.09	0.11	0.01
Per meal	7.91	8.14	0.37	0.66
Per day	61.24	63.93	2.62	0.49
Eating rate, kg				
Per visit	0.26	0.31	0.02	0.03
Per meal	1.25	1.21	0.04	0.51
Per min	0.157	0.142	0.01	0.08

[1] Treatment: CON = heifers did not receive vitamin and mineral bolus, or MIN = heifers received vitamin and mineral bolus.

[2] gain-to-feed ratio.

[3] A visit was defined as each time the Insentec system (Hokofarm Group B.V., the Netherlands detected a heifer at a bunk.

[4] A meal was defined as eating periods that might include short breaks separated by intervals not longer than seven minutes (Montanholi et al., 2010; Swanson et al., 2014).

Liver Mineral Concentrations

There were no interactions for treatment by time ($P > 0.06$; Table 4.4) for liver mineral concentrations. Concentrations of Se, Fe, Cu, Zn, Mn, Mo and Co were similar ($P > 0.06$) between treatments throughout the experiment. However, concentrations of Se, Cu, Mo, Mn and Co decreased over time on feed ($P < 0.05$) and concentrations of Fe increased ($P < 0.001$) over time. By the end of the finishing period, liver concentrations of Cu were considered marginal (33 to 125 µg/g DM; Kincaid, 2000). As defined by Kincaid (2000), the heifers in this study were marginally deficient (7 to 15 µg/g DM) for Mn. Heifer liver Se concentrations fell within adequate ranges (1.25 to 2.50 µg/g DM; Kincaid, 2000). Likewise, liver Co concentrations fell within the satisfactory range of 0.08-0.12 µg/g DM (McNaught, 1948). If Vitamin B12 concentrations in the liver fall below 0.10 µg/g wet weight, this is indicative of Co deficiency (NASEM, 2016). Decreased appetite, growth, feed intake and weight gain, and decreased bone strength have been reported as signs of deficiencies for Co, Cu, Fe, and Mn, respectively (NASEM, 2016).

With an expected life of 250 d, the Reloader bolus would provide approximately 1,040 mg of Zn/d, 240 mg of Cu/d, 10 mg of Co/d, 60 mg of Mn/d, and 10.8 mg of Se/d. However, as reported herein, there were no differences among treatments for liver mineral concentrations. In comparison, the Cosecure bolus had an expected life of 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d (Sprinkle et al., 2006). Cows provided a Cosecure trace mineral bolus had greater concentrations of Cu in the liver and Se in whole blood compared to cows that did not receive a bolus (Sprinkle et al., 2006). However, Sprinkle et al. (2006) reported no differences in concentrations of Zn in the liver or serum of bolus and no bolus cows. These data suggest that the Reloader bolus failed to influence liver mineral concentrations compared to changes that Sprinkle et al. (2006) reported in cows grazing native range using an alternative product.

Recommended allowances for Se, Fe, Cu, Zn, Mn, and Co are 0.10, 50, 10, 30, 20, and 0.15 mg/kg of feed, respectively (NASEM, 2016). However, our analysis of the Se mineral content in our TMR was inconclusive due to Se being below detectable ranges. According to the manufacturer guaranteed analysis, one ounce of Reloader 250 Mineral Bolus contains 104.866 mg of selenium. Moreover, there were no differences in Se liver concentrations among our treatment groups leading to the conclusion that the mineral bolus did not supply any additional Se to the MIN heifers. The current diet exceeds the Fe requirement at 130 mg/kg, which may explain the elevated Fe liver concentrations over the 150 d feeding period. Currently, Mo requirements have not been established (NASEM, 2016). Our analysis of the TMR diet was inconclusive for Co mineral levels because it was below the detectable range. Therefore, we cannot make conclusions about our Co levels in the diet. Overall, the TMR met dietary requirements for Zn and Mn; however, Cu in the diet was below recommended levels.

Carcass Characteristics

No differences (Table 4.5; $P = 0.86$) were observed between treatments for hot carcass weight, which averaged 61%. Modest marbling ranges from 500 to 600 (Emerson et al., 2013); moreover, heifers in the current report fall within the modest range at 584 and 523 for CON and MIN heifers, respectively. We found no differences ($P > 0.38$) in backfat, longissimus area and yield grade between treatments. Reports of zinc supplementation on finishing phase carcass characteristics have found zinc to increase quality grade and marbling in steers, compared with nonsupplemented steers (Spears and Kegley, 2002). Although there were no improvements to performance, supplementation of inorganic zinc still altered quality grades in steers (Spears and Kegley, 2002). Whereas, Malcolm-Callis et al. (2000) reported that HCW, dressing percentage, longissimus muscle area, marbling score and yield grade were not affected by zinc source. Greene et al. (1988) compared carcass characteristics of control steers fed a diet containing 82 mg Zn/kg DM to steers supplemented an additional 360 mg Zn/d either from ZnO or Zn methionine. Steers fed Zn methionine had increased fat thickness, marbling score, percentage of kidney, pelvic and heart fat, and quality grade compared to ZnO and control steers (Greene et al., 1988). Carcass characteristics to Zn supplementation for finishing steers has been variable; however, heifers reported herein have similar dressing percentages, backfat thickness, and longissimus muscle area to steers from Malcolm-Callis et al. (2000) and Spears and Kegley (2002).

Conclusions

Overall, the inclusion of a slow-release vitamin and mineral bolus evaluated failed to influence heifer performance. Control heifers attended the feeders more frequently. However, the number of meals heifers ate was not affected by treatment. In this experiment, the slow-release vitamin and mineral bolus evaluated failed to influence liver mineral concentrations during the finishing period or influence carcass characteristics. Overall, our results indicate that finishing beef heifers using feeds sourced from the Northern Great Plains meet dietary requirements for Fe, Zn, and Mn with Cu falling below requirements in the diet provided. Therefore, for the duration of the feeding period, heifers reported herein were still within marginal range for liver mineral concentrations. However, if heifers were fed for a longer duration, evaluation of mineral concentrations may need to be assessed to ensure heifers don’t fall below deficient levels with no inclusion of vitamins or minerals in the diet.

Table 4.4. Liver mineral concentrations from heifers receiving vitamin and mineral bolus.

	Treatment[1]									
	Time[2] 1		Time 2		Time 3				*P*-value	
Item, µg/g	CON	MIN	CON	MIN	CON	MIN	SEM	TRT	Time	TRT*Time
Se	1.89	1.87	1.64	1.71	1.53	1.55	0.08	0.75	0.0007	0.86
Fe	125	122	137	146	163	174	9	0.43	<0.0001	0.68
Cu	131	136	93	107	77	81	13	0.46	0.0002	0.91
Zn	104	107	102	111	101	104	6	0.27	0.73	0.86
Mo	3.95	3.86	3.40	3.53	3.54	3.47	0.14	0.93	0.005	0.70
Mn	8.92	9.26	7.95	8.43	8.18	8.54	0.37	0.21	0.05	0.98
Co	0.13	0.13	0.10	0.12	0.12	0.13	0.01	0.06	0.02	0.06

[1] Treatment: CON = heifers did not receive vitamin and mineral bolus, or MIN = heifers received vitamin and mineral bolus.

[2] Time: Time 1 = first biopsy on day zero; Time 2 = second biopsy on day 69; Time 3 = final biopsy on day 134.

Table 4.5. Carcass characteristics from heifers receiving vitamin and mineral bolus.

	Treatment[1]			
Item	CON	MIN	SEM	*P*-value
HCW[2], kg	342	340	9	0.86
Dressing percentage	0.61	0.61	0.004	0.94
Marbling score[3]	584	523	33	0.19
Backfat, cm	1.48	1.31	0.13	0.38
Longissimus area, cm^2	87.2	86.1	2.8	0.79
Calculated yield grade	2.85	2.83	0.20	0.95

[1] Treatment: CON = heifers did not receive vitamin and mineral bolus, or MIN = heifers received vitamin and mineral bolus.

[2] HCW = hot carcass weight.

[3] Marbling score: small = 400-499, modest = 500-599 and moderate = 600-699 (Emerson et al., 2013).

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CHAPTER 5: PRECISION MANAGEMENT TECHNOLOGIES FOR BEEF CATTLE: INFLUENCE OF STRATEGIC SUPPLEMENTATION ON INTAKE, BLOOD METABOLITES, LIVER MINERAL CONCENTRATIONS AND REPRODUCTIVE BEHAVIOR IN BEEF HEIFERS GRAZING NATIVE RANGE IN THE NORTHERN GREAT PLAINS

Abstract

Crossbred Angus yearling heifers (n = 60; initial BW = 400.4 ± 6.2 kg) at the Central Grasslands Research Extension Center (Streeter, ND) were used to evaluate an electronic feeder and activity monitoring tags to measure mineral and energy supplement intake, liver mineral concentrations, metabolites and activity data while grazing native range. Heifers were fitted with radio frequency identification (RFID) ear tags that allowed access to an electronic feeder (SmartFeed system; C-Lock Inc., Rapid City, SD) and activity monitoring tags (CowManager B.V., The Netherlands) that monitored cow reproductive, feeding-related, and health-associated data. Heifers were assigned randomly to one of three dietary treatments; 1) no access to feed supplements (**CON**; n = 20); 2) free choice access to mineral supplement (**MIN**; Purina Wind and Rain Storm [Land O'Lakes, Inc.], n = 20); or 3) free choice access to an energy and mineral supplement (**NRG**; Purina Accuration Range Supplement [Land O'Lakes, Inc.], n = 20). The MIN and NRG supplements were delivered via SmartFeed units and intakes were determined over a 57 d monitoring period. Consecutive day weights, along with blood and liver biopsy samples were collected at pasture turnout and final day of monitoring. By design, intake of mineral was greatest in MIN heifers (49.3 ± 37 g/d) and intake of energy supplement was greatest in NRG heifers (1,257.1 ± 37 g/d) but heifer final BW and ADG were similar among treatments (*P* > 0.42). There were no differences (*P* = 0.85) among treatments in concentrations

of NEFA; however, NRG heifers had greater (*P* = 0.01) concentrations of glucose compared with CON and MIN heifers on d 57 of monitoring period. Final liver concentrations of Se, Cu, and Co in NRG heifers were greater (*P* < 0.05) than CON and MIN heifers; whereas Fe tended (*P* = 0.10) to be greater in NRG heifers and there were no differences (*P* > 0.13) among treatments for Zn, Mo, and Mn. Activity from the CowManager tag indicate that time spent eating, ruminating, not active, or active were not impacted by treatment (*P* > 0.32). However, time spent being "highly active" was greater (*P* = 0.007) in NRG heifers compared to CON and MIN heifers. In addition, data retrieved from the ear tag identified 16 of 28 heifers exhibiting some type of estrus behavior that were already confirmed pregnant. Overall, the electronic feeders were able to control intake of individual animals assigned to different treatments in a group pasture scenario.

Introduction

Technology continues to improve at an amazing rate and some sectors of agriculture are rapidly implementing new innovations into diverse applications. However, the beef industry is slower than some other agricultural industries in rate of adoption. Several reasons likely exist for this adoption lag, foremost of which are the lack of comprehensive technological solutions that can be implemented in expansive pasture settings, and the lack of solutions from which management decisions can be made over the life of an animal. Individual animals within a herd of cattle are unique, are in varying stages of production, have specific nutritional needs, and present differing health statuses. Within the herd, individual animal variation exists and changes throughout the production year, presenting real and relevant management decision issues for progressive producers.

To maintain targeted production goals for growth and reproductive performance (Schillo et al., 1992; Ciccioli et al., 2005; Cappellozza et al., 2014) and to offset forage nutritive decline throughout the grazing season (Schauer et al., 2004; Cline et al., 2009) producers often provide mineral and/or protein and energy supplements to grazing cattle. An issue observed with providing supplements on pasture is the large variability in consumption by individuals within a group (Tait and Fisher, 1996; Bowman and Sowell, 1997; Cockwill et al., 2000; Patterson et al., 2013), which is largely unseen and unknown by cattle management personnel. In addition, frequent observation of activity and reproductive behavior of grazing cattle is often difficult due to the expansive area occupied by pastures. However, electronic systems are available to monitor feeding, physical activity, and reproductive-related behavior.

Activities reported herein are aimed at developing a system (the Mobile Cow Command Center) that pairs multiple technologies into a single portable unit that would allow for precision management of individuals within a herd on expansive pastures to optimize production efficiency, improve animal health, and enhance profitability. Our objectives were to develop a Mobile Cow Command Center (MCCC) for monitoring heifers on native range specifically to, 1) examine the relationship between mineral and energy supplementation on intake, liver mineral concentrations, and metabolites, and 2) examine activity and reproductive behavior.

Materials and Methods

All animal procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University (A18069).

Study Area

Research was conducted at the Central Grasslands Research Extension Center (CGREC), located in Streeter, ND from July 25, 2018 to September 19, 2018. This area is characterized by a continental climate with warm summers and cold winters with a majority (72%) of precipitation occurring between May and September (Limb et al., 2018). August is the warmest month with a mean temperature of 18.6°C (NDAWN, 2017).

The pasture was 70 ha with a stocking rate of 1.99 Animal Unit Months (AUMs)/ha. The vegetation is classified as mixed-grass prairie dominated by western wheatgrass (*Pascopyrum smithii* [Rydb.] À. Löve), green needlegrass (*Nassella viridula* [Trin.] Barkworth) and blue grama (*Bouteloua graciles* [Willd. ex Kunth] Lag. ex Griffiths). Other important species include sedges (*Carex* spp.), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.), sages (*Artemisia* spp.), goldenrods (*Solidago* spp.), kentucky bluegrass (*Poa pratensis* L.) a non-native grass and western snowberry (*Symphoricarpos occidentalis* Hook.) a native shrub (Limb et al., 2018).

Mobile Cow Command Center Units

Each of two Mobile Cow Command Center (MCCC) units were developed by pairing two commercially available technologies into single trailer units that can be transported and function anywhere that cattle are managed. The first technology is the SmartFeed device (C-lock Inc., Rapid City, SD), which is a self-contained system designed to measure supplement intake and feeding behavior from individual cattle in group settings. The system is solar powered and includes a radio-frequency identification (RFID) reader, weigh scales, access control gate, a feed bin, and a cloud-based interface which continuously logs feed intake and feeding behavior data. The second technology included in the MCCC was the CowManager system (CowManager B.V., The Netherlands), which uses RFID tags and additional sensors to monitor cow reproductive (estrus alerts), feeding-related (eating, rumination, and activity level), and health-associated data. The CowManager ear tag continuously registers movements from the cow's ear and classifies the data through proprietary algorithms (Pereira et al., 2015). Data is sent through a wireless connection, via a router placed on the top of the SmartFeed trailer unit. That data is then received through the coordinator unit that is attached to a computer in a lab (approximately 200 m from the MCCC units) that automatically uploaded the data for viewing on any device with an internet connection. Each MCCC contains 2 SmartFeed units, controlling hardware and the CowManager router in an enclosed trailer with open feed access areas and retractable wheels for easy transport.

Training Period

The MCCC units were each placed into a separate dry lot heifer development pen (n = 63 per pen) at the CGREC for a two week period. Corn silage was placed into the feed bins and heifer intake was monitored. Only heifers with a history of feed consumption from the feeders were selected for further use in this experiment.

Heifer Selection

All heifers were estrus synchronized using a controlled internal drug release (CIDR; Zoetis) protocol (7 d CO-Synch plus CIDR), with heifers receiving 2 cc intramuscularly GnRH (Factrel; Zoetis, Parsippany, NJ) and CIDR insert on d 0. Seven days later, the CIDR insert was removed and a single injection of $PGF_{2\alpha}$ (5 cc intramuscularly; Lutalyse; Zoetis, Parsippany, NJ) were administered followed by GnRH and artificial insemination approximately 60 h later. All heifers received an estrus detection patch (Estrotect; Rockway Inc., Spring Valley, WI) to determine heat state. On the day of artificial insemination (AI), final heifer selection for the experiment was made based on 1) history of feed consumption from SmartFeed feeders; and 2) activated estrus detection patches All selected heifers (n = 60) were AI bred using sexed semen (Tehama Tahoe B767) for female offspring.

Grazing Period

Sixty crossbred yearling Angus heifers (initial BW = 400 ± 6 kg) were managed as a single pasture group with free access to graze native range and were randomly assigned to 1 of 3 dietary treatments; 1) no access to feed supplements (**CON;** n = 20); 2) free choice access to mineral supplement (**MIN**; Purina Wind and Rain Storm [Land O'Lakes, Inc.], n = 20); or 3) free choice access to energy supplement (**NRG**; Purina Accuration Range Supplement [Land O'Lakes, Inc.], n = 20). The NRG supplement was formulated with inclusion of ground corn and 3% of the MIN treatment were added to the commercial Accuration preparation (25.5 % CP; Table 5.1). The MIN and NRG supplements were delivered via the SmartFeed units and trailers were located next to the water source in the pasture. Because few heifers consumed either supplement early in the grazing season (Figure 5.1), feed intake data were summarized over a 57 d period; from the time of pregnancy diagnosis (July 25, 2018) until removal from pasture (September 19, 2018). Heifers assigned to MIN and NRG treatments that did not consume the respective supplements were added to CON treatment for analysis, resulting in a final n of CON (n = 29), MIN (n = 18) and NRG (n = 13).

Table 5.1. Dietary ingredient and nutrient composition of mineral and energy supplement fed to grazing beef heifers

	% DM basis	
Nutrient Analysis	NRG[1]	MIN[2]
DM	94.95	--
Ash	12.69	--
CP	25.49	--
N	4.08	--
NDF	15.77	--
ADF	5.78	--
Ether extract	6.17	--
Mineral Analysis, mg/kg		
Ca	18,499	176,939
P	10,047	76,274
S	7,150	8,165
Se	<100.0	<100.0
Fe	462	6,628
Cu	1,079	796.3
Zn	429.9	2,590.5
Mo	8.6	15.7
Mn	202.6	2,860.4
Co	67.14	10.35

[1] NRG = Purina Accuration Range Supplement (Land O'Lakes, Inc., Arden Hills, MN). Ingredients formulation: 60% Accuration, 40% ground corn, 3% Purina Wind and Rain Storm (Land O'Lakes, Inc., Arden Hills, MN).

[2] MIN = Purina Wind and Rain Storm (Land O'Lakes, Inc., Arden Hills, MN). Ingredients: Dicalcium Phosphate, Monocalcium Phosphate, Calcium Carbonate, Salt, Processed Grain By-Products, Vegetable Fat, Plant Protein Products, Potassium Chloride, Magnesium Oxide, Vitamin E Supplement, Vitamin A Supplement, Natural and Artificial Flavors, Calcium Lignin Sulfonate, Ethoxyquin (a Preservative), Manganese Sulfate, Vitamin D3 Supplement, Zinc Sulfate, Basic Copper Chloride, Ethylenediamine Dihydroiodide, Cobalt Carbonate.

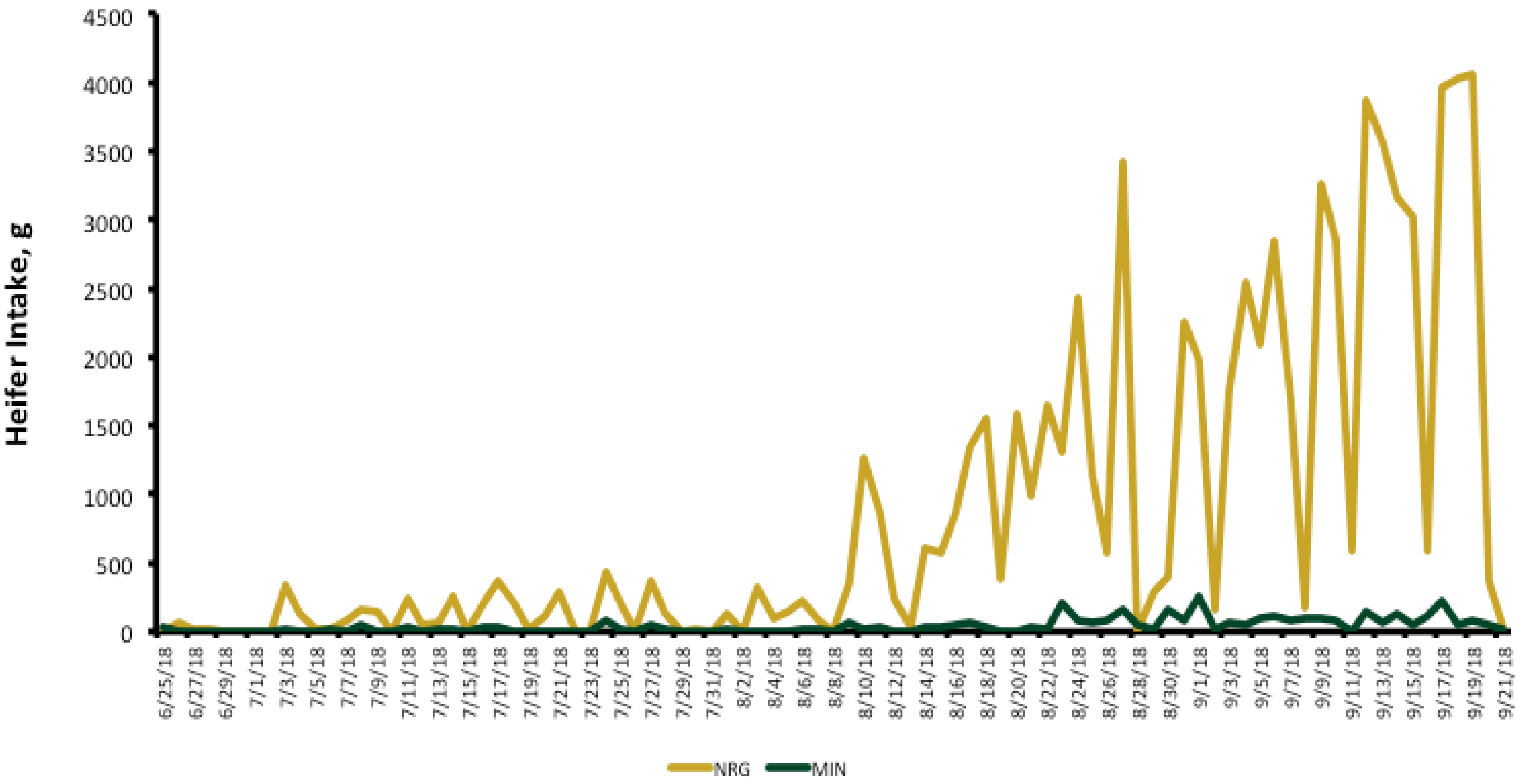

Figure 5.1. Effects of mineral or energy with mineral supplements on individual intakes in heifers grazing native range.

Estrus-related alerts were generated via the CowManager system, including in heat, potential, or suspicious. Pregnancy detection was performed 34 d after AI via rectal ultrasonography (7.0-MHz transducer, 500 V Aloka, Wallingford, CT). Continuous monitoring with the CowManager tag provided data related to heifer estrus activity. A retrospective analysis was conducted to determine the accuracy of estrus-related alerts generated via the CowManager system versus a known pregnancy status determined via ultrasound. Similarly, a retrospective analysis was conducted to evaluate the accuracy of health events that were flagged via the CowManager system (reported as sick, very sick, or no movement) by comparing electronic alerts with treatment logs generated by the animal care staff at the CGREC. The CowManager system also reported the minutes spent during each hour of every day in activity categories including eating, ruminating, not active, active, and highly active.

Forage Collection and Analysis

Forage samples were obtained every two weeks from twenty different locations in the pasture in a diagonal line across the pasture. The forage samples were hand clipped to a height of 3.75 cm above ground. Forage samples were dried in a forced-air oven at 60°C for at least 48 h and then ground to pass through a 2-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Clipped forage samples for each location reported herein are composite over all locations within the representative sampling date. Forage samples were analyzed at the North Dakota State University Nutrition Laboratory for dry matter (DM), crude protein (CP), ash, N (Kjehldahl method), Ca, P and ether extract (EE) by standard procedures (AOAC, 1990). Multiplying N by 6.25 determined crude protein calculation. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined by the modified method of Van Soest et al. (1991) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). Samples were also analyzed for Cu, Zn, Co, Mo, Fe, S, and Se using inductively coupled plasma optical emission spectroscopy by the Veterinary Diagnostic Laboratory at Michigan State University.

Blood Collection and Serum Analysis

Blood metabolites were analyzed from a subset of heifers from each respective treatment (n = 24; 8 per treatment) with the addition of 6 heifers that were consuming supplements but had not been randomly selected for liver biopsy. Blood samples were collected via jugular venipuncture into serum tubes (10 mL; Becton Dickinson Co., Franklin Lakes, NJ), allowed to clot for 30 min and centrifuged at 1,500 × g at 4°C for 20 min. Serum was separated and stored in plastic vials at −20°C until further analysis. Serum samples were analyzed for glucose and NEFA. Samples were analyzed using the Synergy H1 Microplate Reader (Biotek, Winooski, VT) with the Infinity Glucose Hexokinase Kit (Thermo Scientific, Waltham, MA) and NEFA-C Kit (WAKO Chemicals, Inc., Richmond, VA). The intra- and interassay CV was 2.62 and 3.41%, for serum glucose, respectively and 7.75 and 8.29%, for serum NEFA, respectively.

Liver Sample Collection and Analysis

Liver samples were collected at pasture turnout and at the final day of monitoring via biopsy from a subset of heifers from each respective treatment (n = 24; 8 per treatment). Heifers were restrained in a squeeze chute and the hair between the 10th and 12th ribs was clipped with size 40 blades (Oster; Sunbeam Products Inc., Boca Raton, FL). Liver biopsy samples (approximately 20 mg) were collected using the method of Engle and Spears (2000) with the modifications that all heifers were given an intradermal 3 mL injection of Lidocaine Injectable-2% (MWI, Boise, ID) at the target biopsy site. An imaginary line is drawn from the tuber coxae (hook) to the elbow. At the intersection with a line drawn horizontally from the greater trochanter, a stab incision was then made between the 10th intercostal space. A core sample of liver was taken via the Tru-Cut biopsy trochar (14 g; Merit Medical, South Jordan, UT).

The liver sample was placed on ashless filter paper (Whatman 541 Hardened Ashless filter paper, GE Healthcare Bio-Sciences, Pittsburg, PA) and then stored in tubes designed for trace mineral analysis (potassium EDTA; Becton Dickinson Co., Franklin Lakes, NJ) and stored at -20°C until further analysis. After obtaining liver biopsies, a staple (Disposable Skin Staple 35 Wide; Amerisource Bergen, Chesterbrook, PA) and topical antibiotic (Aluspray; Neogen Animal Safety, Lexington, KY) was applied to the surgical site and an injectable NSAID (Banamine; Merck Animal Health, Madison, NJ) was given intravenously at 1.1 mg/kg of body weight. Liver samples were sent to the Veterinary Diagnostic Laboratory at Michigan State University and were evaluated for concentrations of minerals using inductively coupled plasma mass spectrometry.

Statistical Analysis

Data were analyzed as a completely randomized design with heifer used as the experimental unit for all analysis. Performance, intake and behavior data were analyzed using the GLM procedure of SAS (9.4, SAS Inst. Inc., Cary, NC) with treatment as the fixed effect. Liver mineral concentration data were analyzed using the GLM procedure and the model statement used contained the effects of treatment and baseline liver sample (used as a covariate). Blood metabolites were also analyzed using the GLM procedure and the model statement used contained the effects of treatment and baseline serum metabolite concentrations at pasture turnout. Results are reported as least square means using the LSMEANS statement for liver and plasma and separated using PDIFF. For all analysis, significance was set at $P \leq 0.05$, and tendencies were determined if $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Heifer Intakes, Feeding Behavior, and Performance

Intake of energy and mineral supplements was very low during the early portion of the grazing season but began to increase in mid-August as the quality of native range declined. Heifers attended the NRG feeders 38.7 ± 1.2 d of the 57 d (68% attendance), whereas, the MIN heifers attended 23.1 ± 1.2 d of the 57 d (41% attendance). On days that heifers attended the feeders, NRG heifers consumed 1,877 ± 76 g/d; whereas, MIN heifers consumed 122 ± 76 g/d of mineral supplement. Energy supplement heifers spent 4.1 ± 0.6 min/d at the feeders on days they were present at the feeder, whereas mineral heifers spent 2.1 ± 0.6 min/d ($P = 0.01$).

From July 25, 2018 until September 19, 2018 heifers in the MIN treatment consumed 49.3 ± 37 g/d of mineral supplement. Heifers in the NRG treatment consumed 1,257.1 ± 37 g/d of energy supplement. Control heifers consumed 9.1 ± 37 g/d of available NRG or MIN supplement. Mean values for NRG supplement intake by heifers in the CON treatment were driven by 3 heifers that consumed NRG supplement. Whereas, mean values for MIN supplement intake by heifers in the CON treatment were driven by 26 heifers that consumed 2.8 g/d of MIN supplement during 7.7 of the 57 d (13% attendance) during the monitoring period. Over the monitoring period, NRG heifers spent 2.9 ± 0.3 min/d at the mineral feeder compared to 0.7 ± 0.3 min/d that mineral heifers spent at feeders. Overall, the SmartFeed system was able to keep heifers assigned to control treatment out of the feeders over the course of the monitoring period. Cows that were being monitored with the same electronic feeders the previous summer consumed more mineral supplement on average (125.4 g/d) than heifers herein (McCarthy et al., 2018).

In comparison, Smith et al. (2016) built a custom mineral feeder with an RFID reader and reported that steers that had access to a commercially available free-choice mineral consumed 72 g/d per head over a 90 d grazing period. The mineral disappearance in Smith et al. (2016) was within range of manufacturer recommended intakes of 40 to 125 g/head per day. Moreover, researchers in Oklahoma (Reuter et al., 2017) conducted a pilot study using the SmartFeed system to characterize the daily variation in soybean meal supplement with the inclusion of salt on intake by group-housed, self-fed grazing steers. Fifteen steers from Reuter et al. (2017) consumed 1,210 g/d of supplement with a 45% salt inclusion for a 14 d period. Although steers consumed a similar amount of supplement compared to heifers reported herein, variation among animals was also reported with animals visiting 5.1 ± 1.3 times/d over the 14 d period (Reuter et al., 2017). The variation among animals from Reuter et al. (2017) suggests that competition for use of one SmartFeed unit may have been a challenge because intervals between different RFID readings (animals exchanging places at the feeder) was less than 1 s per animal. The heifers in the current study may have been exhibiting similar challenges with competition at the feeder even though they had an additional SmartFeed unit to visit.

The manufacturer label for the mineral supplement provided recommended optimum intakes of 113 g/head daily; whereas, the energy supplement intake is recommended at a range of 1,817.4 to 3,175.2 g/head daily. Over the 57 d monitoring period, heifers in their respective treatment groups did not consume recommended intakes. However, on days that heifers attended the feeders, heifers met the recommended feeding rates. Variation in individual consumption has been known to vary depending on feeder number and placement, individual animal preference, weather, individual and herd behavior, characteristics of the feedstuff, and feed additives that may be included (Tait and Fisher, 1996; Bowman and Sowell, 1997; Smith et al., 2016).

Overall, heifer final BW was similar among treatments (433 ± 6 kg; *P* = 0.42). Interestingly, treatment did not influence weight gain (*P* = 0.76) during the monitoring period, with heifer ADG equal to 0.46 kg/d. Previous experiments have reported that neither trace mineral supplementation nor source (organic and inorganic) affected cow BW or BCS (Olson et al., 1999; Muehlenbein et al., 2001; Ahola et al., 2004).

Forage Analysis

Forage nutrient content appeared to decrease over the course of the grazing period (Table 5.2) observed by percentage of CP decreasing and greater NDF values over the season. A decrease in the forage nutritive value is typical in diets of grazing cattle during the advancing season (Bedell, 1971; Johnson et al., 1998; Cline et al., 2009). The nutrient availability of grazed forages fluctuates by environmental conditions, forage species, soil type, and stage of maturity (NASEM, 2016).

Recommended allowances for Se, Fe, Cu, Zn, and Mn are 0.10, 50, 10, 30, and 40 mg/kg of diet, respectively (NASEM, 2016). Selenium in forage can range widely within and between different types of feedstuffs (Suttle, 2010). Iron in pastures has been shown to have seasonal fluctuations with peaks in spring and autumn (Suttle, 2010), where our current forage Fe concentrations are greater over the course of the grazing season. According to Corah and Dargatz (1996), forage Fe is within adequate levels at 50 to 200 mg/kg. Whereas, most forage contains 70 to 500 mg Fe/kg (NASEM, 2016), which the current pasture meets requirements. Concentrations of Cu in forage were marginal to deficient (4 to 7 vs. < 4 mg/kg, respectively; Corah and Dargatz, 1996). Forages vary in Cu content, with legumes usually having higher content than grasses (NASEM, 2016). Moreover, concentrations of Zn were deficient (< 20 mg/kg) until mid-August to early September. Whereas, according to Corah and Dargatz (1996) Mo, Co, and Mn were adequate (< 1, 0.1 to 0.25, and > 40 mg/kg, respectively). As stated by Suttle (2010), Mn values for pastures vary, with a mean value of 86 mg/kg. In addition, Mn requirements for breeding cattle are higher than growing and finishing cattle due to reproduction demands (NASEM, 2016).

Table 5.2. Forage analysis of pasture grazed by beef heifers provided either mineral or energy with mineral supplement from June to September 2018[1].

	Grazing Period[2]			
Item	June	July	August	September
TDN[3]	60.5	62.0	60.6	58.6
CP, %	9.02	7.1	6.8	5.9
Ash	10.04	9.4	10.3	10.5
NDF, %	62.87	59.1	61.1	64.5
ADF, %	35.9	34.1	35.9	38.4
Ca, %	0.21	0.33	0.41	0.42
P, %	0.40	0.14	0.12	0.10
S, mg/kg	1,416	1,498	1,616	1,503
Se, mg/kg	<10.0	<10.0	<10.0	<10.0
Fe, mg/kg	<50	101	130	166
Cu, mg/kg	4.6	4.1	4.5	3.8
Zn, mg/kg	14.8	17.7	20.0	23.7
Mo, mg/kg	1.4	1.4	1.7	1.3
Mn, mg/kg	59	60.7	84.0	100.4
Co, mg/kg	<1.00	<1.00	<1.00	<1.00

[1] Clipped forage samples from 20 different locations reported herein are composite over all locations within the representative sampling dates.

[2] Values presented are mean values of the representative sampling dates within the given month: June (n = 1), July (n = 3), August (n = 2) and September (n = 3).

[3] TDN = 88.9 – (0.79 × ADF%); Lardy, 2018

Blood Metabolites

There were no differences among treatments in concentrations of NEFA in serum at the conclusion of the experiment ($P = 0.85$; Table 5.3). Circulating NEFA concentrations reflect fat mobilized from body reserves. As animals experience compensatory gain, concentrations of

NEFA have been reported to rapidly decline (Ellenberger et al., 1989). McFarlane et al. (2017) provided protein supplement to growing heifers grazing winter forage and reported no differences in circulating serum NEFA concentrations, which was not expected due to the fact that the authors observed BW changes in heifers. Nevertheless, it is important to note that heifers from all treatments were in a positive nutritional status based on similar ADG and, therefore, no mobilization of body reserves was necessary in any treatments.

Table 5.3. Effects of mineral or energy with mineral supplements on serum metabolite concentrations in heifers grazing native range.

	Treatment[1]				*P*-value
Item	CON	MIN	NRG	SEM	TRT
NEFA, µmol/L	327.1	326.2	291.7	47	0.85
Glucose, mg/dL	66.7^{b}	66.5^{b}	75.9^{a}	2.1	0.01

^{ab}Means within row lacking common superscripts differ ($P < 0.05$)

[1] Treatments include: CON (n = 12), no access to feed supplements; MIN (n = 10), free choice access to mineral supplement; NRG (n = 8), free choice access to energy supplement

Concentrations of glucose in serum were greater ($P = 0.01$) in NRG heifers compared with CON and MIN heifers at the end of the monitoring period. Studies with heifers grazing low-quality forage and provided 1.40 kg of DM/heifer of an energy supplement have reported plasma glucose levels at 65 mg/dL (Cappellozza et al., 2014). Whereas, plasma glucose concentrations of beef heifers offered low-starch energy supplements daily or 3 times weekly were 76.3 and 70.5 mg/dL, respectively (Moriel et al., 2012). Glucose concentrations of NRG heifers were 14% greater than CON and MIN heifers. Since starch is a major dietary precursor for glucose in ruminants (Huntington, 1997) the observation of elevated concentrations of glucose in NRG heifers was not surprising.

Liver Mineral Concentrations

At the end of the monitoring period, concentration of Se in livers of NRG heifers were greater (*P* = 0.01; Table 5.4) than CON, whereas MIN were intermediate. Concentrations of Fe in livers of NRG heifers tended (*P* = 0.10) to be greater than other treatments. Furthermore, concentrations of Cu in livers of NRG heifers were greater (*P* = 0.007) than CON heifers, whereas MIN were similar. There were no differences (*P* > 0.13) in concentrations of Zn, Mo, and Mn in livers among treatments. Concentrations of Co in livers of NRG heifers were greater (*P* < 0.001) than CON and MIN heifers at the end of the monitoring period.

Table 5.4. Effects of mineral or energy with mineral supplements on liver mineral concentrations in heifers grazing native range.

	Treatment[1]				*P*-value
Item, µg/g	CON	MIN	NRG	SEM	TRT
Se	1.40^{b}	1.61^{ab}	1.85^{a}	0.09	0.01
Fe	198^{e}	213^{e}	286^{d}	23	0.10
Cu	75^{b}	106^{ab}	110^{a}	14	0.007
Zn	100	103	113	7	0.25
Mo	3.65	3.93	3.69	0.22	0.13
Mn	9.25	8.99	10.66	0.67	0.35
Co	0.13^{c}	0.32^{b}	0.41^{a}	0.02	<0.001

^{ab}Means within row lacking common superscripts differ (*P* < 0.05)

^{de}Means within row lacking common superscripts tend to differ (*P* ≤ 0.10)

[1] Treatments include: CON (n = 12), no access to feed supplements; MIN (n = 7), free choice access to mineral supplement; NRG (n = 5), free choice access to energy and mineral supplement

According to guidelines published by Kincaid (2000), liver concentrations of Fe, Zn, Se, Mo, and Mn in all treatment groups were considered adequate at the end of the grazing period. In contrast, Cu values in CON heifers would be considered marginal (33 to 125 µg/g DM; Kincaid, 2000) whereas MIN and NRG are considered adequate. Additionally, concentrations of Co in livers of all treatment groups were above satisfactory levels (0.08 to 0.12 µg/g DM;

McNaught, 1948). Overall, heifers in their respective treatment groups had marginal to adequate liver mineral concentrations.

CowManager Activity

Data from the CowManager tags indicated no differences among treatments ($P \geq 0.32$) in activity categories including eating, ruminating, not active, or active (Table 5.5). However, heifers in the NRG treatment spent 20 more ($P = 0.007$) minutes daily being highly active compared with heifers in the other treatments. The observed additional time NRG heifers spent being highly active was likely related to competitive behaviors immediately around the time of NRG consumption, where 13 heifers were competing for two feeding spaces. Validations using the CowManager system with dairy cattle in freestall (Bikker et al., 2014) and grazing scenarios (Pereira et al., 2018) have been performed with the rumination and activity measures; however, little data is available with beef cattle in feedlots (Wolfger et al., 2015) and to our knowledge, nothing regarding grazing beef cattle. Additionally, 34 out of 60 heifers generated 146 health alerts, but only 3 heifers needed clinical treatment. An additional nine heifers required treatment for which no health alert was generated by the CowManager system.

The retrospective evaluation of estrus alerts generated via the CowManager system revealed that 16 of 28 heifers (57%) confirmed pregnant via ultrasound were incorrectly identified as displaying some type of estrus behavior (two reported as in heat, 11 reported as potential, and three reported as suspicious). If producers were using this technology for estrus detection in a pasture setting, additional confirmation of estrus behavior would be important to consider for use in AI breeding. Additional resources such as estrus detection patches to determine heat state or visual observations may be beneficial to have as alternative means to ensure that the CowManager alerts are reporting correctly. Multiple estrus detection technologies

[Cowmanager SensOor (Agis Automatisering, Harmelen, the Netherlands), HR Tag (SCR Engineers Ltd., Netanya, Israel), Ice-Qube (IceRobotics Ltd., Edinburgh, UK), DVM bolus (DVM Systems, LLC, Greeley, CO) and The Track a Cow (Animart Inc., Beaver Dam, WI)] have been validated on dairy cattle (Dolecheck et al., 2015), which all activity measures increased during estrus compared to animals not in estrus. However, these validations have analyzed correlations among different technologies on the same animal or comparing human observations of estrus or activity measures. Nevertheless, the current study did not evaluate additional technologies to compare estrus activity or have visual observations as the other studies.

Table 5.5. Activity of heifers monitored using CowManager ear tags while grazing native range and access to mineral or energy with mineral supplements.

	Treatment[1]				
Parameter[2], min/d	CON	MIN	NRG	SEM	*P*-Value
Eating	522	570	495	33	0.32
Ruminating	343	344	392	24	0.35
Not Active	193	180	198	17	0.77
Active	233	200	187	30	0.49
Highly active	147^a	141^a	165^b	5	0.007

[ab]Means within row lacking common superscripts differ ($P < 0.05$)

[1]Treatments include: CON (n = 29), no access to feed supplements; MIN (n = 18), free choice access to mineral supplement; NRG (n = 13), free choice access to energy supplement

[2]Parameters from the CowManager system (CowManager B.V, The Netherlands) are collected continuously and each minute is classified into behavioral categories (i.e. “eating”, “ruminating”, “not active”, “active”, and “highly active”) using a proprietary model

Conclusions

The MCCC units were deployed successfully and serve as portable units that use solar power to run individual components and upload data to cloud-based data acquisition platforms. SmartFeed units were able to control intake of individual animals assigned to different treatments in a group pasture scenario. Our results clearly show that the feed controlling portion of the MCCC can be used for precision feeding of individuals in extensive group managed scenarios. The potential exists to develop targeted management strategies for cattle with distinct nutrient needs (i.e. high and low body condition scores or mixed groups of cows and heifers) while being managed in common pastures. Though heifers reported herein had similar BW and ADG among treatment groups, treatments that provided supplemental mineral enhanced liver concentrations of Se, Fe, Cu, and Co Furthermore, the CowManager system was able to detect divergence in highly active behavior among treatment groups, but also reported many false health and estrus-related alerts.

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CHAPTER 6: SUMMARY AND CONCLUSIONS

Typically, when supplementing mineral, intakes are on a group basis, with the assumption that animals are consuming targeted amounts. Generally, understanding if individual animals are consuming mineral or supplement at recommended feeding rates is typically unknown. However, we know that meeting mineral requirements in beef cattle is critical for optimal production and health of cows and their offspring. Therefore, we utilized available technologies to gain an understanding of individual cattle intake and feeding behavior when provided mineral and/or energy supplements in extensive grazing scenarios. Our data results show that variability in mineral intake exists among cows and calves grazing native range. Individual intake can be monitored and provides opportunities to do further research with targeting cow and calf supplementation strategies and potential impacts on performance, health, and cow reproduction. The data we acquired using the SmartFeed system clearly shows that the feed controlling portion can be used for precision feeding of individuals. The potential exists to develop targeted management strategies for cattle with distinct nutrient needs (i.e. high and low body condition scores or mixed groups of cows and heifers) while being managed in common pastures.

Furthermore, wide variation exists among beef producers when it comes to providing supplemental mineral to their herds. Inadequate trace mineral consumption can compromise reproduction, animal health and animal growth (NRC, 2005; NASEM, 2016). Additionally, dietary requirements for trace minerals are essential for both the immediate and long-term well-being of the embryo, fetus and neonate (Ashworth and Antipatis, 2001). Understanding how individual intake varies and meeting individual animal requirements may be important to ensure performance and reproduction demands are being met. Our results showed that cows grazing native range had decreased ADG over the course of the monitoring period. However, our heifers that were provided energy and mineral supplements had similar ADG over the grazing period. Implementation of energy supplementation to first calf cows may be an area to investigate further. Supplementation strategies may be able to offset performance with meeting demands for growth, lactation, and reproduction in those first calf cows.

Furthermore, our lab has demonstrated that we can impact production efficiencies in beef cattle through moderate nutrient restriction and subsequently impact genes in functional categories in tissues such as the fetal liver where metabolic pathways, and protein kinases can be affected (Crouse et al., 2017). Moreover, Crouse et al. (2017) reported that transcript abundance of genes and functional categories in fetal cerebrum are affected by nutritional treatment and have impacts on metal-binding genes and hippocampus and neurogenesis. In the previous model of early pregnancy all cattle received supplemental trace minerals. Not providing supplemental mineral in diets may alter fetal and placental development. With such large variation in mineral delivery and supplementation strategies in place on beef operations, however, it would be a great benefit to our industry to understand the impacts that pre-breeding supplementation has on reproductive processes and fetal growth and development.

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