SALT LIMITED INTAKE: IMPACTS OF SALT LEVEL AND FORM OF SUPPLEMENT ON INTAKE, NUTRIENT DIGESTION, AND VARIABILITY OF SUPPLEMENT INTAKE IN BEEF CATTLE

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ABSTRACT

For centuries, salt has been used as a cost effective intake-limiter of supplements for ruminants. Beef cattle production in the western United States relies on self-fed, salt-limited supplement to offset seasonal nutrient deficiencies which, in turn, may improve performance and increase forage intake. However, research has found high variation in individual supplement intake among animals and across days. If cattle are over consuming high-salt diets, this may result in negative impacts on animal performance and additional cost for the producer. Two studies were conducted to evaluate the effects of form of supplement on supplement intake behavior, body weight, and body condition change and the impacts of supplemental salt levels on forage intake, water intake, dry matter digestibility, and rumen fermentation of yearling heifers consuming low quality forages. During a two-year summer grazing trial, individual supplement intake, time spent at the feeder, and frequency of visits was measured. It was found that supplementation and form of supplement did not influence heifer weight gain or intake CV ($P = 0.26$), but heifers in the pelleted treatment consumed more supplement (grams/kg BW), and at a faster rate compared to heifers fed the loose supplement form ($P < 0.01$). In study 2, six ruminally cannulated heifers were assigned to treatments to determine the effect of salt levels on digestibility and rumen parameters. Salt treatments consisted of: 1) control, no salt (CON), 2) 0.05% of BW salt (LOW), and 3) 0.1% of BW salt (HIGH). Forage and water intake, digestibility, and rumen parameters were measured. Supplemental salt tended to decrease forage intake (grams/kg BW; $P = 0.06$) and tended to increase DM fill ($P = 0.07$). Both water intake and liquid fill increased with increasing level of salt ($P < 0.01$). Ruminal pH and ammonia levels decreased with increasing salt ($P < 0.01$) while acetate concentration increased ($P < 0.01$). Digestibility was not influenced by salt levels ($P > 0.05$). Our results suggest that pelleting salt-limited supplements has a masking effect on the intake regulation of salt. Additionally, increasing levels of salt modifies rumen fermentation and digestion suggesting lower efficiency of intake and use with high-salt diets.

GENERAL INTRODUCTION

One of the greatest challenges that western beef producers face is the need for supplemental nutritional inputs, especially in arid and high elevation rangelands where seasonal deficiencies of nutrients are frequent (DelCurto et al., 2000). Producers who are dependent on forage resources as a main source for feed must develop strategies that maximize forage use with minimal supplemental inputs in order to reduce costs while maintaining acceptable levels of beef cattle production (DelCurto et al., 2000). To offset seasonal deficiencies in nutrients, supplements are used to increase forage intake, digestibility, and improve animal performance (McCollum and Horn, 1990; Kunkle et al., 2000; Bodine et al., 2001).

Knowledge of supplement intake is needed to correct nutritional deficiencies (DelCurto et al., 2000; Kunkle et al., 2000), and is a vital measurement of animal performance (Van Soest, 1994). However, there are several variables that can impact supplement intake and intake CV including, delivery method, trough space, previous experience with supplements, social interactions, supplement allowance, forage quality and availability, and supplement form. Coefficient of variation (CV) for supplement intake is an important measurement that not only influences animal performance, but also effects cost (Bowman and Sowell, 1997). Self-fed supplementation programs, which are a popular choice of beef cattle producers, rely on the assumption that animals consume a targeted quantity of supplement (Bowman and Sowell, 1997; DelCurto et al., 2000). A high CV percentage, which are higher with self-fed supplements, is indicative of inefficiency, displaying that a larger percentage of the herd is not consuming the average rate (Bowman and Sowell, 1997). This inefficiency of supplementation can also be influenced by form (Hentges et al., 1967; Bowman and Sowell, 1997; Kunkle et al., 2000), however this has not been evaluated with individual daily supplement intake over time using a loose or pelleted form of a supplement, and specific to grazing beef cattle.

The addition of automated feed systems allows us to easily measure individual supplement intake and intake behaviors such as intake rate (g/min), and time spent at the supplement. An animal who consumes at a faster rate, is significantly more efficient in terms of weight gain (Frisch and Vercoe, 1969). Conversely, an animal who spends more time at the supplement, is spending less time utilizing the available forage. DelCurto et al. (1990) found that cattle winter grazing dormant tall grass prairie that were supplemented alfalfa hay spent less time grazing ($P < 0.01$) than cattle supplemented with dehydrated alfalfa pellets, suggesting that the form of supplement fed may influence grazing behavior and have an impact on efficiency. Our research found it imperative to measure individual supplement intake, intake CV of the supplement, and intake behaviors to better understand the influence of form of supplement on animal performance of yearling heifers grazing summer pasture to provide better precision of strategic supplementation programs.

One of the main limitations to providing supplementation to grazing cattle is the inability to control individual animal consumption of supplement and reduce intake variation (Bowman and Sowell, 1995). Salt is the most popular intake limiter as it is less palatable in high amounts, readily available, and generally considered safe (Kunkle et al., 2000). It has been recommended that producers should assume .1% BW of salt initially to limit supplement intake, then adjust accordingly because cattle tend to acclimate to salt over time, with the amount of salt needing to increase to be effective as an intake limiter (Kunkle et al., 2000). However, some research has shown that the use of NaCl to reach a desired level of intake may not be precise, and some adjustments may be required (Riggs et al., 1953; Kunkle et al., 2000). Additionally, many recent studies have found a large amount of supplement intake variability between animals across days as well as across animals within days when consuming salt-limited supplements (Bowman and Sowell, 1997; Williams et al., 2018; Wyffels et al., 2018) which may result in negative effects on forage intake and digestibility (Harvey et al., 1986; Bowman and Sowell, 1997).

A high supplement intake CV means individual animal supplement intake varies dramatically in respect to the group mean. If animals are over consuming, the influence of high salt in the diet could impact forage intake, digestibility, and rumen fermentation. Individual forage intake will be measured to evaluate animal productivity and performance. Past studies have reported either no effect (Riggs et al., 1953; Chicco et al., 1971; Harvey et al., 1986), or decreased forage intake with high supplemental salt levels (Meyer et al., 1955; Moseley and Jones, 1974; Rogers et al., 1982). The research on the impacts on forage intake have not been performed with large enough sample sizes or populations that could be related to beef cattle consuming low-quality forages. It is accepted that an increase of salt in the diet increases individual water consumption (Archer et al., 1952; Weir and Miller, 1953; Harvey et al., 1986). This is due to salt's effect on the osmotic pressure and is hypothesized from the adaptation of the animal to maintain electrolyte homeostasis (Croom et al., 1982). However, the measure of water intake is vital to understanding the effects on digesta kinetics and possible dilution effects on ruminal pH, ammonia, and VFAs (Van Soest, 1994). Increased dilution rates have been observed in dairy cattle (Rogers et al., 1982; Harvey et al., 1986). Research on rumen kinetics, fermentation, and digestibility is conflicting and incomplete with regards to supplementing salt levels on beef cattle consuming low-quality forage. With conflicting results and lack of representation of beef cattle consuming low quality forages, more research is needed to evaluate the impacts of high salt on forage intake.

In general, there is a gap in the research of how supplement form, specific to loose form and pelleting, influences the effectiveness of self-fed supplements. Additionally, with variation in intake of salt-limited supplements, we do not fully understand the impacts of high supplemental salt levels on forage intake, rumen kinetics, or nutrient digestion specific to beef cattle consuming low quality forages. This research provides more insight on 1) the impacts of form of salt-limited supplement on supplement intake behavior and performance with yearling heifers grazing dryland pastures using automated feed technology and 2) how forage intake, rumen kinetics, and nutrient digestion are impacted by increasing salt levels in cattle fed low-quality diets.

LITERATURE REVIEW

Need for Supplementation

Rangeland and pastures comprise approximately 31% of the land or 308 million ha in the United States, with the majority occurring in the West (Havstad et al., 2009; NASEM, 2016). These lands are found mainly in arid, semiarid, or high elevation regions and are managed as a natural ecosystem supporting vegetation of grasses, grass-like plants, forbs, or shrubs. Western rangelands are diverse lands that can include wet grasslands, desert shrub ecosystems, high mountain meadows and desert floors (Havstad et al., 2009; DelCurto et al., 2000; NASEM, 2016). The unifying characteristic of these landscapes is that they are water-limited; often, this co-occurs with deficiencies in other nutrients (Havstad et al., 2009; DelCurto et al., 2000; NASEM, 2016). Cattle production systems using arid rangelands and pastures or high elevation areas as a primary source of feed can experience nutrient deficiency due to low precipitation, and short growing seasons. These arid areas with low precipitation are characterized by low annual production, low crude protein (CP) levels and early plant senescence due to low soil moisture (Barnes et al., 2007). Other factors that can contribute to nutritional deficiencies in grazing animals are those resulting from poor rangeland management, incorrect feeding practices and, and mineral deficiencies in the soil (NASEM, 2016).

Nutritional deficiencies resulting from low-quality forage and seasonal differences can be corrected by supplemental feeding. Producers need to be aware of the nutritional requirements of livestock and how requirements change throughout the year and, in turn, how these requirements can vary by weight, genetics, and production level of the individual animal (Kunkle et al., 2000; NASEM, 2016). Inadequate protein, depending on season, is the most common of all nutrient deficiencies (Kunkle et al., 2000). Supplements that have been balanced with protein, minerals, and vitamins, are often needed to meet desired performance (Kunkle et al., 2000). Supplementing protein allows for the correction of the ruminal nitrogen deficiency, which can improve forage intake (McCollum and Horn, 1990). Caton et. al. (1988) determined that protein supplementation can alter ruminal ammonia (NH3) and VFA concentrations, while improving passage rates and digestibly of forage with a slight increase on intake. Insufficient N from the diet suppresses forage digestibility and intake and decreases the efficiency of metabolizable energy utilization (McCollum and Gaylean, 1985; MacRae et al., 1985).

In addition to meeting the animal's nutrition requirements during deficiencies, there are other reasons for supplementation of rangeland cattle. With supplementation, producers can improve forage utilization, improve animal performance, manage cattle behavior, and increase economic return (Clanton, 1982; Wallace, 1987; DelCurto et al., 2000).

Beef producers in the western United States who rely on these rangelands and their deficiencies must utilize strategic supplementation to maximize available forage use, while minimizing supplemental inputs in order to reduce costs and maintain acceptable levels of beef cattle production (DelCurto et al., 2000).

Supplement intake and intake variation

Intake has been determined as the factor with the most influence on animal performance. In general, the more an animal consumes, the more nutrients available to improve performance (Van Soest, 1994). As emphasized previously, with cattle on rangelands, the goal of producers is to increase the intake of available forage and minimize the costs of supplement. The goal of strategic supplementation should be to use the most efficient delivery system to minimize costs and variation of animal intake within a group of cattle (Bowman and Sowell, 1997; DelCurto et al., 2000; Kunkle et al., 2000).

With differences in geographic location, forage type and availability; different forms and types of supplement are needed. There are many options for selecting the supplement types and form for the goals of each operation. Supplement can be delivered in several forms, including: loose meal, liquid, pellets, cubes, and blocks and can be either hand fed or self-fed (Bowman and Sowell, 1997).

Hand feeding supplements requires more labor by delivering the supplement manually each feeding but can minimize variation between animals. Bowman and Sowell (1997) suggested that high levels of competition for the supplement (i.e., limited trough space) generally increases the proportion of non-feeders, whereas low levels of competition, as with self-fed supplements, generally increases variation in individual supplement intake. Hand fed supplements involve feeding the supplement frequently, not in block form, and without limiters, in a trough or bunk and calculated by your target amount multiplied by the number of animals. This can minimize variation by increasing competition between animals and leaves less to be over consumed (Bowman and Sowell, 1997). One study that demonstrates the differences in supplement intake variation between hand-fed and self-fed is by Holst et al. (1994). Their researched involved 100 head of grazing wethers fed a lupine seed supplement by either feeding it on the ground daily or fed in a self-feeder at the same rate of 600g/d. The CV for those fed daily by hand (on ground) was 47% versus 83% for the wethers fed by self-feeder. Additionally, the number of non-feeders (less than 100g/d consumed) was lower within the hand-fed group compared to the self-fed lambs, with 10% compared to 27%. Although, in the self-fed treatment, the mean intake was a greater percentage of the target intake with 84% compared to hand-fed at 71%.

Conversely, self-fed supplementation programs, which are a popular choice of beef cattle producers, rely on the assumption that animals consume a targeted quantity of supplement (Bowman and Sowell, 1997; DelCurto et al., 2000). To offset seasonal deficiencies in nutrients, self-fed supplements are used to increase forage intake and improve animal performance, while lowering labor costs to the producer (McCollum and Horn, 1990; Bowman and Sowell, 1997; Bodine et al., 2001). Intake of self-fed supplements is usually measured by dividing the supplement disappearance by the number of animal x days (Bowman and Sowell, 1997). This method does not consider variation in intake by individual animals and the potential problems if supplement is not consumed at the targeted amount (Bowman and Sowell, 1997). Coefficient of variation for supplement intake is an important measurement that not only influences animal performance, but also effects the cost of the producer. A high CV percentage, as often seen with self-fed supplements is indicative of inefficiency, displaying that a larger percentage of the herd is not consuming the supplement at the average rate, animals under-consuming, or overconsuming the supplement in a spread away from the mean (Bowman and Sowell, 1997). If an animal is under consuming, or a non-feeder, that individual isn’t receiving the formulated nutrient intake or maintaining the desired performance level of the producer (Bowman and Sowell, 1997). If animals consume more than the target amount, supplementation costs are increased, and there can be potential negative impacts on forage intake and digestibility (Bowman and Sowell, 1997).

Historically, it has been difficult to measure individual intake and intake variation with self-fed supplements. This is in part due to the inability to efficiently measure intake of animals grazing rangeland in a herd setting. Past methods for determining individual supplement intake and visits to the feeder were labor intensive and have included use of markers (e.g., chromium, ytterbium and tritiated water), observation and direct weighing, dyes to mark animals at the feeder, and cameras to monitor behavior and attendance (Tait and Fisher, 1996).

With the recent addition of automated feeding systems that can measure individual intake of a self-fed supplement, we can now evaluate supplement intake on a animal and day basis which was not possible in past research (Reuter et al., 2016; Williams et al., 2018; Wyffels et al., 2018). A pilot study was conducted by Reuter et al. (2016) using an automated supplement intake monitoring system (Smart-Feed; C-lock Inc., Rapid City, SD). Fifteen steers grazing dormant native range pasture for 61 days had ad libitum access to the supplement feeder. The individual supplement intake per day was 1.21 ± 1.15 kg/d. This high CV indicated the high level of variation in daily supplement intake among a group of self-fed cattle (CV = 69%). The range of individual intake of supplement ranged from 0 to over 4 kg per day. They also observed that supplement intake increased, but then decreased over time, which may be due to steers adapting to higher levels over time, then as the cool season plants began to grow, and the possible appetite for fresh forage may have reduced the animal's appetite for protein. On average, as reviewed by past studies, the CV of individual intake of supplement, is higher in self-fed supplement settings with an average of 71% as compared to hand-fed supplements at 38% (Holst et al., 1994; Lobato and Pearce, Kendall et al., 1983). However, in a review of supplement delivery methods, Bowman and Sowell (1997) suggested that in addition to delivery method, there are other factors that affect supplement intake. Trough space, previous experience with supplements, social interactions, supplement allowance, forage quality and availability, and supplement form all influence the variation of intake of self-fed supplements.

Self-fed supplements can reduce labor and equipment costs but continue to challenge beef producers and ruminant nutritionists due to the variation between animals, across environmental situations, and time periods (Kunkle et al., 2000).

Form of supplement

It has been proposed that supplement form can influence supplement intake (Dove and Freer, 1986; Bowman and Sowell, 1997; Kunkle et al., 2000). While several methods can be utilized by producers, loose (finely ground) supplement and pelleted supplement are two popular formulations for beef cattle supplement. It has been hypothesized that pelleting a supplement may have a masking effect on unpalatable ingredients meant to limit, compared to the loose, granular form.

Taste has been reported as the most influential sense of livestock (Krueger et al., 1974), and is important in animal nutrition due to its involvement in motivating and regulating ingestive behavior (Goetcher and Church, 1970). The tongue of beef cattle fills most of the space within the oral cavity and is comprised of fungiform and vallate papillae, which are characterized histologically by the presence of taste buds with gustatory receptors (Church, 1975). The increased surface area of a loose-form, supplement may cover more area within the oral cavity and effect more taste receptors than a pelleted version with less surface area and the same ingredients.

A study by Dove and Freer (1986) with 40 grazing lambs were split into 4 groups by weight. Animals grazed in 0.4 ha plots of clover pasture with an initial weight of approximately 32 kg. The groups were fed either sunflower meal or pelleted sunflower meal offered via hand-fed or self-fed nutrient delivery. The study used tritiated gypsum for estimating individual intake and the authors observed small differences in CV averaging 21% and 8% for the meal and pelleted forms, respectively. In contrast, Kendall et al. (1983) reported 35% CV of pelleted compared to 31% loose forms of supplement. With the additional technology the industry has to measure individual intake within a herd, there is a need to reexamine the intake variation between loose and pelleted supplement forms and expand on the impacts on performance with automated supplement intake monitoring systems to better understand implications specific to cattle grazing low-quality rangelands.

Intake behavior variables

With the addition of automated feed systems, we can easily measure individual supplement intake and additional intake behavior such as intake rate (g/min), and time spent at the supplement. The importance of intake rate is the known correlation to the intake of the diet, and the subsequent effect on overall performance. Frisch and Vercoe (1969) observed that the eating rate of animals was highly repeatable and significantly correlated with voluntary food intake (P <0.01) and live weight gain (P <0.01). This demonstrates that an animal who consumes at a faster rate, is significantly more efficient in terms of weight gain. Conversely, an animal who spends more time at the supplement, has less time available to graze the available forage, making the animal less efficient at utilizing that resource. A study by DelCurto et al. (1990) found that cattle winter grazing dormant tall grass prairie that were supplemented alfalfa hay spent less time grazing (P <0.01) then cattle supplemented with dehydrated alfalfa pellets, suggesting that the form of supplement fed may influence grazing behavior and have an impact on efficiency.

Limiting supplement intake

To offset seasonal deficiencies in nutrients, especially in arid and high elevation rangelands, self-fed supplements are used to increase forage intake and improve animal performance (McCollum and Horn, 1990; Bowman and Sowell, 1997; Bodine et al., 2001). Labor costs are therefore lowered because large amounts of supplement can be placed in a self-feeder and remain on the range during certain seasons or when access is limited (Bowman and Sowell, 1997). One of the main limitations to providing supplementation to grazing cattle is the inability to control individual animal consumption of supplement (Bowman and Sowell, 1995). Previous studies that have evaluated the intake variation of individual supplement consumption have shown that some animals refuse supplements altogether (nonfeeders), while others consume excessive amounts (Bowman and Sowell, 1997; Williams et al., 2018; Wyffels et al., 2018). The inability to regulate supplement intake results in an asynchrony between animal nutrient requirement and nutrient supply (Bowman and Sowell, 1995). Self-fed supplements are popular among western beef cattle producers and must utilize a mechanism to limit intake thus reducing this potential of animals over consuming supplements and as a result, substituting or reducing low-quality forage intake. The commercial feed industry commonly uses physical form (blocks, tubs, and liquids) as well as intake-limiting compounds such as salt, monensin, and calcium chloride to control supplement consumption (Kunkle et al., 2000). Salt is the most common intake limiter because it is readily available, generally safe, and salt level can be modified to achieve the desired intake amount (Kunkle et al. 2000).

Salt as an intake limiter

Salt is used in supplements as an intake limiter as it is less palatable in high amounts, and may provide help livestock meet Na and Cl nutritional requirements. Salt has been known to aid in maintaining the osmotic gradients, regulating water balance and controlling the acid-base balance (NASEM, 2016). Salt (NaCl) is one of the essential minerals needed by all animals and is usually lacking in the diet of western rangeland livestock, with most grasses containing less than 1 percent salt (Cardon et al., 1953; Meyer et al., 1955). Cattle typically consume salt at a rate of .05 to .15% of BW when salt is used as an intake limiter, therefore producers should assume .1% BW initially then adjust accordingly because cattle tend to acclimate to salt over time, with the amount of salt needing to increase to be effective as an intake limiter (Kunkle et al., 2000).

Past studies have reported that salt can be an effective supplement intake-limiter (Cardon et al., 1953; Riggs et al., 1953; Beeson et al., 1977). Nelson et al. (1955), Archer et al. (1952), and Riggs et al. (1953) all reported that salt was an effective limiter of a protein supplement for beef cows grazing dry winter ranges and that cows receiving salt-limited (from 25 to 35% salt) supplements performed similar to those being hand-fed the same levels of protein supplement. A study by Schauer et al. (2004), fed yearling steers different supplement treatments to determine the effectiveness of three intake limiters. Treatments included 1) control, or no supplement; 2) hand-fed supplement without limiters; 3) 16% salt; 4) 5.25% ammonium chloride and ammonium sulfate; and 5) 7% calcium hydroxide. Treatments were mixed into the base supplement of wheat middlings, barley malt sprouts, and soybean hulls at 40% of CP intake of 350 kg steers. They found that self-feeding with salt as the limiter often resulted in similar supplement intake compared to hand feeding. In general, levels of salt that have been observed to limit supplement intake range from 20 and 29.5% (Weir and Torrell, 1953; Rush et al., 1975; Kunkle et al., 2000).

Some research has shown that the use of NaCl to reach a desired level of intake may not be precise, and some adjustments may be required (Riggs et al., 1953; Kunkle et al., 2000). While salt may be generally accepted as an intake limiter, concerns exist relative to the variation of supplement intake with animals in group-fed and extensive rangeland environments. A study performed by Hentges et al. (1967) stated salt lacked efficacy as a consistent, precise and proportional supplement intake regulator, because of lack of predictability of its regulating effect due to high variability among individual steers. Additional research has found that self-fed supplements containing salt as an intake-limiter can have high amounts of variation and sacrifice efficiency in supplement intake between animals as well as days (Williams et al., 2018; Wyffels et al., 2018), which may result in negative effects on animal performance (Harvey et al., 1986; Bowman and Sowell, 1997). In a recent study by Williams et al. (2018), intakes and intake behavior of steers consuming a loose form, salt-limited supplement was measured. Salt was added at 25, 30, and 45% for d 1 to 7, 8 to 14, and 15 to 56, respectively. They observed an overall supplement intake mean of 0 to 1.21 kg per steer per day. The CV for supplement intake across animals was 51%, whereas the CV for intake across day within animal was 72%. These results demonstrated the high amount of variation between individuals within the herd, but even higher variation within one animal between days.

Additionally, in a winter grazing trial with beef cows fed a protein supplement via an automated system, Wyffels et al. (2018) recorded intake and intake behavior of a self-fed, 25% salt-limited supplement. Over the winter grazing period, a higher amount of variation was observed with younger animals and some individuals were observed to consume up to 9 kg of supplement in one day. The observance of 9 kg of salt in one day may be an extreme case, but it displays the amount of variation in intake and that some individuals are consuming high amounts of supplemental salt. With these recorded levels of over consumption, it would be of great importance to the beef cattle industry to know the effects of high salt levels on forage intake, water intake, digestibility and rumen kinetics. In the following thesis chapters, the levels of supplemental salt were calculated based on observances of supplement intake (salt-limited) from Wyffels et al. (2018). The results were determined within age groups, and the target intake of the supplement was .91 kg per day. Animals were reported to consume the salt-limited supplement at rates between 0.67 and 1.59 kg had a daily intake CVs between 80.8 and 105.5%. Therefore, our levels were chosen at 1) control no salt, 2) 0.05 % of BW, and 3) 0.1% of BW to capture levels above and below their average recorded intakes.

Forage intake and performance

The measurement of forage intake is vital to and strongly correlates to animal performance (Van Soest, 1994). Additionally, if grazing cattle have increased forage intake, producers will maximize the use of available forage resources and therefore, be more cost effective (DelCurto et al., 2000). In a digestion study using 15 ruminally and 12 esophageally fisulated steers, Brandyberry et al. (1991) evaluated the effects of self-feeding and hand-feeding with salt on grazing distribution, diet selection, and digestion parameters. They found no evidence to expect a negative impact on animal performance and that self-feeding a salt-limited supplement could result in considerable savings in labor costs. This aligns with other past studies that demonstrate no consistent significant effects on intake or performance with high salt diets (Riggs et al., 1953; Chicco et al., 1971; Harvey et al., 1986). However, some research has found significant negative impacts.

Croom et al. (1982) conducted trials to determine the effects of high salt and limestone levels in the finishing diet of Hereford steers to improve performance. In the first trial, 24 steers were separated into groups containing 0.5-7.0% salt for 126 d. This study reported that feed intakes were reduced at the highest salt level (7%). This is in agreement with Mosely and Jones (1974), Rogers et al. (1982), and Meyer et al. (1955). These studies all reported a decrease in feed intakes but these studies focus on dairy cattle and ruminants fed high concentrate diets.

Weight losses have also been reported with some trials involving high salt amounts in supplement. In a study by Pickett and Smith (1949) using two-year-old steers grazing bluestem pasture, steers hand fed 3 lbs of cottonseed cake daily gained 0.43lbs more per day on 0.54 lbs less cottonseed cake than steers self-fed a 30% salt 70% cottonseed meal mixture. Although, this study was performed with only two animals per treatment, and with such low numbers, it would be difficult to apply the results or be representative. Archer et al (1952) used a herd of Hereford cows (37 in yr 1 and 48 in yr 2) to evaluate the effects of self-feeding a salt-limited cottonseed meal to grazing pregnant cows over winter. Cows were either handfed cottonseed meal in a cake without salt, or self-fed cottonseed meal with an added 1.1 lbs of salt daily. The self-fed cows lost an average of 18 lbs. over the winter compared to the hand fed group losing only 8 lbs.

It has been reported that the decrease in DMI, possibly affecting a decreased gain as seen in previously mentioned studies could be due to decreased cellulose degradation as a possible result of increased osmotic pressure of the increased rumen fluid volume

(Rogers et al., 1982). Further research is needed to evaluate the impacts of increasing salt levels on forage intake.

Water intake and kinetics

As salt increases in the diet, water consumption increases (Archer et al., 1952; Weir and Miller, 1953; Harvey et al., 1986). This is due to salts effect on osmotic pressure and is predicted from the adaptation of the animal to maintain electrolyte homeostasis (Croom et al., 1982). Specifically, one study observed an added 35 ml of additional water per each additional gram of salt (Meyer et al., 1955). While we know the effect of added salt on water intake, the importance of measuring water intake primarily relates to water effects on other ruminal parameters. Increased water levels can modify liquid kinetics, affecting liquid fill, liquid dilution rates, and flow rate within the rumen which can be correlated with digestibility (Harvey et al., 1986). High osmotic pressure in the rumen reduces the absorption of water and with that increased osmotic pressure, rumen washout is promoted as demonstrated by an increase in liquid passage (Van Soest, 1994). An increase in water intake and dilution rate can additionally impact the microbial community and digestibility by affecting microbial generation time and loss of digestible substrate (Van Soest, 1994). The impacts of water intake are far reaching in terms of animal performance and should be integral to research involving the effects of high salt diets.

In the grazing and digestion study by Brandyberry et al. (1991), no effect was observed on ruminal DM or fluid fill ($P = 0.10$) with high salt in the diet, similar to findings of Harvey et al. (1986). However, during the summer grazing period dilution rate was faster in treatment groups receiving salt, which is similar to the increased dilution rate reported by other studies with dairy and beef cattle fed moderate to high quality diets (Rogers et al., 1982; Harvey et al., 1986). The study evaluating high salt diets with dairy cattle also reported an increase in ruminal outflow. This effect on ruminal outflow was attributed to increased ruminal osmolality and increased water consumption with high salt diets (Rogers et al., 1982). They additionally hypothesized that the increased dilution rate may increase the flow of starch out of the rumen, therefore reducing the rate of fermentation. These studies have evaluated the effect of high salt diets on ruminal parameters and digestion with livestock fed high concentrate diets, or with dairy cattle. Therefore, research evaluating the effect of salt intake on digesta kinetics and ruminal parameters specific to beef cattle consuming low quality forages would exceedingly expand the understanding of the high salt diets in grazing or low-quality forage scenarios.

Digestibility

Digestibility has been identified as one of the most important factors affecting animal productivity, with the rate of digestion correlated to the amount of food energy available to the animal (Van Soest, 1994). These rates in turn affect rumen fermentation and the VFA population. Neutral detergent fiber (NDF) digestibility is related specifically to the plant’s structural components which are the main source of fiber in low-quality high-fiber forages. In general, increased NDF digestibility will result in higher digestible energy and forage intakes (Van Soest, 1994). In a study evaluating the effects of high salt diets with fattening wethers and steers, Meyer et al. (1955) found that a high salt intake (up to 12.8% NaCl) did not influence digestibility. This agrees with the work by Archer et al. (1952), Cardon (1953), and Brandyberry et al. (1991) that found no influence on digestibility.

Archer et al. (1952) performed a metabolism study with steers fed a ration of prairie hay and cottonseed meal with either 10g or 250g of salt. It was reported that a high salt diet did not significantly affect nutrient digestion. Similar results were observed in a study by Cardon (1953) where they utilized three 1000lb Hereford cows consuming ground alfalfa hay. After an adjustment period, the cows were fed the daily alfalfa ration with an added 1.8 lbs. of salt. For the third period, the cows were fed the basal ration with an added 2lbs. of salt split between two feedings. A following in vitro experiment, with rumen fluid and the basal diet of ground alfalfa, found that digestible protein, cellulose, and gross energy were not significantly altered by added salt levels. Brandyberry et al. (1991) reported no treatment effect influenced NDF digestibility.

However other studies have observed conflicting results and display that high salt levels could have a significant influence on nutrient digestibility. Nelson et al. (1955) used 4 Hereford steers weighing approximately 226 kg in two trials. They were fed a basal ration of bluestem grass hay and cottonseed meal mixed with 6% salt. The steers would not consume the salt while in metabolism stalls, so the additional salt was fed via gelatin capsules. 2 steers were fed only the base ration, and the other two the base ration with the added 6% salt, after the first period the treatments switched. They reported that digestibility of various nutrients was slightly lower with the high salt ration, than the basal control treatment, although the results may not be significant due to the low number of individuals. Additionally, Moseley and Jones (1974) observed a decrease in organic matter digestibility for wethers fed grass hay as salt increased in the ration from 0 to 3.0% and concluded that salt can negatively affect forage digestibility when consumed at high levels.

Another study that observed negative impacts from high salt diets on digestibility was Chicco et al. (1971). Thirty-six crossbred steers (Bos indicus and Bos taurus) were uniformly assigned to three treatments; control, pasture and supplement with 30% salt, and pasture with supplement fed the same intake as the second group without any added salt. The supplement was self-fed once weekly at 30% above the proceeding week's consumption and the available pasture was 5.5% CP. Concluding the 120-d trial, two animals per treatment were used in a digestion study. Results reported a decrease in cellulose digestion in the rumen. These results are conflicting and include many studies evaluating unrepresentative groups with either low sample sizes or communities that are not representative of beef cattle consuming low quality forages, demonstrating the need for further research.

VFA and microbial concentrations

Cattle grazing low quality forage, especially when it is deficient in protein, need the supplemental protein source to provide precursors to produce volatile fatty acids (VFAs) through ruminal fermentation. The majority (50-85%) of the energy cattle receive is in the form of VFAs. The main VFAs produced and absorbed in the rumen have distinctive metabolic roles. Acetate is utilized minimally in the liver, oxidized throughout the body to generate ATP, and is a major source of acetyl CoA which aids in the synthesis of lipids. Propionate, which is mainly removed via portal blood and transported to the liver to serve as the major substrate for gluconeogenesis, which is critical to the ruminant because almost no glucose reaches the small intestine for absorption. Butyrate is transported from the rumen as the ketone beta-hydroxybutyric acid, is oxidized in many tissues for energy production. The metabolism of other odd-carbon fatty acids, such as valerate, parallels that of acetate and propionate, into which they are split, and involves production of at least one propionyl group on degradation (Van Soest, 1994). Additionally, isoacids (isobutyrate and isovalerate) play a small role in glucogenic metabolism (Van Soest, 1994). The ratio of acetate:propionate can be indicative of the type of diet the animal is consuming and tends to be increased with cattle fed forage-based diets (Blaxter, 1962). When the acetate to propionate ratio decreases, CH4 production declines, and energy retention by the cattle increases (Wolin, 1960). The VFA population is an indicator of animal performance and is directly affected by several factors, including the diet, microbial species present in the rumen, and ruminal pH (Van Soest, 1967), therefore making it an important measurement for digestion studies. Another factor in the efficiency in ruminal fermentation is ammonia concentration. Many fiber digesting rumen bacteria require ammonia, which is supplied in general fermentation and is the preferred substrate for protein synthesis (Van Soest, 1994), although optimal levels remain controversial (NASEM, 2016). Orskov (1982) implied that higher amounts of ammonia concentrations in the rumen were required by microbes to maximize digestion for low-quality high fiber feeds.

In studies with cattle consuming forage-based diets, although none were specific to low quality forages, effects on the VFA population and concentration were reported. Harvey et al. (1986) conducted two trials to evaluate the influence of high salt diets with a protein or energy supplement on performance, digestive, and metabolic parameters of growing beef cattle. In the first trial, 24 Hereford steers averaging 196 kg were individually fed corn silage or fescue hay both 8.8% CP and fed a soybean meal supplement with either 23 g or 227 g of salt. In trial 2, the corn silage had a CP of 6.9% and the fescue hay 8.7%. The animals fed fescue hay received a mixture of corn and soybean meal, but the corn silage group were only supplemented with soybean meal and the same salt treatments of the first trial were applied to both. Molar proportions of acetate were higher for high salt diets, while isovalerate and valerate were lower for high salt treatments. The authors suspected the decreased valerate to be a result of decreased degradation of soybean meal associated with an increased rate of passage. It was also reported that molar proportions of propionate, butyrate, isobutyrate, and the acetate: propionate ratio were not influenced by salt. Chicco et al. (1971) reported molar proportion of VFAs were depressed ($P < 0.05$) with increased levels of salt.

Additional impacts on VFAs were observed by dairy cattle studies with high concentrate diets. Rogers et al. (1982) reported decreased molar proportion of total VFAs, an increase in acetate, decrease in propionate, but no effect on the acetate: propionate ratio. Rogers and Davis (1982) did report an increased acetate: propionate ratio with salt treatments, along with a decrease in total VFAs. The study by Croom et al. (1982), reported an increased acetate: propionate ratio from 1.9 to 2.8 ($P < 0.05$) with high salt diets. The changes to acetate to propionate ratio has been observed in other studies and may be attributed to the correlation of increased ruminal fluid dilution rate in sheep and cattle (Harrison et al., 1975; Hodgson and Thomas, 1975; Rogers et al., 1979). Surprisingly, Wiedmeier et al. (1987) reported somewhat different results in terms of VFAs. They reported an increase in branched chain VFAs while observing no treatment effects on total VFA proportions. The authors concluded that dietary salt is effective in maintaining more optimum levels of pH and liquid dilution rate, thus increasing cellulolytic activity and digestion, however this directly conflicts with similar studies observing salts' effect on dairy cattle (Rogers et al., 1982; Rogers and Davis, 1982; Croom et al., 1982).

In contrast, Brandyberry et al. (1991) reported that animals with supplements with salt had higher molar concentration of propionate and a lower acetate to propionate ratio. This did not agree with previous studies with dairy cows and cattle fed high concentrate diets by Rogers et al. (1982) and Rogers and Davis (1982), who saw steers consuming high concentrate diets displayed decreased molar proportion of propionate, but Brandyberry et al. (1991) explained that the differences in their results could be due to the difference in diet selected by grazing animals and the deficiency in salt observed with the control group. Brandyberry et al. (1991) reported no effect of salt on the concentration of ammonia, however they hypothesized that the protein supplement provide adequate levels of NH3-N to support fermentation. This lack of influence on ammonia concentrations agrees with research in dairy cattle by Wiedmeier et al. (1986), but disagrees with research that has demonstrated a decrease in ammonia concentrations with high salt diets on finishing steers by (Harvey et al., 1986) who explains this may be due to increased dilution rate.

According to Van Soest (1994), ecological conditions in the rumen must be kept within limits to maintain normal microbial growth and metabolism, and therefore affect the well-being of the ruminant animal. Cellulolytic organisms grow optimally at a pH of 6.7, with deviations from this level being inhibitory (± 0.5 pH units). A decrease in pH to 6.2 inhibits the rate of digestion and increases lag (Grant and Mertens, 1992). The rumen pH is maintained largely through the high buffering of saliva and the removal of VFAs through absorption (Van Soest, 1994), and past studies have again reported conflicting results in terms of the influence from salt levels.

In the study by Cardon et al. (1953), added salt had no appreciable difference on final pH. Additionally, this study claimed that added salt had no effect on the activity of microorganisms as measured by the lack of effect on digestibility, although the microbial population itself was not evaluated.

Similarly, Brandyberry et al. (1991) reported that the pH level, of self-fed, salt-limited steers had slightly lower ($P = 0.06$) ruminal pH than the other two groups, although this was not significant. The authors stated that although the differences in pH were statistically significant, the biological significance is most likely limited, given that all pH levels were above levels that would be considered to have a depressing effect on fiber degradation by cellulolytic bacteria (Owens and Goetsch, 1988). The same study did not measure the microbial population directly but reported an increased OM digestibility ($P = 0.02$) for steers in the self-fed salt-limited treatment group, which they hypothesized could have been due to salt's effect on microbial growth and activity. They expand by mentioning sodium is required by anaerobic ruminal bacteria (Caldwell and Hudson, 1974) and since the available forage was considered deficient in salt, the lack of salt could have influenced the microbial population and activity with the control group receiving no salt in the control supplement.

Wiedmier (1987) conversely reported an increase in ruminal pH and cellulolytic bacteria. The authors of that study concluded that dietary salt is effective in maintaining more optimum levels of pH and liquid dilution rate, thus increasing cellulolytic activity, however this conflicts with the previous mentioned research with dairy cattle fed high concentrate diets, that reported a decrease in pH (Rogers et al., 1982; Rogers and Davis, 1982), and is not representative of beef cattle consuming low quality forages.

Rationale for research

The need for supplementation of beef cattle on western rangelands have been demonstrated (DelCurto et al., 2000; Kunkle et al., 2000). Supplementation is used to offset seasonal deficiencies in nutrients, increase forage intake and improve animal performance (McCollum and Horn, 1990; Bowman and Sowell, 1997; Bodine et al., 2001). Many of these rangelands are in remote areas or can be difficult to access during inclement weather or certain seasons. Self-feeding supplements is a practical method of supplementation because labor and equipment costs can be lowered by leaving the supplement on the range or in the pasture to cover a longer length of time (Bowman and Sowell, 1997). However, with self-fed supplementation comes a high degree of variation between animals and across days, with some influence due to the form of supplement.

Supplement intake and intake CV of the supplement directly affects the performance of the animal and the effectiveness of strategic supplementation. Additionally, intake behaviors such as individual intake rate and time spent at the supplement influence the performance of the animal and the use of available forage. Research has not been done with the newly added technology of automated feed systems that can measure daily, individual supplement intake over time, to evaluate the difference between a loose form and pelleted form of a supplement. It would be important to measure forms' influence on intake, intake CV, and intake behaviors such as intake rate and time spent at the feeder, which impact animal productivity and efficiency of the self-fed supplement. The authors of this paper believe that there will be an influence on supplement intake and intake behavior between a loose form and a pelleted form of the same supplement, therefore impacting performance variables.

In addition, limiting intake of self-fed supplements is necessary to maintain cost effective management of grazing beef cattle (Bowman and Sowell, 1995; Kunkle et al., 2000). Of the intake limiters available to producers, salt is the most popular because it is readily available, generally safe, and salt level can be modified to achieve the desired intake amount (Kunkle et al., 2000). Salt provides ruminants with Na and Cl nutritional requirements, but also has been known to aid in regulating water and osmotic balances (NASEM, 2016). Salts' effectiveness as an intake limiter has been reported with a general range of 20-29% in the supplement (Weir and Torrell, 1953; Rush et al., 1975; Kunkle et al., 2000) however, the practice may not be precise. Hentges et al., (1967) stated salt lacked efficacy as a consistent, precise and proportional supplement intake regulator, because of lack of predictability of its regulating effect due to high variability among steers. This observation has been supported by other studies that have observed high variation in supplement intake (Bowman and Sowell, 1997; Williams et al., 2018; Wyffels et al., 2018) and could result in negative effects on animal performance (Harvey et al., 1986; Bowman and Sowell, 1997). Forage intakes, which influence animal performance (Van Soest, 1994), have been reported by some to not be influenced by high salt diets (Riggs et al., 1953; Chicco et al., 1971; Harvey et al., 1986), whereas others report reduced forage intake and performance (Meyer et al., 1955; Rogers et al. 1982; Croom et al., 1982). Furthermore, most research to date have not focused on low-quality, high-fiber, forage base diets. Rumen kinetics and fermentation could be significantly impacted by salt, since we know of salts' recorded impacts on increased water intake (Archer et al., 1952; Weir and Miller, 1953; Harvey et al., 1986). Studies with dairy cattle and ruminants fed high concentrate feeds have reported increased dilution rates and increased rumen outflow (Rogers et al., 1982; Harvey et al., 1986), which can also affect loss of digestible substrate, VFA concentrations, and microbial fermentation (Van Soest, 1994). The importance of measuring salts impacts on forage intake, water intake, digesta kinetics, VFA concentrations, and the microbial populations, relate directly to animal productivity and the effectiveness of beef cattle management practices. This brings into question the potential effects of high salt levels on forage intake, water intake, and rumen kinetics and fermentation. Therefore, further research is needed regarding the effects of supplemental salt levels with beef cattle consuming low-quality forages.

Our research determines the impacts of salt level and form of salt-limited supplements on intake, nutrient digestion, and variability of supplement intake specific to beef cattle consuming low-quality forage diets. In Chapter 3, we evaluate the specific impacts that the form of a salt-limited has on supplement intake behavior and animal performance with yearling heifers grazing dryland pastures. In Chapter 4 we evaluate the effects of increasing salt levels on intake, digestion, and rumen fermentation characteristics with beef cattle consuming low-quality forages. Lastly in Chapter 5 we provide an overall conclusion from our research and discuss how our results can contribute to future studies of supplementation with beef cattle consuming low-quality forages or be utilized to better understand strategic supplementation on rangeland in the western United States.

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IMPACTS OF FORM OF SALT-LIMITED SUPPLEMENT ON SUPPLEMENT INTAKE BEHAVIOR AND PERFORMANCE WITH YEARLING HEIFERS GRAZING DRYLAND PASTURES

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HIGHLIGHTS

- Self-fed supplements are commonly used in extensive, forage base, beef production systems
- Salt is commonly used to limit intake of supplements but may result in intake variation
- Pelleting supplements reduced the limiting effect of salt resulting in greater supplement intakes.
- Pelleting supplements resulted in faster intake rates while reducing or having no impact on times spent at the supplement feeder
- Salt-limited supplement intake increased with lower forage quality and availability as well as increased acclimation to supplement

ABSTRACT

The objectives of this study were to evaluate the impacts of supplement form on supplement intake behavior, body weight (BW), and body condition score (BCS) change of yearling heifers grazing dryland pastures during the summer. In each of two years, Angus crossbred heifers (14 mo of age; Year 1, n = 57, BW = 449 kg; Year 2, n = 58, BW = 328 kg) were used in an 84-d completely randomized design evaluating the following treatments: 1) a control, no supplement (n=19); 2) salt-limited supplement in pelleted form (n=19); and 3) a salt-limited supplement in loose form (n=19). Individual supplement intake (kg and g/kg BW), time spent at the feeder (min/d), and frequency of visits was measured throughout the course of the study. On days 0, 42, and 84, the heifers were weighed, and body condition scored following a 16 h shrink. Supplementation and form of supplement did not influence heifer weight gain (P = 0.26) averaging 0.79 kg/day in Year 1 and 1.17 kg/day in Year 2. In contrast, body condition change displayed a treatment by year interaction (P < 0.01) with heifers receiving the loose supplement displaying greater positive change in BCS in year 1 compared to control or pelleted groups. In year 2, however, heifers receiving control and pelleted supplement displayed positive BCS changes ($P < 0.01$), whereas heifers consuming loose supplement lost body condition ($P < 0.01$). Supplement intake expressed in kg/day and grams/kg BW displayed a treatment by period interaction ($P < 0.01$) with pelleted heifers consuming more supplement and the magnitude of difference being greater from days 42 to 84. Intake rate (grams/min) displayed a treatment by year interaction ($P < 0.01$) with heifers consuming the pelleted supplement having greater intake rates and the magnitude of difference was greatest in year one. Heifers on both supplement treatments consumed more supplement during the 42-84d period compared to the first 42 days ($P < 0.01$).Supplement intake was not influenced by year ($P = 0.88$). Supplement intake CV was not influenced by treatment and averaged 72.9 % of the mean ($P = 0.21$). Our results suggest that salt-limited supplements have a high degree of intake variation and pelleting could have a masking effect on the taste of salt as indicated by the greater intake and intake rate of supplement with heifers consuming the pelleted supplement.

Key words: Physical form of supplement, supplement intake behavior, salt-limited supplement, yearling heifers

INTRODUCTION

Western beef producers often graze cattle on arid and high elevation rangelands where seasonal deficiencies of nutrients are frequent (DelCurto et al., 2000). To offset seasonal deficiencies in nutrients, protein supplements are used to increase forage intake and improve animal performance (McCollum and Horn, 1990; Bowman and Sowell, 1997; Bodine et al., 2001). Therefore, forage based production systems must develop strategies that maximize forage use while minimizing supplemental inputs in order to reduce feed costs and maintain acceptable levels of beef cattle performance (DelCurto et al., 2000). The strategy or goal of strategic supplementation should be to use the most efficient feed delivery system to minimize costs and utilize supplements that reduce variation of animal intake (Bowman and Sowell, 1997; DelCurto et al., 2000; Kunkle et al., 2000). Multiple supplement delivery systems and forms are available commercially to meet animal nutrient demands including loose meal, liquid, pellets, cubes, and blocks, which can be either hand-fed or self-fed (Bowman and Sowell, 1997).

Under most rangeland cattle production scenarios, self-fed systems are often preferred due to ease of delivery and reduction in labor. However, self-fed supplementation programs assume that animals, when group fed, consume a targeted quantity of supplement (Bowman and Sowell, 1997; DelCurto et al., 2000). This assumption does not consider variation in intake by individual animals and the potential negative outcomes on animal performance and/or decreased profits margins for the producer if supplement is not consumed at the targeted amount (Bowman and Sowell, 1997; Williams et al., 2018; Wyffels et al., 2020).

In addition to delivery method, Bowman and Sowell (1997) suggest that there are other factors that affect variation of supplement intake such as supplement form. Loose (finely ground) supplement and pelleted supplement are two popular formulations for protein supplements. The most common method to limit intake of self-fed supplements is the use of salt ranging from 20 to 30% of the supplement composition (Weir and Torrell, 1953; Rush et al, 1975; Kunkle et al., 2000). However, it has been proposed that supplement form can mediate the effectiveness of salt as an intake limiter for self-fed supplement (Hentges et al., 1967, Dove and Freer, 1986; Kunkle et al., 2000).

Research evaluating the effectiveness of salt as an intake limiter within different supplements forms (loose and pelleted) and the effect of supplement form on supplement intake behavior is limited. Therefore, our research evaluated the impacts of supplement form (loose versus pelleted) on individual supplement intake and intake behavior of yearling heifers consuming a self-fed, salt limited supplement while grazing low-quality forages. We hypothesized that pelleting of supplement will have a masking effect on salt, resulting in increased supplement intake and influence intake behavior.

MATERIALS AND METHODS

Experimental procedures described herein were approved by the Agriculture Animal Care and Use Committees of Montana State University (#2017-AA09). All animals used in this study were provided by the Montana Agricultural Experiment Station. This study was conducted at the Fort Ellis Research Center at Montana State University in Bozeman, Montana, USA. The average precipitation is 46.9 cm with snow representing 59.3%. The average temperature is 9.74 °C with 113 total growing season days.

This study was conducted with Angus crossbred heifers (14 months of age) summer grazing a 93 ha dryland pasture. Heifers were stratified by body condition score (BCS) and body weight (BW; n = 57 heifers in year 1, average BW = 449 kg; n = 58 heifers in year 2, average BW = 328 kg) and, within stratum, randomly allotted to one of three supplement treatments: 1) control, no supplement; 2) 25 % salt-limited supplement in pelleted form (approximately 3/16" diameter); and 3) 25% salt-limited supplement in loose form (finely ground and mixed). The pelleted and loose forms of the supplement were isonitrogenous, isocaloric, and formulated to meet the protein needs of yearling cattle on summer pasture (Table 1). Differences between the supplement composition were primarily due to the addition of binding agents for pelleting. The target daily supplement intake was 0.91 kg/heifer.

Each heifer was equipped with an electronic ID tag (Allflex USA, Inc., Dallas-Fort Worth, TX, USA) attached to the exterior of the left ear for the measurement of individual supplement intake (kg/day and g/kg BW/day), number of visits, visit length (minutes), and intake rate (g/minute) using a SmartFeed Pro self-feeder system (C-Lock Inc., Rapid City, SD, USA; Figure 1) which provided a total of four feeding stations (Wyffels et al., 2020). The SmartFeed Pro unit limits access to the feedbunks via mechanical locking gates which allows multiple treatments within a single pasture. Two feeding units supplied the loose supplement and two units supplied the pelleted supplement with the control animals locked out of all four units. The supplement trailer was oriented so that solar panels were facing south. Treatment supplement feed units were randomly assigned for both the north and south facing directions. By recording individual animal feeding events, we were able to measure and account for supplement consumption by animals not in the assigned treatment. Non-assigned supplement intake represented 14% of the total supplement intake. However, non-assigned supplement intake of control, non-supplemented heifers, represented 11% of the total non-assigned supplement intake. A substantial amount of non-assigned intake corresponded to mechanical failure of the gate locking mechanism for a 3-day period on the SmartFeed Pro system.

Body weight and BCS were collected on days 0, 42 and 84 following a 16 hr shrink. Heifer BCS was evaluated independently by two observers using a 9-point scale (1 = extremely emaciated, 9 = extremely obese; Neumann and Lusby, 1986). The same technicians measured BCS throughout the study period. Pasture production was measured by clipping a 0.25 m^2 plot at 10 sites on days 0, 42, and 84 (Table 2). All clipped samples were composited by time period and sent to a commercial laboratory (Dairy One, Ithaca, NY) and analyzed for DM, CP, TDN, NDF, and ADF.

The effects of supplement form on daily supplement intake, time spent at the supplement feeder, and the rate of supplement intake were analyzed using generalized linear mixed models in an ANOVA framework with supplement treatment, period, year and all two-way interactions as fixed effects and individual animal as a random effect. The effects of supplementation, supplement form on heifer body weight and condition change within the 42-d grazing periods and across the total 84-d summer grazing period were analyzed using ANOVA with generalized linear models for a complete randomized design with treatment, year and their interaction as fixed effects. Data were plotted and log-transformed if needed to satisfy assumptions of normality and homogeneity of variance. Statistical significance was accepted at an alpha of < 0.05. All statistical analyses were performed in R (R Core Team, 2017).

RESULTS

Influence of supplementation and form on performance variables are listed in Table 3. There was a year effect on initial heifer weights ($P < 0.01$) with heifers in year 2 being 36.9% lighter than heifers in year 1. Likewise, heifers BCS were 0.68 units lower in year 2 ($P < 0.01$) compared to heifers in year 1. Supplementation and form of supplement did not influence body weight change for yearling heifers within or across study grazing periods ($P \geq 0.62$). Body condition was not influenced by supplementation and form within the 0 – 42 or 42 – 84-d periods ($P \geq 0.26$), but displayed a treatment by year interaction for the 84-d summer grazing period ($P < 0.01$) where in year 1, heifers provided loose supplement had greater body condition gains than non-supplemented heifers ($P = 0.02$) and heifers provided pelleted supplement ($P = 0.03$) with no treatment effects observed in year 2 ($P \geq 0.18$). Over the 84-d period, BW gains were lower in year 1 compared to year 2 ($P < 0.01$), averaging 0.78 kg/d and 1.17 kg/d, respectively.

Supplement intake (kg/d and g/kg BW) displayed a treatment × period interaction ($P < 0.01$). Supplement intake (kg/d) of heifers consuming pelleted supplement was 40 and 46% greater than heifers consuming loose supplement in period 1 and 2, respectively ($P \leq 0.02$). Supplement intake (g/kgBW) of heifer consuming pelleted supplement tended to be greater than heifers consuming loose supplement in period 1($P = 0.05$) and was

47% greater in period 2 ($P < 0.01$). Overall, supplement intake in period 1 was less than half that of period 2, averaging 0.50 and 1.14 kg/day, respectively ($P < 0.01$). We saw a treatment × year interaction for heifer intake rate ($P < 0.01$) with heifers offered pelleted supplements consuming 2.8 and 1.7 times faster than heifers offered loose supplement in year 1 and 2, respectively ($P < 0.01$). Additionally, intake rate was 22% lower in period 1 as compared to period 2 ($P < 0.01$) averaging 115 and 147 g/min. We observed a treatment × period interaction ($P = 0.03$) for time spent at the supplement feeder with heifers fed pelleted supplements spending less time at the feeder during period 1 ($P = 0.02$) compared to heifers fed loose supplement. However, no difference was observed in period 2 ($P = 0.57$) with heifers spending on average 14.5 minutes per day at the supplement feeders. Variation in supplement intake (% CV) was greater in period 1 compared to period 2, averaging 119 and 91 %, respectively ($P = 0.03$). In addition, variation in supplement intake was higher in year 2 than year 1, averaging 122 and 88 % ($P = 0.03$).

DISCUSSION

Ruminate production systems research continues to strive for precision management of nutrient use in grazing environments with strategic supplementation approaches that optimize the use of forage resources. In extensive rangeland environments, supplements are often provided in self-fed forms because of the difficult terrain, lack of accessibility to the animals, and reduced labor requirements (Bowman and Sowell, 1997; Kunkle et al., 2000). Methods to limit intake of free-choice self-fed supplements often involve the use of salt combined with various changes in texture, supplement forms, bitterness, and hardness. These methods, however, often result in considerable intake variation and, as a result, reduced effectiveness of nutrient delivery.

Our study focused on the intake and intake behavior of heifers consuming loose versus pelleted forms of the same supplement. Pelleting increased supplement intake by 30 to 50% as compared to the same supplement in a loose or granular form. The intake levels of our study were similar to those reported by Wyffels and coworkers (2020) in a winter grazing environment where cattle consumed a pelleted salt-limited supplement at a rate of .5 to 2.5 grams/kg body weight/day. In addition, yearling heifer intake expressed on a body weight basis was higher during periods of cold stress compared to mature cows across the two-year study. Supplement intake rate (grams per minute) was 1.8 to 2.7 times greater with the pelleted supplement suggesting that the "intake-limiting" effects of salt was dramatically reduced in the pellet form. Since the majority of the oral cavity is filled by the tongue of the beef cow (Church, 1974; Cheeke, 2010), a loose-form supplement with more surface area most likely covers more gustatory or taste bud receptors compared to a pelleted form. Therefore, the prehensile grasping of supplement by a heifer may result in larger bite sizes due to the hardened texture of a pelleted-form and less surface area contact with taste buds on the tongue. This assumes that the negative aversion to high salt is mediated through gustatory or taste bud receptors rather than digestive or metabolic effects of the increased salt.

Corresponding to large increases in supplement intake and intake rate (grams/minute); time spent at the supplement feeder was reduced early in the grazing period and did not differ in the latter portions of the grazing period for heifers consuming pelleted supplement compared to heifers consuming the loose form. Time spent at the supplement feeders are surprisingly consistent ranging from 5 to 15 minutes per day and are similar to other studies using similar research technology but other supplement forms and forage conditions (Rueter et al., 2017; McClain et al., 2020; Wyffels et al., 2020). Therefore, the increase in supplement intake did not result in increased time at the supplement feeder allowing the animals equal access to grazing opportunities.

Variation of supplement intake (% CV) was not influenced by supplement form but declined in the later portions of the grazing season. However, variation of supplement intake ranged from 80 to 120 % of the mean intake. This observation is consistent with recent research evaluating salt-limited supplement intake (Rueter et al., 2017; Williams et al., 2018; Wyffels et al., 2020) as well as researchers evaluating baked molasses block intake which combine salt, texture and hardness intake limiter mechanisms (McClain et al., 2020; Wyffels et al., 2020b; Parsons et al., 2021). The decrease in intake variation later in the grazing period has also been observed by other researchers (McClain et al., 2020; Wyffels et al., 2020b).

Supplement intake increased and variation in supplement intake declined in the second half of the grazing period. While heifer gains for this study would be considered adequate over the 84-d grazing periods; forage quantity and quality (Table 2) was highest at the beginning of the grazing period and declined to levels below the nutrient requirements of growing yearling heifers for the second half of the grazing period (NASEM, 2016). Similar to our study, other researchers have observed forage quality/quantity impacts on supplement intakes with intake increasing with declining forage quality and availability (Wagnon, 1965; Ducker et al., 1981; Bowman and Sowell, 1997). It has also been reported that the limiting effects of salt on supplement intake decline over time with ruminants increasing tolerance to high salt levels when fed for long periods (Kunkle et al., 2000).

Implications

Our results suggest that salt-limited supplements have a high degree of overall intake variation including variation between animals, over time periods and across years. Physical form modification, such as pelleting, does have a masking effect on the intake limiting influence of supplemental salt as indicated by the higher intake and intake rate of the pelleted supplement. Therefore, pelleting of supplements may be an effective tool in increasing the intake of self-fed supplements. In addition, supplement intake increases over time with an increasing delivery of nutrients with declining forage quality and availability. This research contributes to the continued efforts to refine strategic supplementation practices that provide the right amount of nutrients, to the target animals, at the right time.

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Table 1. Composition of supplements developed for yearling heifers grazing summer pastures.

	Loose	Pelleted
Ingredient	Percent	Percent
Wheat Midds, STD	57.10	53.54
Salt, Bulk	25.00	25.00
Soybean - Hi Pro	8.50	9.50
Calcium Carbonate	5.50	5.45
Molasses, Cane	—	5.00
Lots-O-Lass	2.50	—
Bentonite Powder	1.00	1.00
Phos 21% Dical	0.15	0.25
CHS TM- Range[2]	0.10	0.10
Bovatec 91-Dry[1]	0.07	0.07
Selenium 1600	0.06	0.06
CHS PN VT-Range[2]	0.02	0.02
Chemical		
TDN	48.68	47.64
CP	14.14	14.09
ADF	6.56	6.23
NDF	21.09	19.92

[1]Bovatec® by Zoetis Services LLC, Parsippany, NJ
[2]CHS Inc., Sioux Falls, SD

Table 2. Forage production (kg/ha) and composition (%) of improved summer pastures grazed by yearling heifers during summer grazing period (84 d) over two years in Bozeman, MT, USA.

	Production	DM	TDN	CP	NDF	ADF
Year 1						
Day 42	1915	93.7	61	8.9	57.7	35.1
Day 84	719	93.3	59	5.3	65.2	42.1
Year 2						
Day 0	2181	92.3	61	9.9	57.5	36.1
Day 42	1082	94.7	57	5.8	72.1	45.4
Day 84	659	94.9	60	5.9	60.8	37.2

Table 3. Influence of supplementation and form of supplement on yearling heifer performance over two summers grazing improved dryland pastures.

	Treatments[1]				*P* values		
Initial	Control	Loose	Pelleted	SEM[2]	TRT[3]	YR[4]	TRT×YR[5]
Body Wt, kg					0.99	<0.01	0.88
Year 1	449.0	449.0	449.0	6.23			
Year 2	330.0	324.0	329.0	6.18			
Body Cond.					0.88	<0.01	0.93
Year 1	5.14	5.11	5.14	0.06			
Year 2	4.49	4.40	4.47	0.06			
0-42 d							
Δ Body Wt, kg	45.80	43.80	42.40	1.44	0.62	0.20	0.62
Δ Body Cond.					0.26	<0.01	0.85
Year 1	0.13	0.29	0.17	0.07			
Year 2	0.50	0.61	0.46	0.55			
42-84 d							
Δ Body Wt, kg					0.84	<0.01	0.21
Year 1	23.0	24.7	23.0	2.28			
Year 2	49.1	54.0	57.1	2.22			
Δ Body Cond.					0.34	0.03	0.01
Year 1	0.39	0.52	0.37	0.08			
Year 2	0.15	-0.75	0.25	0.08			
0-84 d							
Δ Body Wt, kg					0.69	<0.01	0.42
Year 1	67.0	67.7	64.7	2.58			
Year 2	96.8	97.7	100.4	2.57			
Δ Body Cond.					<0.01	0.22	<0.01
Year 1	0.53	0.79	0.54	0.07			
Year 2	0.65	0.54	0.71	0.07			

[1]Treatments are 1). Control, no supplement, 2). Supplement in loose form, 3). Supplement in pelleted form
[2]SEM = Standard Error (N=20)
[3]Treatment main effect
[4]Year main effect
[5]Treatment by year interaction

Table 4. Influence of physical form of supplement, loose vs. pelleted, on supplement intake behavior of yearling cattle grazing dryland pastures.

Item	Treatments[1]		SEM[2]	*P* values				
	Loose	Pelleted		TRT[3]	PD[4]	YR[5]	TRT×PD[6]	TRT×YR[7]
Intake, kg				<0.01	<0.01	0.80	<0.01	0.58
0-42 d	0.42	0.59	0.05					
42-84 d	0.93	1.35	0.05					
Intake, g/kg BW				<0.01	<0.01	<0.01	<0.01	0.92
0-42 d	1.16	1.53	0.14					
42-84 d	2.19	3.22	0.14					
Intake rate g/min				<0.01	<0.01	<0.01	0.10	<0.01
Year 1	80.4	226.6	6.90					
Year 2	79.8	137.5	7.03					
Time at supp., min/d				0.12	<0.01	<0.01	0.03	0.24
0-42 d	10.10	7.13	0.90					
42-84 d	14.87	14.14	0.90					
Intake, CV				0.20	0.03	0.03	0.28	0.56
0-42 d	137.4	99.9	13.5					
42-84 d	95.2	87.2	13.7					

[1]Treatments are 1). Control, no supplement, 2). Supplement in loose form, 3). Supplement in pelleted form
[2]SEM = Standard Error (N=20)
[3]Treatment main effect
[4]Period main effect
[5]Year main effect
[6]Treatment × period interaction
[7]Treatment × year interaction

Figure 1. SmartFeed Pro (C-Lock Inc., Rapid City, SD USA) Feed Unit Trailer. Trailer has four feeding stations with two feeders randomly assigned to each treatment supplement.

CHAPTER FOUR

IMPACTS OF INCREASING LEVELS OF SALT ON INTAKE, DIGESTION, AND RUMEN FERMENTATION WITH BEEF CATTLE CONSUMING LOW-QUALITY FORAGES

Contribution of Authors and Co-Authors

Author: H.C. White

Contributions: Main author and lead scientist responsible for data collection, data analysis and interpretation, and drafting of this thesis.

Co-Author: N. G. Davis

Contributions: Critical in data collection, data analysis and thesis revisions.

Co-Author: M. L. Van Emon

Contributions: Aided in experimental design and revisions.

Co-Author: S. A. Wyffels

Contributions: Critical in experimental design, data collections, data analysis, and revisions.

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Contributions: Critical in experimental design, data collection, data analysis and interpretation, and revisions for this thesis.

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ABSTRACT

The objectives of this study were to evaluate the impacts of supplemental salt levels on forage intake, water intake, dry matter digestibility, and rumen fermentation. Six ruminally cannulated, Angus crossbred heifers (14 mo of age; 449 kg ± 24 kg BW) were used in a dual 3X3 Latin square design. The heifers were housed in individual stalls with two animals assigned to each treatment per period. Salt treatments were mixed into a protein supplement of 50% cracked corn and 50% soybean meal and fed at 0.3% of shrunk BW. Salt treatments consisted of: 1) control, no salt (CON), 2) 0.05% of BW salt (LOW), and 3) 0.1% of BW salt (HIGH). Each period included a 14 d diet adaptation, 6 d of sample collection, 1 d collection of rumen fluid samples for ruminal and microbial profiles. Individual forage dry matter intake, water intake, and dry matter digestibility were measured during the 6 d collection period. Rumen pH, ammonia levels, and VFA concentrations were measured during the 1 d ruminal profile. Rumen DM and liquid fill were determined with a 5 hr post feeding rumen evacuation. Supplemental salt had no influence on forage intake ($P = 0.20$) expressed on a kg/day basis yet tended to decrease ($P = 0.06$) with increasing levels of salt when expressed on a grams/kg body weight basis. Dry matter digestibility was not influenced by salt levels ($P > 0.05$), but DM fill tended to increase with increasing salt levels ($P = 0.07$). Water intake and liquid fill, however, increased with increasing level of salt ($P < 0.01$) with an 18.9% increase in water intake and 16.6% increase in liquid fill (l) compared to control animals. Ruminal pH and ammonia levels both decreased with increasing salt ($P < 0.01$). Acetate concentration and acetate: propionate ratio increased with increasing levels of salt (*P* <

0.01). In contrast, isobutyrate and butyrate concentrations decreased with increasing levels of salt ($P < 0.01$). Our research suggests that increasing levels of salt modifies rumen fermentation and digestion. Results from this research provides additional information on how high salt diets can impact nutrient digestion in beef cattle.

Keywords: Beef cattle, digestibility, intake, rumen fermentation, salt-limited supplement

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INTRODUCTION

Self-limited supplements are popular among beef cattle producers that utilize low quality forage resources as a main feed source (DelCurto et al., 2000). One of the main limitations to providing self-fed supplements to grazing cattle is the inability to control individual animal consumption of supplement (Bowman and Sowell, 1995). Past studies have evaluated the intake variation of individual supplement consumption and have found that some animals refuse supplements altogether (nonfeeders), while others consume excessive amounts (Bowman and Sowell, 1997; Williams et al., 2018; Wyffels et al., 2018). The inability to regulate supplement intake results in an asynchrony between animal nutrient requirement and nutrient supply (Bowman and Sowell, 1995).

Salt (NaCl) is the most common intake limiter because it is readily available, generally safe, and salt level can be modified to achieve the desired intake amount (Kunkle et al. 2000). Labor costs are therefore lowered because large amounts of supplement can be placed in a self-feeder and left in the pasture (Bowman and Sowell, 1997). However, daily individual intake of salt-limited supplement can be highly variable (Williams et al., 2018; Wyffels et al., 2018). This high variability of self-fed supplement intake between individuals can have negative effects on the profit of the producer by increasing costs (Bowman and Sowell, 1997), however little is known on the effects of high salt levels on the intake and digestion of low-quality roughages. Impacts could be extremely important as salt has been known to affect the osmotic gradient, regulation of water balance and control of the acid-base balance (NASEM, 2016).

The objectives of this study were to evaluate the impacts of increasing supplemental salt levels on forage intake, water intake, digestibility, and rumen fermentation of beef cattle consuming high fiber, low-quality forages. We hypothesized that increasing levels of salt modifies rumen fermentation and digestion by increasing water levels and effecting kinetics variables which in turn can affect digestibility and rumen fermentation.

MATERIALS AND METHODS

Experimental procedures described herein were approved by the Agriculture Animal Care and Use Committees of Montana State University (#2017-AA09). All animals used in this study were provided by the Montana Agricultural Experiment Station, and the study was conducted during the summer period at the Bozeman Agriculture Research and Teaching (BART) farm at Montana State University in Bozeman, MT.

Six Angus crossbred heifers (14 mo of age; 449 kg ± 24 kg BW) were surgically fitted with a ruminal cannula (Bar Diamond, Inc. Parma, ID, USA), housed in individual stalls, and randomly assigned to 3 supplemental treatments in dual 3X3 Latin square design. Two animals were assigned to each treatment per period to determine the impact of salt level on DMI, water intake, dry matter digestibility, digesta kinetics and rumen fermentation. Salt treatments consisted of: 1) control, no salt (CON), 2) 0.05% of BW salt (LOW), and 3) 0.1% of BW salt (HIGH). A protein supplement of 50% cracked corn and 50% soybean meal fed at 0.3% of BW was mixed with salt treatments resulting in a total supplement composition fed at 0.3%, 0.35%, and 0.4% for CON, LOW, and HIGH, respectively. Diets were formulated to meet or exceed nutritional requirements for yearling heifers gaining 0.5 kg/day (NASEM, 2016). Chopped grass hay was used as the base ration and was provided daily at 120% of the average daily intake of the previous 3 days (Table 1). Before the start of the experiment, heifers were adapted to a salt-limited (25% salt) supplement for 14 days prior to the initiation of the trial. Each period included a 14 d diet adaptation, 6 d of sample collection, and 1 d collection of rumen fluid samples for ruminal and microbial profiles. Orts were collected daily, and each animal's daily forage consumption was calculated. Supplement/salt treatments were provided at 0800 and then after total consumption of supplement, the basal diet was offered.

During the 6-d collection period, feed, supplement, orts, and fecal output were measured for each individual animal and used to calculate total track DM digestibility. Daily water intake was measured by weighing disappearance corrected for evaporation. Feed, supplement, and ort samples were dried at 55° C for 48 h and fecal samples were dried at 55° for 96 h in a forced air oven and ground to pass through a 1 mm screen using a Wiley mill. Feed samples were analyzed for DM, CP, NDF, and ADF (Van Soest, 1967).

On the 20th day of each period, the rumen was dosed with a liquid marker of Cromium EDTA at hour 0 or 0800. Samples were then taken at hours 0, 3, 6, 9, 12, 18, and 24 to determine liquid kinetics. Liquid kinetics were calculated using atomic absorption spectroscopy with a Perkin Elmer AAnalyst 300 and protocols from the Laboratory Procedures in Animal Nutrition Research (NMSU Lab Manual, Galyean). Rumen fluid pH measurements were taken immediately after extraction, then samples were stored at -20° C. Rumen fluid samples were analyzed for ammonia (NH_3-N) concentrations using methods similar to those described by Sigma Technical Bulletin #640, Chaney & Marback (1962), Horn & Squire (1967), and Weichselbaum et al., (1969). Rumen fluid samples were also analyzed for individual volatile fatty acid (VFA) concentrations using a gas chromatography procedure similar to that described by Baumgardt (1964). Ruminal contents were thoroughly mixed and subsampled in duplicate to determine DM fill and digesta kinetics 3 hours post feeding on day 21 of each period via ruminal cannula (Van Soest, 1994).

The effects of salt level on intake, water consumption, and digesta kinetics were analyzed using an ANOVA with a generalized linear model for a replicated Latin square design. The effects of salt level on VFAs, pH, and ammonia were analyzed using ANOVA with generalized mixed models for a repeated measure analysis in a replicated Latin square design. Data were plotted and log-transformed if needed to satisfy assumptions of normality and homogeneity of variance. Statistical significance was accepted at an alpha of 0.05 and trends were considered between 0.05 and 0.10. All statistical analyses were performed in R (R Core Team 2017).

RESULTS

Influence of salt level on intake digestibility and rumen fill are listed in Table 2. Salt level had no influence on total forage intake (kg/day, P = 0.20), dry matter digestibility (P = 0.75), or NDF digestibility (P = 0.95). This is similar to past studies that found no effect on nutrient digestion with high salt diets (Archer, 1952; Cardon, 1953; Nelson et al., 1955). However, intake expressed on a grams/kg body weight tended (P =0.07) to decrease with increasing levels of salt, this displays an inefficiency since the goal of supplementation is to increase intake of available forage. Similarly, dry matter fill tended to increase with increasing levels of salt or dry matter fill (P = 0.07). An increase in DM fill suggests a decreased digestion rate which can negatively impact performance.

Increasing salt level unsurprisingly increased water intake and liquid fill (P < 0.01) ranging from 50.8 to 60.4 and 62.7 to 73.1 liters, respectively. Increased water levels can contribute to liquid kinetics, affecting liquid fill, liquid dilution rates, and flow rate within the rumen which can be correlated with digestibility (Harvey et al., 1986), and was observed in our results. Fluid dilution rate increased linearly with increased salt levels (P = 0.04), but fluid flow rate, and turnover time were not influenced (P = 0.20). Increased fluid dilution rate can impact the microbial community and digestibility by affecting microbial generation time and loss of digestible substrate (Van Soest, 1994).

Ruminal pH and ammonia levels both decreased with increasing salt level (*P* < 0.01; Table 3), although pH levels were still within optimal levels for fermentation. Total VFA concentrations were not influenced (*P* = 0.84) by salt levels averaging 82.8 mol/dl. Acetate molar concentration increased with increasing levels of salt (*P* < 0.01) suggesting decreasing fermentation efficiency with increasing levels of salt, however the at the biological level, this increase may not have a strong negative effect as the increase did not affect the acetate: propionate ratio. In contrast, isobutyrate and butyrate concentrations decreased with increasing salt levels (*P* < 0.01). Valerate displayed a treatment × time interaction with treatment differences observed 3 hours post feeding (*P* = 0.01), with control and low salt having a higher molar concentration compared to the high salt treatment (Figure 1) which could be a result of decreased degradation of soybean meal associated with an increased rate of passage (Harvey et al.,1986). Our results agree with Harvey et al. (1986) who reported that molar proportions of propionate, and the acetate: propionate ratio were not influenced by salt, however our study is specific to cattle consuming low quality forages, which is more representative of grazing cattle on western rangelands.

Although certain ruminal kinetics and fermentation variables were altered by salt intake in the current study, this did not impact overall digestibility or the microbial population and therefore, biological effects may be minimal. Despite the lack of information relative to salt and cattle consuming low-quality forages, impacts of salt on rumen function appear to be similar to research conducted with high concentrate, dairy and finishing rations.

Implications

Our results demonstrate that high salt diets alter rumen function by impacting digesta kinetics and ruminal fermentation. In addition, our research suggests that self-fed, salt-limited supplements may control supplement intake, but, the impact of additional salt may result in lower intakes and less efficient rumen fermentation due to the impact on dilution rate, and rumen fill with beef cattle consuming low-quality forages.

Future research could include increasing the amount of salt in the high treatments. In this study, salt was added to the diet at 0.1%of BW, this level is a conservative estimate and could be increased after acclimating the animal to see a more representative treatment of animals who overconsume. The authors of this study found trends in decreased forage intake and a trend in increased DM fill. Higher levels of salt could potentially make a significant impact on those factors. In addition to increasing salt levels, different frequencies of high salt being fed could have an impact. The authors believe these future research questions would continue to provide additional understanding of the impacts of salt-limited supplements fed to beef cattle.

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Table 1. Composition of protein supplement and chopped grass hay fed to yearling heifers.

Item	DM	TDN	CP	NDF	ADF
Supplement[1]					
Period 1	90.4	86	36.1	9.4	7.1
Period 2	90.6	84	31.9	10.4	5.5
Period 3	90.7	84	30.1	9.9	5.1
Hay					
Period 1	93.6	57	7.5	65.4	42.9
Period 2	96.4	58	7.3	63.1	41.2
Period 3	95.1	57	7.4	64.2	41.5

[1]Supplements were composed of 50% soybean meal and 50% corn

Table 2. Effect of increasing salt levels on intake, digestibility, and rumen fill of yearling heifers consuming low-quality forages.

	Salt Levels[1]				*P-values*		
Item	CON	LOW	HIGH	SEM	TRT[2]	LIN[3]	QUAD[4]
Forage intake, kg	9.5	9.6	9.2	0.14	0.20	0.16	0.22
Supplement intake, kg	1.0	1.2	1.4	0.01			
Total intake, kg	10.5	10.6	10.2	0.14	0.20	0.19	0.21
Forage intake, g/kg BW	25.6	25.3	24.3	0.33	0.06	0.03	0.42
Supplement intake, g/kg BW	2.7	3.2	3.7				
Total intake, g/kg BW	28.3	28.0	27.0	0.33	0.06	0.03	0.42
Water intake, l	50.8	53.1	60.4	1.30	<0.01	<0.01	0.15
DM digestibility, %	56.3	56.3	55.0	0.88	0.75	0.32	0.54
NDF digestibility, %	51.2	51.3	50.6	1.54	0.95	0.80	0.86

[1]Salt levels include 1). CON, no salt, 2). LOW, 0.05% of BW, and 3). HIGH, 0.1% of BW

[2]Treatment main effect

[3]Linear preplanned contrast

[4]Quadratic pre planned contrast

Table 3. Effect of increasing salt levels on fluid dilution rate, fluid flow rate, ruminal fluid volume, turnover time, liquid fill, and dry matter (DM) fill of yearling heifers consuming low-quality forages.

	Salt Levels[1]				*P-values*		
Item	CON	LOW	HIGH	SEM	TRT[2]	LIN[3]	QUAD[4]
Fluid dilution rate, %/h	10.23	11.02	13.40	0.74	0.04	0.05	0.06
Fluid flow rate, L/h	8.36	7.82	7.17	0.49	0.29	0.45	0.17
Ruminal fluid volume, L	62.18	69.31	72.58	1.08	>0.01	>0.01	0.18
Turnover time, h	8.35	10.99	10.50	1.00	0.20	0.16	0.24
Liquid fill, l	62.7	69.9	73.1	1.09	<0.01	<0.01	0.18
DM fill, kg	10.8	11.5	12.1	0.33	0.07	0.23	0.86

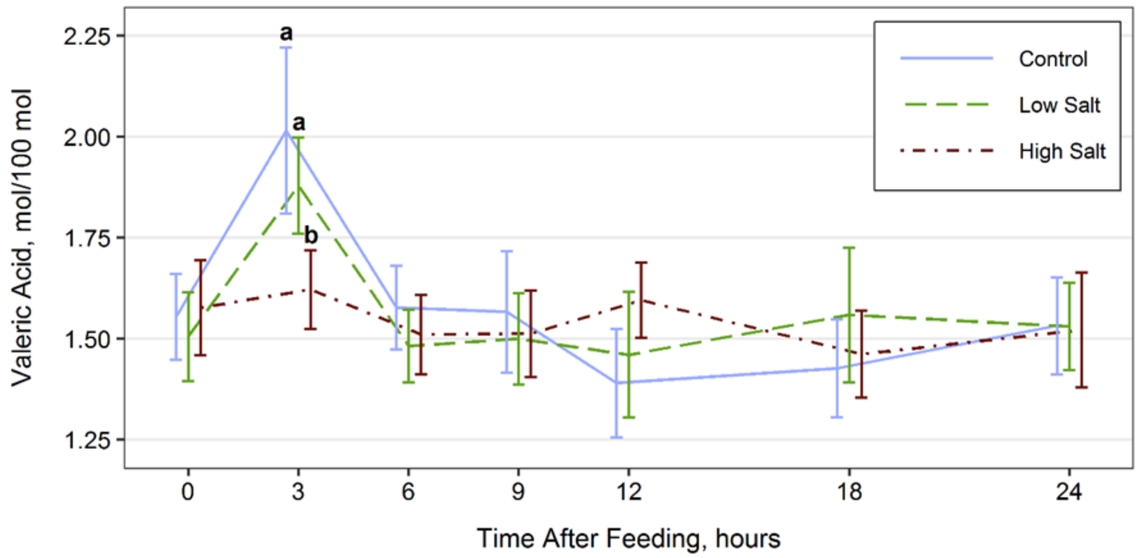
[1]Salt levels include 1). CON, no salt, 2). LOW, 0.05% of BW, and 3). HIGH, 0.1% of BW
[2]Treatment main effect
[3]Linear preplanned contrast
[4]Quadratic preplanned contrast

Table 4. Effect of salt levels on ruminal parameters of yearling heifers consuming low-quality forages.

	Salt Levels[1]				*P - values*		
Item	CON	LOW	HIGH	SEM	TRT[2]	LIN[3]	QUAD[4]
pH	6.90	6.87	6.76	0.37	<0.01	<0.01	0.13
Ammonia, mg/dl	4.41	3.92	3.53	0.34	0.01	<0.01	0.84
Acetic, mol/100 mol	68.60	69.23	69.62	0.33	<0.01	<0.01	0.67
Propionic, mol/100 mol	16.66	16.71	16.66	0.17	0.94	0.97	0.73
Isobutyric, mol/100 mol	1.52	1.43	1.40	0.02	<0.01	<0.01	0.48
Butyric, mol/100 mol	9.92	9.42	9.16	0.23	<0.01	<0.01	0.31
Isovaleric, mol/100 mol	1.73	1.65	1.63	0.06	0.21	0.09	0.57
A:P ratio[5]	4.14	4.19	4.21	0.06	0.59	0.33	0.74
Total VFAs, mol/dl	84.16	82.55	81.51	3.90	0.84	0.56	0.94

[1]Salt levels include 1) CON, no salt, 2) LOW, 0.05% of BW, and 3) HIGH, 0.1% of BW
[2]Treatment main effect
[3]Linear preplanned contrast
[4]Quadratic pre planned contrast
[5]Acetate:propionate

Figure 1. Effects of salt levels in supplement on concentration of valeric acid with an hour × treatment interaction (*P* =0.01). Treatments include 1) CON, no salt, 2) LOW, 0.05% of BW, and 3) HIGH, 0.1% of BW. Means within hour that do not share a common letter differ (*P* <0.05)



CHAPTER FIVE

CONCLUSIONS

The research projects detailed in chapters 3 and 4 were conducted to evaluate the influence of salt level and physical form of salt-limited supplements on supplement intake behavior, intake, digestion, ruminal fermentation characteristics and beef cattle performance. These projects were part of a continuing series of supplementation projects at Montana State University focused on strategic supplementation. Specifically, Wyffels et al. (2018) observed beef cows during a winter grazing trial with high amounts of individual variation, with some cows consuming up to 9 kg of a 25% salt, pelleted protein supplement. Additionally, the authors of that study reported variation across time with some individuals going 3-4 days without supplement. A similar study by Williams (2018) measured intakes and intake behavior of steers grazing dormant tallgrass prairie and consuming a loose form, salt-limited supplement. Salt was added at 25, 30, and 45% for d 1 to 7, 8 to 14, and 15 to 56, respectively. They observed an overall supplement intake mean of 0 to 1.21 kg per steer per day. The CV for supplement intake across animals was 51%, whereas the CV for intake across day within animal was 72%. This high amount of variation between individuals and across days raised questions the efficacy of salt-limited self-fed supplements. The authors of this study wanted to know 1) if physical form of supplement influenced individual supplement intake, intake CV, and intake behavior, and 2) if increasing supplemental salt levels has an impact on forage intake, water intake, dry matter digestibility, and rumen fermentation of beef cattle consuming high fiber, low-quality forages. We hypothesized that pelleting a salt-limited supplement would have masking effects and that increasing levels of salt would modify rumen fermentation and digestion.

In the first study, authors reported that while supplementation and form of supplement did not directly influence performance variables (Table 3.3) this was most likely due to the season and available forage, with control animals having sufficient amounts of nutrients available during the summer grazing season (Table 3.2). Intake CV was not influenced by form (Table 3.4, $P = 0.21$). The lack of impact on performance variables agrees with past studies that reported no consistent effect on the performance of beef steers with salt-limited supplements (McIlvain and Savage, 1951; Chicco et al., 1971; Harvey et al., 1986). Even though there was no significant effect of treatment on CV, the data displayed a period and year effect ($P = 0.03$) with higher variation in the first period (d 0 to 42) and greater variation in year 2. This agrees with past research on the influence of season and year on intake CV (Bowman and Sowell, 1997; Kunkle et al., 2000).

The pelleted group consumed more supplement with the greatest magnitude of difference observed during the 42-84 d period. Additionally, intake rate showed a treatment × year interaction ($P < 0.01$) with heifers fed pelleted supplements consuming the supplement at a faster rate ($P < 0.01$) and the magnitude of difference was greatest again during the latter period ($P < 0.01$). The pelleted group also spent less time at the feeder during the 0-42 d period ($P < 0.01$). Since the majority of the oral cavity is filled by the tongue of the beef cow (Church, 1974), a loose-form supplement with more surface area most likely covers more gustatory or taste bud receptors compared to a pelleted form. With the pelleted treatment, a cow may have been able to get a larger bite due to the hardened texture of a pelleted-form with less contact of salt with taste buds on the tongue, and therefore able to consume more and at a faster rate. Intake rate would be important to the animal as its correlation to performance of the animal by the influence on total intake (Frisch and Vercoe, 1969). Pelleted animals could have had more time to graze with less time spent at the supplement, making the animal more efficient at utilizing that resource (DelCurto et al., 1990; Wyffels et al., 2018) however, this was not reflected in measured performance variables within this study.

These results suggest that self-fed, salt-limited supplements have a high degree of overall intake variation including variation between animals, over time periods and across years. This research reports that physical form modification, such as pelleting, may have a masking effect as indicated by the higher intake and intake rate of the pelleted supplement, and the loose version is more effective in limiting intake with the target of .91 kg. However, if cattle are not consuming enough supplement to reach the target amount, a pelleted version may increase their intake by masking the effect of salt. Overall, all this research contributes to the continued efforts to refine strategic supplementation practices that provide the right amount of nutrients, to the target animals, at the right time.

The second study included a digestion study to evaluate the effects of increasing salt levels on forage intake, water intake, dry matter digestibility, and rumen fermentation of beef cattle consuming high fiber, low-quality forages. Increasing supplemental salt levels had no influence on total forage intake (kg/day, $P = 0.20$). However, intake expressed on a grams/kg body weight tended ($P = 0.07$) to decrease with increasing levels of salt, which has been reported in past studies (Meyer et al., 1955; Masters et al., 2005). Decreased forage intake directly effects the animal's productivity and efficiency at utilizing available forage. Similarly, dry matter fill tended to increase with increasing levels of salt ($P = 0.07$). An increased dry matter fill could be indicative of a slower digestion rate. Increasing salt levels increased water intake and liquid fill ($P < 0.01$) ranging from 50.8 to 60.4 water intake and 62.7 to 73.1 liters of fill, which agrees with studies reported in the dairy and concentrate feeding industries (Meyer et al., 1955; Rogers et al., 1982; Wiedmeier et al., 1987). Fluid dilution rate increased linearly with increased salt levels ($P = 0.04$), but fluid flow rate, and turnover time were not influenced ($P = 0.20$). Dilution rate has been known to influence other variables such as the microbial community and digestibility by affecting microbial generation time and loss of digestible substrate (Van Soest, 1994). Additionally, dilution rate may increase the flow of starch out of the rumen, therefore reducing the rate of fermentation (Rogers et al., 1982). There was no reported influence on dry matter digestibility ($P = 0.75$), or NDF digestibility ($P = 0.95$). This is similar to past studies that found no effect on nutrient digestion with high salt diets (Archer, 1952; Cardon, 1953; Nelson et al., 1955) and suggests that while it had an influence on certain rumen parameters, it may not be significant biologically.

Ruminal pH and ammonia levels both decreased with increasing salt level ($P < 0.01$; Table 4.3) which may negatively impact fermentation. However, total VFA concentrations were not influenced ($P = 0.84$) by salt levels averaging 82.8 mol/dl. Acetate molar concentration increased with increasing levels of salt ($P < 0.01$) suggesting decreasing fermentation efficiency with increasing levels of salt, however the at the biological level, this increase may not have a strong negative effect since the acetate: propionate ratio and digestibility was not influenced. In contrast, isobutyrate and butyrate concentrations decreased with increasing salt levels ($P < 0.01$). Valerate displayed a treatment × time interaction with treatment differences observed 3 hours post feeding ($P = 0.01$), with control and low salt having a higher molar concentration compared to the high salt treatment (Figure 1). This could be a result of decreased degradation of soybean meal, however there was no influence on flow rate or turnover time which it is typically associated with (Harvey et al., 1986). These results somewhat agree with studies performed in the dairy industry with differences in feed and management which reported high salt diets to decrease ruminal pH and ammonia and increase molar proportions of acetate (Croom et al., 1982;Rogers et al., 1982; Wiedmeier et al., 1987). Despite the lack of information relative to salt and low-quality forages, impacts of salt on rumen function appear to be similar to research conducted with high concentrate, dairy and finishing rations. Although certain rumen fermentation characteristics (dilution rate, liquid fill) were altered by salt intake in this study, this did not impact overall digestibility, total VFAs, or the microbial population.

The results of the second study demonstrate that high salt diets alter certain rumen parameters and suggests that self-fed, salt-limited supplements may control intake, but may also result in lower intakes and less efficient rumen fermentation due to the influence on rumen kinetics with beef cattle consuming low-quality forages. Although there was a statistical significance on certain ruminal parameters, the biological effects seem to have been minimal.

Future research is warranted in the field of salt-limited supplements. After concluding the experiments reported in this thesis, other potential research objectives would be to increase levels of salt, and deliver the increasing salt levels at different frequencies. Heifers on the high salt treatment in this study were fed salt daily at 0.1% of BW. It would be interesting to see if higher salt levels would display a stronger influence, while also being more representative of the animals in recent studies that consumed extremely high amounts (Williams et al., 2018; Wyffels et al., 2018), but on an infrequent basis . Authors hypothesize that higher levels of salt (above 0.1% BW), may significantly influence forage intake and DM fill. Furthermore, different frequencies of high salt being fed could have an impact. All levels in this study were delivered daily. In recent studies, variation was observed in both supplement intake by individual, but also across days. Some animals were reported to consume over-target, high amounts and then go several days without consuming supplement. The authors believe these future research questions would provide a better understanding of the impacts of salt-limited supplements fed to beef cattle. In conclusion, the use of salt-limited supplement as a method for self-feeding animals within a cowherd should be practiced with some caution.

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