

IMPACT OF INCREASING NACL LEVELS IN LIVESTOCK DRINKING WATER ON THE
INTAKE AND UTILIZATION OF LOW-QUALITY FORAGES BY BEEF CATTLE

by

Makae Frances Nack

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Animal Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2022

©COPYRIGHT

by

Makae Frances Nack

2022

All Rights Reserved

ACKNOWLEDGEMENTS

I could not have accomplished this thesis nor be the person I am today without the unwavering support I received. First and foremost, I would like to sincerely thank my advisor Dr. Tim DelCurto. He has been extremely supportive and encouraging throughout the years. I am forever grateful for his wealth of knowledge, time, guidance and humor he has shared with me to aid in completing my research. I would also like to express my gratitude towards Hannah Delcurto-Wyffels for recognizing my passion for agriculture and giving me a chance to first work for and then attend grad school. This opportunity provided me with irreplaceable experience as well as knowledge. Lastly, I would also like to deeply thank Megan Van Emon and Sam Wyffels for all of their assistance and guidance.

Additionally, I am grateful for the DelCurto/Van Emon lab groups who supported and encouraged me, and assisted in collecting samples. Thank you for getting up at all hours of the night, evacuating more rumens than thought possible and shoveling more crap than most people have seen. I could not have survived this thesis without their assistance and support. The MSU BART Farm crew assisted in laborious and non-glamorous jobs without complaint and I thank them sincerely.

Lastly, I would like to acknowledge my family. They have always pushed me to work harder, be better, and study more. They always supported me in all of my endeavors that lead me to where I am. Their love, support and encouragement to shoot for the stars is priceless and words cannot begin to express how thankful I am for them. I am the person I am today, because of them.

TABLE OF CONTENTS

1. GENERAL INTRODUCTION.....	1
Ruminant Livestock Industry	1
2. LITERATURE REVIEW.....	5
Forage Intake and Performance	5
Digestibility.....	6
Volatile Fatty Acids.....	9
Water.....	12
Salt.....	17
Sources of Salt in Ruminant Diets.....	19
Salt in Supplements.....	21
Rationale for Research.....	25
References Cited.....	28
3. IMPACT OF INCREASING NACL LEVELS IN LIVESTOCK DRINKING WATER ON INTAKE AND UTILIZATION OF LOW-QUALITY FORAGES BY BEEF CATTLE.....	34
Abstract.....	37
Introduction.....	37
Materials and Methods.....	41
Results	44
Study 1	44
Study 2	45
Discussion.....	45
Implications.....	51
References Cited.....	52
4. CONCLUSION.....	64
REFERENCES CITED.....	68

LIST OF TABLES

Table	Page
2.1 TDS Levels	14
3.1. Nutrient analysis of Hay.....	59
3.2. Nutrient Analysis of Supplements	60
3.3. Effect of Increasing Levels of NaCl in Livestock Drinking Water on Intake, Digestion and Liquid Kinetics of Cows Consuming Low-Quality Forages and a Salt-Excluded Supplement	61
3.4. Effect of Increasing Levels of NaCl in Livestock Drinking Water on Intake, Digestion and Liquid Kinetics of Cows Consuming Low-Quality Forages and a Salt-Included Supplement	62

LIST OF FIGURES

Figure	Page
3.1. Study Timeline	63

ABSTRACT

Water is one of the most important nutrients for livestock production (Petersen et al., 2015) but its quality is often overlooked in western range settings. The western United States and more specifically, Montana, are prone to variable precipitation and droughts, reducing the quantity and quality of livestock drinking water as well as limited forage quality/quantity. Dormant season grazing of rangeland forages often involves utilizing self-fed, salt limited supplements to meet cattle nutrition requirements and better utilize forage. Self-fed supplements commonly add salt as an intake limiter because it is effective, cheap and necessary in beef cattle diets (Cardon et al., 1951). The objective of this study was to evaluate the impacts of increasing NaCl levels in water on low quality forage intake, digestibility, and rumen fermentation of cattle consuming low quality forage. Eight, ruminally-cannulated, Angus crossbred cows were individually stalled and used in two 4 x 4 Latin squares design. One square was hand fed a non-salt supplement; the second square was fed a salt limiting supplement. Two cows (one from each square) were assigned to one of four water treatments per period: 1) control, no added NaCl; 2) 1000 mg NaCl/L; 3) 2000 mg NaCl/L; and 4) 3000 mg NaCl/L. A 14-day adaption period allowed cattle to acclimate to the water; followed by a 6-day total collection period. Rumen fluid samples were collected on day 22 at hours 0, 4, 8, 12, 18 and 24; and on day 23 a total rumen evacuation was conducted to determine total rumen volume and collect rumen content samples. Increasing levels of NaCl did not influence intake in either study ($P \geq 0.36$). Rumen pH was influenced by water NaCl in study 1 ($P = 0.01$), however, post hoc analysis revealed no differences. Volatile fatty acids in both studies were not affected by NaCl in either study ($P \geq 0.39$). Our results suggest the NaCl levels in our study may have little influence on intake, rumen fermentation and liquid kinetics suggesting NaCl levels up to 3,000 are safe for cattle.

CHAPTER ONE

GENERAL INTRODUCTION

Ruminant Livestock Industry

Water is the most important nutrient for life, simply, all processes of life require clean, high-quality water (Petersen et al., 2015). Ruminants acquire water from drinking, feed sources and normal body processes. The quality of water consumed can have a marked impact on cattle health and performance. However, water quality and its overall role in ruminant nutrition is often overlooked. The water available for livestock consumption can be influenced by environmental factors. Precipitation and droughts can greatly influence total dissolved solids (TDS) and salt (NaCl) levels in water (Petersen et al., 2015). Annual precipitation in Montana averages 25.4 centimeters, with the majority received in spring (Petersen et al., 2015). However, precipitation is highly variable, and Montana is often prone to droughts. Below average precipitation can result in increasing amounts of TDS in drinking water. In Central and Eastern Montana, TDS and NaCl levels in water can be highly variable. A study conducted at USDA-ARS Fort Keogh Livestock and Range Research laboratory near Miles City, Montana, observed 1.5% of samples were above the TDS maximum upper level of 3,000 mg/L (Petersen et al., 2015). A second study conducted by Rinella et al. (2021), concluded that TDS levels are most problematic during drought years due to water evaporation and a higher mineral concentration. High levels of TDS and more specifically NaCl, are unpredictable and can be problematic to cattle causing osmolar imbalances (Van Soest, 1994). High salt levels in water, the minimum and maximum thresholds, and their influence on ruminant nutrition are not well understood.

Roughly half the land in the world is classified as rangelands (Holechek et al., 2004). These lands include rough hillsides, valleys and benches that are difficult to access and are unusable for cultivation and urban development (Holechek et al., 2004). Fortunately, rangelands are ideal for grazing cattle as they can traverse the difficult country and terrain. Many operations in the Western United States are extensive, and rely on rangelands to supply cattle with forage for much of the year. Many of these rangelands are characterized as arid- or semi-arid environments which, in turn, can greatly influence forage quality and quantity (DelCurto et al., 2000). On average, the growing season in Eastern Montana is 110 days (USDA, 2021). The majority of the forages grown in Montana are cool season grasses that green up early and senesce when temperatures turn hot. During the growing season, plants mature and lignify resulting in higher stem:leaf ratios. As a result, forages are often low-quality or senesced for much of the year.

Low-quality forage commonly has low protein ranging from 6-8%. Thus, protein supplements are often supplied to cattle to help improve digestion and meet their necessary protein requirements. Oftentimes, supplements are offered as self-fed, to reduce labor. In self-fed supplementation strategies, free choice supplements are offered with an intake limiter which attempts to restrict supplement intake to the desired quantity. Salt is commonly used to limit intake as it is effective, cheap and essential in the diet (Cardon et al., 1951; Riggs et al., 1953). However, self-fed supplements tend to assume all cattle consume the same amount of supplement. Moreover, Bowman and Sowell (1997), concluded that high intake variation is associated with self-fed supplements.

With high intake variation, greater salt intake levels are observed in cattle consuming large amounts of supplement. Petersen et al. (2015), suggests that cattle have a maximum tolerance for NaCl consumption. Suggesting that cattle consuming large amounts of NaCl in their diet may avoid waters containing large amounts of salts. Alternatively, cattle consuming large amounts of NaCl from their water may avoid or under consume self-fed, salt-limiting supplements. However, there is limited research to support this.

The majority of research evaluating NaCl levels in water were conducted in the 1950's and 1960's. This research mainly evaluated the influence of NaCl on water and forage intake (Weeth et al., 1960; Weeth and Haverland, 1961; Weeth and Hunter, 1971). Ultimately, approximate thresholds and tolerance levels have been agreed upon based on negative impacts on health. Still, we do not understand the subacute affects NaCl has on livestock relating to digestion, ruminal fermentation and liquid kinetics. In addition, few studies have evaluated salt's influence on forage digestion and liquid kinetic, and to date, the results of these studies are conflicting. Some research suggests digestion is improved with the addition of NaCl to the diet (Brandyberry et al. 1987); while others report no alteration (Cardon, 1953). Conflicting data as well as lack of research specific to the interaction of salt containing supplements and salt within livestock drinking water suggests that further research is warranted.

A gap exists in the research concerning self-fed salt-limiting supplementation strategies and how it influences or is influenced by livestock drinking water containing salt. To our knowledge there is no research discussing this interaction and its impact on intake of a low-quality forage intake, digestion and liquid kinetics. This research attempts to shed light on the chronic effects of NaCl (<3,000 mg/kg within drinking sources) on forage intake, digestion and

liquid kinetics, as well as the interaction of salt-limited supplement and increasing NaCl levels in livestock drinking water.

CHAPTER TWO

LITERATURE REVIEW

Forage Intake and Performance

Forage intake is critical for grazing livestock, and heavily influences performance. Typically, average intake is estimated on a metabolic body size (body weight $\text{kg}^{0.75}$) or % body weight basis and is largely influenced by quality (Van Soest, 1994). Low-quality forages typically have high cellulose, hemicellulose and lignin content which are the constituents of neutral detergent fiber (NDF) content (Welch, 1982). Cell wall content of the forage resources, in turn, may restrict feed intake of the forage due to limiting fill, slow passage rate, and suppressed digestibility (Van Soest, 1994). Furthermore, NDF is negatively correlated to intake, which means as plants senesce, intake of these forage declines (Van Soest, 1994). In addition, time spent ruminating increases as forage quality decreases, thus increasing retention time slowing the rate of passage and posing a possible limit to intake (Van Soest, 1994). Therefore, rumen fill potential is an important physiological trait related to intake regulation (Van Soest, 1994). Other factors influencing intake include stage of gestation and gender. Stage of gestation plays a large role in rumen capacity, where third trimester cows have lower ruminal capacity than early gestation or dry cows due to fetus size (Stanley et al., 1993). Males in general are larger, and require greater intake to meet their energy requirements.

Previous research also suggests that water quality and intake can influence forage consumption. Data published by Utley et al. (1970), suggests that cattle will consume 2-4 kg of water per 1 kg of DM intake. In addition, Weeth and co-workers (1960), reported hay intake was

reduced by 74.7% when cattle were offered water containing 20,000 mg/kg NaCl. Weeth and Haverland (1961) reported similar forage consumption results as water quality declined. Utley and company (1970) reported similar results, stating that limited water consumption due to poor quality, can reduce forage consumption. These studies suggest forage and water intake are strongly correlated with one another and low-quality water can influence forage intake.

Digestibility

Nutrient digestibility can be influenced by plant and animal factors. A large influence on digestibility is forage quality. Van Soest (1994) discusses multiple factors related to forage quality including temperature, day length, latitude, water, maturity and whether the forage is a cool season or a warm season variety. Temperature is one of the most important influences on forage quality. Warmer temperatures increase cell wall lignification, reducing digestibility. In addition, quicker metabolic activity occurs at warmer temperatures reducing the quality. Day length also influences metabolic activity through photosynthesis which produces glucose and ammonia from accumulated nitrates. Longer days provide more sunlight and photosynthesis to produce more glucose, thus improving quality. Increased day light also decreases cell wall constituents by increasing amino acids and organic acid formation. In addition, latitude is also suggested to influence forage quality. Cooler temperatures and longer days are associated with higher latitudes, potentially increasing forage quality. Furthermore, plants with limited water/soil nutrients have lower forage production and, structural carbohydrates which may increase digestibility and digesta kinetics (Collins, 1985; Van Soest, 1994). However, optimal amounts of

water and soil nutrients available to plants leads to a larger quantity of forage and, optimal growth rates which, in turn, lead to an increased level of structural carbohydrates which decreases digestibility and slows passage rate of consumed forages (Collins, 1985; Van Soest, 1994). Moreover, as plants mature, lignification, or the increase in lignin linkages, increases and reduces forage digestibility and passage rate (Van Soest, 1994). Mature plants are typically considered low-quality and tend to have high acid detergent fiber (ADF) content. Acid detergent fiber is comprised of the cell wall constituents, cellulose and lignin and is inversely correlated with forage digestibility, where lignin is the main limiter of digestibility (Van Soest, 1994).

In addition, different quality forages, fluids and solids pass through the rumen at different rates (Van Soest, 1994). There are quality differences between warm and cool season grasses. Warm season grasses are lower-quality because they receive more precipitation, are more efficient at photosynthesis, and produce a high quantity of plant material compared to cool season grasses (Van Soest, 1994). Cool season grasses produce a lower quantity but are often higher quality. The majority of Montana rangelands produce cool season grasses. In addition, Montana is located 46 degrees north of the equator, which is a relatively high latitude, and allows for longer days, and cooler temperatures. Montana rangelands receive less than 30 cm of precipitation annually (Peterson et al., 2015), typically allowing for less quantity but greater quality of forage. These environmental factors greatly influencing forage quality on Montana rangelands, and suggests that grasses in Montana will produce a higher-quality forage during the growing season.

Ruminants have an advantage over other species when digesting forages because they can efficiently utilize low-quality forage and convert it into a high-quality protein (Cammack et al.,

2018). Low-quality forages are comprised of large amounts of cellulose which can partially be digested by fermentation in the reticulorumen (Cheek, 2010). Cattle have a large rumen/reticulum relative to body size. This large digestive capacity and body size is correlated to cattle's feeding behavior. Van Soest (1994) discusses forage utilization and digestion by cattle simply stating that cattle are bulk grazers. They are typically unselective and consume large amounts of low-quality forages because of their large mouth size relative to food sources. Thus, a larger rumen is needed to optimize the use of high-fiber forage. As body size increases, retention time also increases which influences digestibility. A larger reticulorumen size has greater capabilities to breakdown and utilize low-quality, fibrous forage. Low-quality forages require increased mastication and rumen mixing/rumination in order to increase surface area and allow for more microbial break down (Van Soest, 1994).

Cattle are able to re-masticate coarse and low-quality forages to reduce particle size and include saliva to extract soluble contents which aids in digestion (Van Soest, 1994). Cattle that consume large amounts of low-quality forage, tend to increase their time ruminating due to lignification (Van Soest, 1994). Low quality forages tend to increase retention time to an average of 40-50 hours (Van Soest, 1994). Furthermore, as intake increases, retention time decreases, potentially decreasing digestibility, which is a main driver for animal performance and depends on forage quality (Van Soest, 1994). Furthermore, particle size reduction is required for the material to pass through the reticulo-omasal orifice (Cheeke, 2010). The fibrous mat also filters particles in the rumen (Cheeke, 2010). Consequently, the reticulo-omasal orifice limits the rate of passage and functions as an intake limiter (Van Soest, 1994). Passage through the reticulo-

omasal orifice and fiber digestion are the main drivers behind low-quality forage intake (Van Soest, 1994).

Volatile Fatty Acids and Microbes

Ruminants are unique because of their symbiotic relationship with microbes that inhabit their rumen. Ruminants provide an ideal environment for the microbes and in turn these microbes are able to breakdown cellulose and provide a source of energy to the ruminant (Russell and Wilson, 1996). The microbes within the rumen include bacteria, protozoa, and fungi.

Bacteria are the most important and can produce up to 70% of dietary energy (Flint and Bayer, 2008). They are also the most numerous within the rumen, upwards of 10^{10} – 10^{11} /ml rumen fluid. They produce enzymes that break bonds linking sugars, freeing up these sugars (Cheeke, 2010). Certain bacteria can also produce cellulase which can break down cellulose, hemicellulose and pectins. This fermentation process is done anaerobically and produces volatile fatty acids (VFAs). Protozoa are the largest in term of size. The concentration of protozoa within rumen fluid ranges from 10^4 - 10^6 /ml. Their specific role is unknown; however, they do consume bacteria and can have cellulolytic capabilities (Cheeke, 2010). Ruminant fungi are the most recent to be discovered within the rumen. They account for about 20% of the microbes in rumen fluid, they number around 10^3 – 10^7 /ml. They are unique due to the fact that they penetrate and break apart lignin via mechanical action, allowing for bacterial invasion (Cheeke, 2010).

Ultimately, the end products of rumen fermentation include VFAs, heat, gasses and microbial protein (Cheeke, 2010). This is done through cellulolytic bacteria producing VFAs, succinate, lactate and formate. Then, other species convert these products to VFAs, carbon dioxide, or methane (Houtert, 1993). Microbial protein is simply, dead microorganisms that pass from the rumen to the abomasum where they are broken down and utilized as protein by the host ruminant. Furthermore, the ruminants' main source of energy is from VFAs (Van Soest, 1994). The VFAs present in the rumen include isobutyric, valeric, and isovaleric acid, however the main three are acetic, propionic, and butyric acid and these can be influenced by diet and methanogenic bacteria population.

Diet influences the concentrations and relative proportions of VFAs in the reticulorumen. High forage diets will have a greater acetate to propionate ratio, whereas a high concentrate diet will have a lower acetate to propionate ratio. Volatile fatty acid concentrations increase immediately after feeding causing the rumen pH to drop. This drop in pH influences the rate of VFA absorption. Blood is typically alkaline and the rumen more acidic, this creates a gradient that draws the VFAs from the rumen into the bloodstream, thus as the rumen pH drops the rate of absorption increases (Van Soest, 1994). Volatile fatty acids need to be absorbed in order to maintain an ideal environment for rumen microbes (Van Soest, 1994). Cellulolytic bacteria prefer a rumen pH above 6.0. When rumen pH falls below 6.0 cellulolytic bacteria cannot grow and fiber digestion is hindered (Stewart, 1977; Grant and Mertens, 1992; Van Soest, 1994). Ruminal pH of steers consuming 5% NaCl in their diet, was 5.6 compared to 6.0 of a control diet (Croom et al., 1985). Similar pH declines were observed by Brandyberry (1991) and, Rogers et

al. (1979). This suggests that salt decreases pH levels in the rumen, however it does not seem to negatively impact digestibility (White et al., 2019).

Some research has evaluated NaCl influence on microbial populations and the rumen environment. Sodium is a growth requirement for the majority of rumen microbes (Caldwell and Hudson, 1974). The specific functions, beyond growth, of Na in microbe function is unknown, however, it cannot be replaced by other ions (Caldwell and Hudson, 1974). The concentrations of Na typically found in the rumen are sufficient for microbial growth (Caldwell and Hudson, 1974). However, salt is recognized as an antimicrobial when provided in high concentrations. It reduces water activity or free water available for microbial growth, and initially prevents the growth of gram-negative bacteria (Feiner, 2006). Eventually, salt is toxic to most bacteria by creating an electrolyte imbalance within the cells (Feiner, 2006). However, the levels of salt and how it impacts the rumen environment are not well understood.

Croom et al. (1982, 1985) noted NaCl levels greater than or equal to 50,000 mg/kg of total diet, shifted rumen fermentation by increasing acetate and decreasing propionate in cattle fed concentrate diets. In addition, Croom et al. (1982) also noted an increase in fecal starch, these coupled together suggest an increase passage rate (Harrison et al., 1975; Hemsley et al., 1975; Croom Jr et al., 1982). Similar to Croom and company (1982, 1985), Rogers (1979), noted an increase in acetate and a decrease in propionate as NaCl levels increased when steers were fed a high concentrate diet. However, when steers were fed a high roughage diet, acetate and propionate ratios were not altered. Wiedmeier et al. (1987) noted an increase in acetate, however propionate was unchanged. Furthermore, Brandyberry and colleagues (1991) noted as NaCl increased there was a decrease in acetate and a greater proportion of propionate with self-fed salt

limiting supplement. However, steers in the latter studies were fed a low-quality forage diet potentially explaining the differences reported in acetate to propionate ratio.

Rogers et al (1979), noted an increase in rumen fluid dilution rate when fed a high concentrate diet. Wiedmeier et al. (1987) also noted an increased dilution rate when steers were fed a high forage diet. Suggesting that, salt within the diet influences water intake as well as osmolarity and increases the liquid flow through the rumen. Furthermore, Wiedmeier et al. (1987) and Rogers et al. (1979) noted that steers on a forage-based diet had an increase in ruminal pH as NaCl levels increased. However, White and company (2019) reported a decline in pH when additional dietary salt was added to a low-quality forage diet. Differences in rumen pH could attribute to differences in diet and quality of forage. These studies suggest high NaCl concentrations tend to shift rumen fermentation regardless of diet.

Water

Water is the most important nutrient for all life processes and is required on a daily basis (Cheeke, 2010), but is often overlooked in western range settings (Kume et al., 2010; Petersen et al., 2015). Water comprises an average of 70% body mass of cattle (NASEM, 2016). In addition, the average water consumption for a dry cow in summer is 45 L, but is influenced by many factors including, size, lactation status, forage base, activity, external temperature, and water quality (Meehan et al., 2015; NASEM, 2016). Ruminants have a greater water requirement than non-ruminants due to suspension of ingesta in the rumen (Cheeke, 2010). Another reason cattle water consumption can be high is because cattle use water for thermoregulation of body temperature (Aiello et al., 2016). Rumination and fermentation produce heat and increase body

temperature (Van Soest, 1994). Webster (1978) reported a 40-80% increase in heat production when sheep began eating (Webster, 1980). Therefore, in hot weather and drought, increased water intake is required for thermoregulation (Aiello et al., 2016). Additionally, cattle will reduce forage intake to aid in reducing heat production and maintain homeothermy (Aiello et al., 2016). It is important cattle maintain their body temperature to perform optimally especially during hot summer months when breeding and early pregnancy occurs.

Digestion, rumen fermentation, body temperature regulation, reproduction and lactation, excretion of wastes, mineral balance and hydration are just a few physiological processes that require water (NASEM, 2016). Low-quality water can negatively affect these processes due to reduced water and forage intake which also slows forage passage rate through the rumen. However, it also suggests lower performance, but tends to increase digestibility and nitrogen retention because of the slower passage rate (NASEM, 2016). Water sources in the Western United states can vary greatly in quality and quantity. The majority of the Western U.S. is arid and semi-arid rangelands (DelCurto et al., 2000). Moisture in these regions is most common in the spring with rain and snow runoff. Rivers, streams, ponds, reservoirs, springs and tanks are water sources commonly available to cattle. These sources vary greatly in quality due to geographical location, year, precipitation, season, recharge site and soil composition (Anderson and Woosley, 2005; Petersen et al., 2015; Alves et al., 2017). One quality factor that is highly variable throughout the Western U.S. is salt concentrations. Additionally, high concentrations of salts in water are most common in arid and semi-arid regions (Beke and Hironaka, 1991). Peterson and coworkers (2015) reported higher levels of Na and total dissolved solids (TDS) in flowing water than in standing water during drought years, suggesting percolation of solutes and

a concentration effect. In general, levels of TDS up to 3,000 mg/L are tolerable, naive cattle may refuse the water due to palatability and diarrhea may be expected, however, it is safe (Beke and Hironaka, 1991; NASEM, 2016). Furthermore, TDS levels above 7,000 mg/L are less tolerable and could potentially be toxic (Table 1; NASEM, 2016). However, understanding what influences water quality is difficult and unclear. Furthermore, these thresholds and symptoms are not well understood nor defined.

TDS (mg/L)	Symptoms
< 3,000	Waters containing less than 3,000 mg/L TDS are tolerable by cattle, however they may cause mild diarrhea and be refused by naïve cattle due to palatability.
3,000-7,000	Waters containing TDS levels between 3,000 and 7,000 mg/L may be refused at first, cause diarrhea, and should be avoided by pregnant and lactating cattle.
7,000-10,000	Waters containing TDS levels between 7,000 and 10,000 mg/L will be refused, cause diarrhea, should be avoided by cattle subject to heat stress or water loss, and it is unfit for pregnant and lactating cattle.
>10,000	Waters containing TDS levels greater than 10,000 are unfit for all classes of cattle, it is toxic and will kill cattle.

Table 1. General recommendations for Total Dissolved Solids in livestock drinking water (Adapted from Berger, 1993).

Early water NaCl concentration research looked at consumption of NaCl water and how it affected dry matter intake (DMI) and weight gain. Research conducted by Heller (1933) provided various NaCl concentrations in water to dairy cattle, which included 10,000 mg/L, 15,000 mg/L, and a 20,000 mg/L NaCl. Weight gain, hay and water intake were reduced in cattle drinking the 20,000 mg/L NaCl water (Heller, 1933). Simply put, they concluded that 20,000

mg/L NaCl in drinking water was toxic. Embry et al. (1959) gave yearling cattle 7,000 mg/L and 10,000 mg/L of NaCl, which resulted in the 10,000 mg/L cattle having a depressed rate of gain, while 7,000 mg/L had no effect (Embry et al., 1959). Both levels of NaCl concentrations reduced the intake of an ad libitum trace mineral salt. This could be due to cattle receiving excess amounts of salt from the water they were consuming. Petersen and coworkers (2015) suggest cattle have a knowledge when it comes to salt consumption and will seek it out when deprived or refuse it when in excess.

Additionally, Weeth (1960) conducted a similar study, looking at the effects of NaCl concentrations in water on growing heifers in winter months. Water consumption and DMI of heifers on 20,000 mg/L NaCl water were lower compared to 10,000 mg/L NaCl water and control waters (no additional NaCl). Females drinking 20,000 mg/L NaCl water also had erratic water consumption and lost an average 14.5% of BW in the first 10 days. Heifers on 10,000 mg/L NaCl water consumed 52.8% more water than heifers on control water (Weeth et al., 1960). The increase in water consumption of 10,000 mg/L NaCl water may have occurred to maintain osmolarity, as salt consumption increases, water consumption also increases. Furthermore, the decrease in 20,000 mg/L NaCl water consumption may have been due to palatability. Salt is an effective intake limiter in supplements (Riggs et al., 1953); therefore, intake of water would be limited if there are high NaCl enough concentrations.

Further investigation by Weeth (1961) looked into varying NaCl levels in water during winter and summer. Heifers on 15,000 mg/L and 17,500 mg/L NaCl water treatments had reduced forage intake and were lethargic, when compared to heifers consuming 12,500 mg/L NaCl water (Weeth and Haverland, 1961). In addition, heifers on 17,500 mg/L NaCl water

consumed 6.4 kg less water than heifers on 12,500 mg/L water. In summer, water consumption for 10,000 mg/L and 12,000 mg/L levels were considerably elevated compared to winter water intake, but females on 12,000 mg/L water consumed on average 88 kg more than females on control water (Weeth and Haverland, 1961). Heifers on 12,000 mg/L NaCl consumed 28.2% less feed than heifers on 10,000 mg/L and control water. The considerable increase in water intake during summer months may be due to body temperature regulation.

An increase of cool water intake helps dissipate heat and also leads to increased evaporative cooling (Arias and Mader, 2011). In addition, palatability of salt may not affect heifers as severely when NaCl is below 20,000 mg/L in water, which could also help explain the increase in water consumption during summer. However, in winter when water consumption is lower, tolerance may be higher because less water is needed (Arias and Mader, 2011). Furthermore, Weeth and Hunter (1971) evaluated heifers on 4,110 mg/L NaCl in water during summer months. This level of NaCl in water caused a 19% increase water intake. Heifers were diuretic and excreted nearly twice as much urine as heifers on control water (Weeth and Hunter, 1971). Feed intake, however, was not altered with the 4,110 mg/L NaCl water. This research suggests water containing 4,110 mg/L NaCl does not negatively affect heifers. Similar to Weeths' previous research (1960), these levels of NaCl do not seem to influence palatability but did influence osmolarity balance and caused heifers to consume more water.

Still, research suggests the quality of water can affect water and forage intake, digestibility, and ultimately, growth and performance (Weeth et al., 1960; Weeth and Haverland, 1961). Cardon (1953) provided a 2,002 mg/kg NaCl drench twice daily to mature cows. There were no significant alterations to protein, cellulose and gross energy digestibility nor to rumen

microbe activity with added NaCl (Cardon, 1953). Similarly, Alves et al. (2017) noted no difference in DMI and digestibility when cattle were consuming up to 8,326 mg/L NaCl in drinking water. They did, however, report a decline in NDF intake and digestibility as total dissolved solids (TDS) increased. The decline in intake of NDF was most likely due to an increase in TDS, causing an increase in water intake and fill. Kume et al. (2000) also suggests TDN may affect total water intake in dairy cows fed silage. Similarly, Weeth and Hunter (1971) reported an increase in water intake and excretion with an increase in NaCl. This is most likely due to the increase of NaCl in water influencing the osmolarity requiring an increase in water intake, but not a high enough amount of salt to reduce intake. Additionally, nitrogen (N) retention also decreased with increasing TDS (Alves et al., 2017). Kume et al. (2000) also noted N can alter water intake and osmolarity to excrete excess amounts of N. These studies suggest that water NaCl levels below 8,000 mg/L may not have negative effects on forage or water intake of cattle. Furthermore, NaCl levels in water of 12,000 mg/L and above show signs of reduced water intake. Still, little research has been done to examine the impact water has on overall cattle performance, rumen fermentation and kinetics (Tomlinson et al., 2003; NASEM., 2016).

Salt

Salt is required in cattle diets at approximately 2,000 mg/kg of the total diet; however, cattle can consume larger quantities in their diet (Aiello et al., 2016). Regardless, Na and Cl are important for many important bodily functions. Sodium is necessary for muscle contraction,

nerve impulses, and sodium potassium pumps for proper absorption of monosaccharides and amino acids (Grim, 1980). Chloride is also required for the acid-base balance in blood and hydrochloric acid production (Berger and Cunha, 1993). Both are needed for electrolyte, water and acid-base balance. Furthermore, along with water, they are needed for rumen osmolarity (Van Soest, 1994).

Although rare, NaCl deficiency can occur if salt is not provided if there is excessive sweating (Aiello et al., 2016). Exact NaCl requirements vary for each individual and include many factors such as diet, salts in water sources, production, potassium in diet, and genetics (Berger and Cunha, 1993; Aiello et al., 2016). Cattle may lick objects, such as rocks or sweat off other animals in order to include NaCl in their diet (Berger and Cunha, 1993; Underwood and Suttle, 1999). Eventually they lose appetite and weight, their coat becomes rough and they look unthrifty. Lastly death can occur if not treated (Berger and Cunha, 1993; Underwood and Suttle, 1999).

Conversely, large amounts of NaCl in cattle diets can occur if cattle drink high saline waters, grazing forages in high saline soils, high salt diets with restricted water intake or waters containing high levels of salt (Underwood and Suttle, 1999; Aiello et al., 2016). MERCK Veterinary Manual (2016) suggests that 2,200 mg/kg of bodyweight is the acute lethal dose for cattle if fresh water is not available, otherwise NaCl toxicity is very unlikely. If fresh water is constantly provided, cattle can consume large amounts of NaCl unaffected. Salt toxicity is directly related to water consumption and affects the central nervous system and the gastrointestinal tract (Aiello et al., 2016). Salt toxicity can cause vomiting, increased water intake and diarrhea. If not treated, hypersensitivity, loss of coordination, blindness and seizures

are possible, followed by death (Berger and Cunha, 1993; Aiello et al., 2016). In some cases, poor temperament can arise (Aiello et al., 2016). Ulcers and lesions in the GI tract can be seen upon postmortem examinations (Aiello et al., 2016). Cattle also can have hydropericardium and edema of skeletal muscles (Aiello et al., 2016).

Sources of Salt in Ruminant Diets

Sodium and chloride can be acquired in cattle diets of forages and grains (Berger and Cunha, 1993). Still, most cattle in Montana are on extensive rangeland consuming forages which typically contain less than 1% Na and Cl (Cardon, 1953; Meyer et al., 1955). Even still, salt is required in the diet and important for growth and weight gain in beef cattle. In a study conducted by Smith and Parrish (1950), calves that did not receive salt in their diet gained an average of 0.29 kg a day compared to calves provided free choice salt gained an average of 0.57 kg a day (Smith and Parrish, 1950). Similarly, Morris and Murphy (1972) had comparable conclusions when Na was added to diets. Calves deprived of Na in their diet had poor intake and gains compared to calves who received Na in their diets (Morris and Murphy, 1972). La Manna et al. (1999), concluded that NaCl included in the diet at less than 10,000 mg/kg on a DM basis, had a tendency to increase DMI (La Manna et al., 1999). This research suggests that salt provided in the diet can improve intake and weight gain. However, the exact salt amounts that improves weight gain are unknown.

In a study conducted by Croom et al. (1982), salt was used in an attempt to improve growth rate, feed efficiency and digestive parameters of steers. Steers were feed a control (5,000 mg/kg), 30,000 mg/kg, 50,000 mg/kg, and 70,000 mg/kg NaCl in addition to a high grain diet. Feed and organic matter intake was unaffected by levels up to 50,000 mg/kg, however, the intake

for the 70,000 mg/kg steers was significantly lower than all other treatments. Furthermore, water intake increased as salt in the diet increased (Croom et al., 1982). This is consistent with research conducted by White et al (2019) who also found increased water intake as a result of greater amounts of salt in the diet. In a later study Croom (1985), fed steers 5,000 mg/kg NaCl, 20,000 mg/kg limestone, 50,000 mg/kg NaCl, or 50,000 mg/kg NaCl with 20,000 mg/kg limestone in finishing rations. They observed reduced total gains, average daily gain (ADG), and carcass weights of steers on 50,000 mg/kg NaCl diets. Both of these studies suggest an optimal level of salt in the finishing ration of fat cattle to be below 50,000 mg/kg. And the former suggesting salt be less than 30,000 mg/kg in the diet, with best gains being with the control diet containing 5,000 mg/kg salt.

In addition, researchers have evaluated the use of salt in diets and its influence on digestion, however this research is minimal. Cardon (1953) conducted a study where cows were provided alfalfa with 54,666.67 mg/kg of NaCl mixed into the ration and an *in vitro* experiment to maintain constant NaCl levels to evaluate digestibility. There was no significant alteration in protein, cellulose and gross energy digestibility and rumen microbe activity was not affected with added NaCl (Cardon, 1953). Ultimately, this study suggests that salt does not aid in cellulose digestion nor improve gain and performance. In addition, Brandyberry et al. (1991) reported increased organic matter digestibility for steers receiving salt in their diet, which is consistent with Riggs et al. (1953), who also noted an increase digestibility, specifically in protein. Suggesting that salt can potentially improve digestibility of low-quality forages. Furthermore, salt has been used in an attempt to improve dilution rate and ultimately digestion. Rogers et al. (1979), evaluated how increasing levels of NaCl mixed with water affects intake of

a high roughage or a high concentrate diet, water intake and rumen parameters. When 55,555.56 mg/L NaCl mixed with water was added intraruminally, there was no difference in hay or grain DMI on either diet. Furthermore, when 111,111.11 mg/L NaCl added to water, there was no difference in grain intake for either diet. However, the high roughage diet recorded a significant decrease in hay intake. In addition, when 55,555.56 mg/L of NaCl was added to both diets, water intake increased from 34.4 L to 40.1 L and 32.2 L to 40.9 L, respectively. Furthermore, when 111,111 mg/L kg of NaCl was added to the rumen, water intake increased for the high concentrate and roughage diets from 34.4 L to 62.5 L and 32.2 L to 58.7 L, respectively (Rogers et al., 1979). The dilution rate for both diets was increased as well as the rumen volume for the roughage diet. The increase in dilution rate can potentially be explained by the increase in water infusion in the rumen as well as intake.

Gaughan and Mader (2009) evaluated the effects of sodium chloride or fat supplementation on finishing steers exposed to hot and cold weather. During thermoneutral conditions 10,000 mg/kg additional salt increased DMI. However, during hot temperatures, DMI decreased and daily water intake (DWI) increased. However, during winter salt decreased DMI and increased DWI, still winter DMI intakes were greater than summer intakes. This research suggests that 10,000 mg/kg salt in the diet during hot temperatures can have adverse effects on forage intake. However, this research suggests the decrease in forage intake and the increase in water intake is due to body temperature regulation by reducing metabolic heat production. This is in agreement with Weeth (1961), who reported similar findings of increased water intakes during hot temperatures.

Salt in Supplements

Salt is typically low in range forages and it is frequently supplemented in western range settings to meet nutrient requirements. It can be supplied in different forms and be fed to cattle in multiple ways (Berger and Cunha, 1993). Loose or block forms are commonly used, depending on preference or practicality. Blocks are common in extensive range settings due to simplicity, whereas loose salt can be used but is also easily mixed into rations (Berger and Cunha, 1993). Smith et al. (1953) determined when offered a loose or block form of NaCl, cattle tended to consume more loose than block NaCl (Smith et al., 1953). The restricted intake of block salt is commonly associated with the hardness of the block, preventing cattle from consuming large amounts. Salt is also used as a carrier of trace minerals to help supply cattle with necessary minerals on poor quality forage (Berger and Cunha, 1993). In addition, salt is commonly and effectively used as a supplement limiter (Cardon et al., 1951; Riggs et al., 1953; Meyer et al., 1955; Berger and Cunha, 1993). It is the most common supplement limiter because it is readily available, cheap and effective (Riggs et al., 1953; Nelson et al., 1955). Riggs et al. (1953), used 4 groups of cows to test the effectiveness of NaCl as an intake limiter. They provided 3 groups a salt-limiting cottonseed meal supplement. Group 4 was the control which had free access to cottonseed meal and salt separately. However, shortly after starting the trial, group 4 required cottonseed meal to be hand-fed at 41,322.31 mg/kg/head of total diet to prevent overconsumption. Groups 1-3 required increasing NaCl levels within the supplement to maintain supplement intake at 41,322.31 mg/kg of total diet per head/day. At the conclusion of the study, group 1 required nearly 41,322.31 mg/kg in the total diet of salt in the cottonseed meal to maintain supplement intake at 41,322.31 mg/kg of total diet per head/day. In the first two periods, group 4 consumed considerably more cottonseed meal than the groups consuming the

salt-limiting supplement. This research simply indicates that salt can effectively limit supplement intake. Cattle that had ad libitum access to hay required less salt to limit their supplement intake. This could be due to fill and the need to consume more low-quality forage to meet nutrient requirements. Cattle who were limited on hay could have potentially needed the higher salt due to boredom or an attempt to fill up on supplement. Supplement intake was similar for self-fed salt limiting and hand-fed intake (Schauer et al., 2004). These findings are consistent between studies and suggests that cattle can acclimate to salt in their diet. It is suggested producers provide NaCl at 1,000 mg/kg BW, monitor intake of the supplement and adjust accordingly (Nelson et al., 1955; Kunkle et al., 2000). However, many factors can influence the supplement intake including body size, acclimation to the salt level, fresh water availability and intake variation and need to be taken into consideration.

Salt-limiting supplements are beneficial on extensive range operations, however, there is an assumption that each individual receives the same amount of supplement. Literature by Bowman and Sowell (1997), reports intake is not consistent between individuals and actually varies greatly. There are factors that can increase self-fed supplement intake variation. Individual animals have different intake preferences and requirements but bunk space, supplement form, experience, dominance, and available forage all influence supplement intake variation (Bowman and Sowell, 1997). Reuter (2017), Williams (2018) and Wyffels (2018) are in agreement with this previous research. Reuter (2017), offered a salt limited supplement containing 355,371.90 mg/kg of salt in supplement an automatic feeder. Individual intake as well as intake between individuals was highly variable (Reuter et al., 2017). In addition, Williams et al. (2018) fed a loose soybean supplement to grazing steers. The control group was hand-fed the supplement

without NaCl. The self-fed group received the supplement with increasing levels of NaCl throughout the study. Average supplement intake ranged from 0-1.21 kg/steer/day. Across the self-fed group, the supplement intake CV was 51%, while across day within animal the CV was 72%. This suggests, individual intake of a supplement varies more over time than overall intake (Williams et al., 2018). Research conducted by Wyffels and company (2018) reported young cattle had high intake variation across days. Cattle would consume large quantities of salt-limited supplement one day and not return for several days. These studies reported large individual intake variation, suggesting cattle are not benefitting or influenced the same by the supplement.

Previous research regarding influences on forage intake and ADG are conflicting. Harvey et al., (1986) compared steers on corn silage diets to fescue hay diets, containing salt in high amounts (227,000 mg/kg/d) or low amounts (23,000 mg/kg/d) in soybean meal. They noted that steers on silage and low salt diets gained 0.18 kg/day more than steers on silage and high salt diets. Alternatively, steers on fescue and high salt diets gained 0.04 kg/day more than steers on fescue and low salt diets (Harvey et al., 1986). Silage and forage intake were not affected. In addition, La Manna et al. (1999) reported that 10,000 mg/kg of salt in the total diet tended to increase forage intake. However, Brandyberry and coworkers (1991) seems to contradict the results reported above. Specifically, two trials were conducted, (one in the summer and one in the winter grazing period), evaluating the following supplement strategies consisting of 1) a self-fed salt limiting, 2) a hand-fed salt limiting, and 3) a hand-fed non-salt supplement. Salt levels in the supplements were 230,000 mg/kg/steer/d in summer and 400,000 mg/kg/steer/d in winter. Feed intake did not differ for grazing periods and treatments. These findings contradict other researchers who state that less than 10,000 mg/kg NaCl in the total diet can increase DMI (La

Manna et al., 1999). However, the salt levels used by Brandyberry and coworkers (1991) were twice that of La Manna and company (1999), potentially explaining the differences in intake. Furthermore, Harvey et al. (1986) and La Manna et al. (1999) provided high quality diets when reporting increases in DMI and ADG. Brandyberry and coworkers (1991) grazed their cattle on forage, potentially explaining the discrepancies seen in DMI and ADG.

Rationale for Research

Water sources in the Western United States are often high in TDS, and in Montana, NaCl is a common salt elevated in water. Low-quality water is also highly variable depending on yearly moisture and water source (Petersen et al., 2015). Previous research suggests water TDS tolerance thresholds; however, this research does not discuss the subacute effects of levels less than 3,000 ppm. In addition, salt is also provided in the diet through self-fed salt-limiting supplements. Additional protein is required in the diet due to poor forage quality, and supplements are provided to meet nutrition requirements of cattle. Self-fed supplements are common on extensive rangelands as the main mode of supplement delivery. Salt is the most common supplement limiter as it is inexpensive, effective and required in the cattle diet (Cardon et al., 1951; Riggs et al., 1953).

However, the majority of NaCl studies related to beef cattle consumption were published in the 1950's and 1960's; in addition, a large number of these publications are conflicting. These studies mostly looked at NaCl in water or supplement and their influence on ruminant livestock performance, such as intake. Furthermore, the majority of these studies used high quality or concentrate diets and not low-quality forage diets. More recent studies have looked at the impact

supplemental NaCl has on supplement intake, forage digestibility and rumen parameters. Still, these studies present conflicting data. In addition, studies evaluating the impact of NaCl on forage digestibility and rumen parameters are minimal and none have evaluated the interaction and impact of supplemental NaCl and drinking water NaCl on forage and water intake as well as rumen kinetics.

More recently López and associates (2014) evaluated a low (800 ppm TDS) and high (7,000 ppm TDS) saline drinking water and its interaction with 0%, 0.2%, and 0.4% BW/d soybean meal protein supplement, water and forage intake and rumen parameters. On the high saline water, they noted a water and supplement interaction where water intake and water intake: total organic matter intake ratio increased with increasing supplement. On the high saline water treatment, a supplement and water interaction were noted as supplement increased forage organic matter intake, total organic matter intake, and neutral detergent fiber intake increased (all on g/kg BW^{0.75}). They suggest the negative effects on water and forage intake by high saline water can be lessened by high levels of protein supplementation (López et al., 2014). However, intake interaction between supplements containing salt and drinking water containing salt is unevaluated.

Furthermore, in early cattle husbandry, salt requirements were recognized and supplementation has been long practiced (Suttle, 2010). In addition, when salt-limited supplements or NaCl is offered, clean drinking water is required. However, water TDS levels in Eastern and Central Montana can vary greatly (Petersen et al., 2015). In regions, such as Montana, where drinking water can contain high NaCl levels, some suggest cattle may not need additional salt supplementation (Kellems, 2002). Petersen and coworkers (2015) suggest that

cattle have a salt wisdom and will seek out sources of NaCl if they are deprived. Others suggest livestock and wildlife, alike, have a salt appetite and will seek it out (Morris, 1980). Furthermore, it is suggested that if cattle receive enough NaCl through their water, they will refuse supplemental NaCl (Petersen et al., 2015). However, there is no research conducted on the interactions between a salt containing supplement and livestock drinking water containing NaCl.

We know little about water quality and the influence it has on cattle performance, yet water is the most important nutrient (Petersen et al., 2015). In the Western United States and particularly Montana, high levels of NaCl in cattle drinking water is common. The overall influence of this water on cattle as well as the influence it has on supplement intake is not understood. The importance of understanding how supplemental NaCl and drinking water NaCl influence one another may help us better manage our supplementation strategies and cattle and optimize beef production in western range settings.

REFERENCES CITED

- Aiello, S. E., M. A. Moses, and D. G. Allen. 2016. The Merck veterinary manual. Merck & Company, Incorporated
- Alves, J. N., G. G. Araujo, S. G. Neto, T. Voltolini, R. D. Santos, P. R. Rosa, L. Guan, T. McAllister, and A. Neves. 2017. Effect of increasing concentrations of total dissolved salts in drinking water on digestion, performance and water balance in heifers. doi:10.1017/S0021859617000120
- Anderson, M. T., and L. H. Woosley. 2005. Water availability for the western United States: key scientific challenges. U.S. Geological Survey Circular 1261, Denver, Colorado USA.
- Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. *Journal of Animal Science* 89(1):245-251. doi: 10.2527/jas.2010-3014
- Beke, G. J., and R. Hironaka. 1991. Toxicity to beef cattle of sulfur in saline well water: A case study. *Science of the Total Environment* 101(3):281-290. doi: 10.1016/0048-9697(91)90042-D
- Berger, L. L., and T. J. Cunha. 1993. Salt and trace minerals for livestock, poultry and other animals. Salt Institute Alexandria, Va, USA.
- Bowman, J. G. P., and B. F. Sowell. 1997. Delivery method and supplement consumption by grazing ruminants: a review. *Journal of Animal Science* 75(2):543-550. doi: 10.2527/1997.752543x
- Brandyberry, S., R. Cochran, E. Vanzant, T. DelCurto, and L. Corah. 1991. Influence of supplementation method on forage use and grazing behavior by beef cattle grazing bluestem range. 69(10):4128-4136. doi: 10.2527/1991.69104128x
- Caldwell, D. R., and R. F. Hudson. 1974. Sodium, an obligate growth requirement for predominant rumen bacteria. *Applied microbiology* 27(3):549-552. doi: 10.1128/AEM.27.3.549-552.1974
- Cammack, K. M., K. J. Austin, W. R. Lamberson, G. C. Conant, and H. Cunningham. 2018. RUMINNAT NUTRITION SYMPOSIUM: Tiny but mighty: the role of the rumen microbes in livestock production. 96(2):752-770. doi: 10.1093/jas/skx053
- Cardon, B. P. 1953. Influence of a High Salt Intake on Cellulose Digestion. *Journal of Animal Science* 12(3):536-540. doi: 10.2527/jas1953.123536x

- Cardon, B. P., E. Stanley, W. Pistor, and J. Nesbitt. 1951. The use of salt as a regulator of supplemental feed intake and its effect on the health of range livestock. College of Agriculture, University of Arizona (Tucson, AZ).
- Cheeke, P. R., and Dierenfeld E. S. 2010. Comparative animal nutrition and metabolism. Cambridge University Press, United Kingdom.
- Collins, M. J. A. J. 1985. Wetting Effects on the Yield and Quality of Legume and Legume-Grass Hays 1. *Agronomy Journal* 77(6):936-941. doi: 10.2134/agronj1985.00021962007700060024x
- Croom-Jr., W. J., R. W. Harvey, D. M. Amaral, and J. W. Spears. 1985. Growth and metabolic parameters in steers fed high levels of sodium chloride and limestone. *Canadian Journal of Animal Science*, 65(3):673-681. doi: 10.4141/cjas85-080
- Croom Jr, W. J., R. W. Harvey, M. Froetschel, and A. C. Linnerud. 1982. High levels of sodium chloride in beef cattle diets. *Canadian journal of Animal Science* 62(1):217-227. doi: 10.4141/cjas82-022
- DelCurto, T., B. W. Hess, J. E. Huston, and K. C. Olson. 2000. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. *Journal of animal science* 77(E-Suppl):1. doi: 10.2527/jas2000.77E-Suppl1v
- Embry, L. B., M. Hoelscher, R. Wahlstrom, and C. Carlson. 1959. Salinity and livestock water quality. *South Dakota Agricultural Experiment Station Bulletin*
- Feiner, G. 2006. Meat products handbook: Practical science and technology. Elsevier.
- Flint, H. J., and E. A. Bayer. 2008. Plant cell wall breakdown by anaerobic microorganisms from the mammalian digestive tract. *Annals of the New York Academy of Sciences*, 1125(1):280-288. doi: 10.1196/annals.1419.022
- Grant, R., and D. R. Mertens. 1992. Influence of buffer pH and raw corn starch addition on in vitro fiber digestion kinetics. *Journal of Dairy Science*, 75(10):2762-2768. doi: 10.3168/jds.S0022-0302(92)78039-4
- Grim, E., and Health. 1980. Sodium: Its absorption and transport within the body. In *Sodium in Medicine and Health*. Ed. by C. Moses. Reese Press Inc. Baltimore, MD.
- Harrison, D., D. Beever, D. Thomson, and D. Osbourn. 1975. Manipulation of rumen fermentation in sheep by increasing the rate of flow of water from the rumen. *Journal of Agricultural Science*, 85(1):93-101. doi:10.1017/S0021859600053454

- Harvey, R. W., W. Croom, K. R. Pond, B. W. Hogarth, and E. S. Leonard. 1986. High levels of sodium chloride in supplements for growing cattle. *Canadian Journal of Animal Science*, 66(2):423-429. doi: 10.4141/cjas86-044
- Heller, V. G. 1933. The effect of saline and alkaline waters on domestic animals. Oklahoma: Oklahoma Agricultural and Mechanical College, Agricultural Experiment Station, 1933, Oklahoma
- Hemsley, J., J. Hogan, and R. Weston. 1975. Effect of high intakes of sodium chloride on the utilization of a protein concentrate by sheep. II.* Digestion and absorption of organic matter and electrolytes. *Australian Journal of Agricultural Research*. 26(4):715-727. doi:10.1071/AR9750715
- Holechek, J., R. Pieper, and C. Herbel. 2004. Range management: Principles and practices. Pearsen Education.
- Houtert, V. 1993. The production and metabolism of volatile fatty acids by ruminants fed roughages: A review. *Animal Feed Science and Technology*, 43(3-4):189-225. doi:10.1016/0377-8401(93)90078-X
- Kellems, R. O., & Church, D. C. (2002). *Livestock feeds and feeding* (No. 04; SF95, K4 2002.). Upper Saddle River: Prentice Hall.
- Kume, S., K. Nonaka, T. Oshita, and T. Kozakai. 2010. Evaluation of drinking water intake, feed water intake and total water intake in dry and lactating cows fed silages. *Livestock Science*, 128(1-3):46-51. doi:10.1016/j.livsci.2009.10.012
- Kunkle, W., J. Johns, M. Poore, and D. Herd. 2000. Designing supplementation programs for beef cattle fed forage-based diets. *Journal of Animal Science* 77(1-11)
- La Manna, A., F. Owens, S. Janloo, T. Shenkoru, and S. Welty. 1999. Impact of dietary salt concentration on water intake and physiological measurements of feedlot cattle. Oklahoma State University Animal Science Research Report. P-973, 159.
- López, A., J. I. Arroquy, A. Juárez Sequeira, M. García, M. Nazareno, H. Coria, and R. Distel. 2014. Effect of protein supplementation on tropical grass hay utilization by beef steers drinking saline water. *Journal of Animal Science*, 92(5):2152-2160. doi:10.2527/jas.2013-7138
- Meehan, M. A., G. L. Stokka, and M. S. Mostrom. 2015. Livestock water requirements. NDSU Extension Service.
- Meyer, J., W. Weir, N. Ittner, and J. Smith. 1955. The influence of high sodium chloride intakes by fattening sheep and cattle. 14(2):412-418. doi:10.2527/jas1955.142412x

- Morris, J., and G. Murphy. 1972. The sodium requirements of beef calves for growth. *The Journal of Agricultural Science*, 78(1):105-108. doi:10.1017/S002185960008775X
- Morris, J. G. 1980. Assessment of sodium requirements of grazing beef cattle: a review. *Journal of Animal Science*, 50(1):145-152. doi:10.2527/jas1980.501145x
- NASEM. 2016. *Nutrient Requirements of Beef Cattle*. Washington, DC: The NationalAcademeies Press.
- Nelson, A. B., R. W. MacVicar, W. Archer, Jr., and J. C. Meiske. 1955. Effect of a High Salt Intake on the Digestibility of Ration Constituents and on Nitrogen, Sodium, and Chloride Retention by Steers and Wethers. *Journal of Animal Science* 14(3):825-830. doi: 10.1093/ansci/14.3.825
- Petersen, M. K., J. M. Muscha, J. T. Mulliniks, R. C. Waterman, A. J. Roberts, and M. J. Rinella. 2015. Sources of variability in livestock water quality over 5 years in the Northern Great Plains. *J Anim Sci* 93(4):1792-1801. doi: 10.2527/jas.2014-8028
- Reuter, R., C. Moffet, G. Horn, S. Zimmerman, and M. Billars. 2017. Daily variation in intake of a salt-limited supplement by grazing steers. 33(3):372-377. doi:10.15232/pas.2016-01577
- Riggs, J. K., R. W. Colby, and L. V. Sells. 1953. The Effect of Self-Feeding Salt-Cottonseed Meal Mixtures to Beef Cows. *Journal of Animal Science* 12(2):379-393. doi: 10.2527/jas1953.122379x
- Rogers, J., B. Marks, C. Davis, and J. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. 62(10):1599-1605. doi:10.3168/jds.S0022-0302(79)83467-0
- Russell, J. B., and D. B. Wilson. 1996. Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? *Journal of Dairy Science*, 79(8):1503-1509. doi:10.3168/jds.S0022-0302(96)76510-4
- Schauer, C. S., G. P. Lardy, W. D. Slinger, M. L. Bauer, and K. K. Sedivec. 2004. Self-limiting supplements fed to cattle grazing native mixed-grass prairie in the northern Great Plains1. *Journal of Animal Science* 82(1):298-306. doi: 10.2527/2004.821298x
- Sexson, J. L., J. J. Wagner, T. E. Engle, and J. W. Spears. 2010. Effects of water quality and dietary potassium on performance and carcass characteristics of yearling steers1,2,3. *Journal of Animal Science* 88(1):296-305. doi: 10.2527/jas.2009-1899

- Smith, E., and D. Parrish. 1950. The influence of salt on the gains of steer calves. Cornell Agriculture Experiment Station Bulletin. 938.
- Smith, S., E. Lengemann, and J. Reid. 1953. Block vs. loose salt consumption by dairy cattle. 36(7):762-765. doi:10.3168/jds.S0022-0302(53)91557-4
- Stanley, T., R. Cochran, E. Vanzant, D. Harmon, and L. Corah. 1993. Periparturient changes in intake, ruminal capacity, and digestive characteristics in beef cows consuming alfalfa hay. 71(3):788-795. doi:10.2527/1993.713788x
- Stewart, C. S. 1977. Factors affecting the cellulolytic activity of rumen contents. Applied and Environmental Microbiology, 33(3):497-502. doi:10.1128/AEM.33.3.497-502.1977
- Suttle, N. F. 2010. Mineral nutrition of livestock. CABI. Wallingford, UK.
- Thomson, D., D. Beever, M. Latham, M. Sharpe, and R. Terry. 1978. The effect of inclusion of mineral salts in the diet on dilution rate, the pattern of rumen fermentation and the composition of the rumen microflora. 91(1):1-7. doi:10.1017/S0021859600056550
- Tomlinson, D. J., M. T. Socha, C. K. Swenson, and L. M. Schugel. 2003. Variability of Water Composition and Potential Impact on Animal Performance. American Association of Bovine practitioners conference proceedings of the annual conference:246. doi:10.21423/aabppro20035339
- Underwood, E. J., and N. Suttle. 1999. Mineral Nutrition of Livestock. CABI, Wallingford, UNITED KINGDOM.
- USDA. 2021. USDA Plant Zone Hardiness Map. [USDA Plant Hardiness Zone Map](#) (Accessed 5/9/2021 2021).
- Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of Restricted Water Intake on Feed Intake, Nutrient Digestibility and Nitrogen Metabolism in Steers. Journal of Animal Science 31(1):130-135. doi: 10.2527/jas1970.311130x
- Van Soest, P. 1994. Nutritional ecology of the ruminant. Second edition. Comstock publishing associates.
- Webster, A. J. F. 1980. The energetic efficiency of growth. Livestock Production Science 7(3):243-252. doi: 10.1016/0301-6226(80)90112-8
- Weeth, H., L. Haverland, and D. Cassard. 1960. Consumption of sodium chloride water by heifers. 19(3):845-851. doi:10.2527/jas1960.193845x

- Weeth, H., and L. J. J. o. A. S. Haverland. 1961. Tolerance of growing cattle for drinking water containing sodium chloride. *Journal of Animal Science*, 20(3):518-521. doi:10.2527/jas1961.203518x
- Weeth, H. J., and J. E. Hunter. 1971. Drinking of Sulfate-Water by Cattle. *Journal of Animal Science* 32(2):277-281. doi: 10.2527/jas1971.322277x
- Welch, J. G. 1982. Rumination, particle size and passage from the rumen. *Journal of Animal Science* 54(4):885-894. doi:10.2527/jas1982.544885x
- White, H. C., N. G. Davis, M. L. Van Emon, S. A. Wyffels, and T. DelCurto. 2019. Impacts of increasing levels of salt on intake, digestion, and rumen fermentation with beef cattle consuming low-quality forages. *Translational Animal Science* 3(Supplement_1):1818-1821. doi:10.1093/tas/txz048
- Wiedmeier, R., M. Arambel, R. Lamb, and D. J. J. o. d. s. Marcinkowski. 1987. Effect of mineral salts, carbachol, and pilocarpine on nutrient digestibility and ruminal characteristics in cattle. *Journal of Dairy Science*, 70(3):592-600.
- Williams, G., M. Beck, L. Thompson, G. Horn, and R. J. T. P. A. S. Reuter. 2018. Variability in supplement intake affects performance of beef steers grazing dormant tallgrass prairie. *The Professional Animal Scientist*, 34(4):364-371.
- Wyffels, S. A., A. R. Williams, C. T. Parsons, J. M. Dafoe, D. L. Boss, T. DelCurto, N. G. Davis, and J. G. P. Bowman. 2018. The influence of age and environmental conditions on supplement intake and behavior of winter grazing beef cattle on mixed-grass rangelands1. *Translational Animal Science* 2(suppl_1):S89-S92. doi: 10.1093/tas/txy046

CHAPTER THREE

IMPACT OF INCREASING NACL LEVELS IN LIVESTOCK DRINKING WATER ON
INTAKE AND UTILIZATION OF LOW-QUALITY FORAGES BY BEEF CATTLE

Contributions of Authors and Co-Authors

Author: M. F. Nack

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

Co-Author: M. L. Van Emon

Contributions: Aided in experimental design and thesis revisions.

Co-Author: H. M. DelCurto – Wyffels

Contributions: Aided in experimental design and thesis revisions.

Co-Author: S. A. Wyffels

Contributions: Aided in data collection, thesis revisions, data analysis and interpretation.

Co-Author: M. K. Manoukian

Contributions: Aided in data collection.

Co-Author: T. J. Carlisle

Contributions: Aided in data collection.

Co-Author: N. G. Davis

Contributions: Aided in data collection.

Co-Author: T. J. Kirkpatrick

Contributions: Aided in data collection.

Co-Author: J. A. Kluth

Contributions: Aided in data collection.

Co-Author: T. DelCurto

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

Manuscript Information

M. F. Nack, M. L. Van Emon, H. M. DelCurto – Wyffels, S. A. Wyffels, M. K. Manoukain, T. J. Carlisle, N. J. Davis, T. J. Kirkpatrick, J. A. Kluth and T. DelCurto

Status of Manuscript: [Put an x in one of the options below, delete this]

☒ Prepared for submission to a peer-reviewed journal

☐ Officially submitted to a peer-reviewed journal

☐ Accepted by a peer-reviewed journal

☐ Published in a peer-reviewed journal

Abstract

Water is one of the most important nutrients for livestock production (Petersen et al., 2015) but often overlooked in western range settings. The objective of this study was to evaluate the impacts of increasing NaCl levels in water on low quality forage intake, digestibility, and rumen fermentation. Eight ruminally cannulated, Angus crossbred cows were individually stalled and used in two 4 x 4 Latin square designs. One square (study 1) was hand fed a non-salt supplement and the second, square (study 2) was fed a salt limiting supplement. Two cows (one from each square) were assigned to one of four water treatments per period: 1) controls, no added NaCl (CON); 2) 1000 mg/L NaCl (LOW); 3) 2000 mg/L NaCl (MED); and 4) 3000 mg/L (HIGH). A 14-day adaption period allowed cattle to acclimate to the water; followed by a 6-day total collection period. Rumen fluid samples were collected on day 22 at hours 0, 4, 8, 12, 18 and 24; and on day 23 a total rumen evacuation was conducted to find total rumen volume and collect a sample of rumen content. Increasing levels of NaCl did not influence intake in either study ($P \geq 0.36$). Rumen pH was influenced by water or supplement NaCl in study 1 ($P = 0.01$), however, post hoc analysis revealed no differences. Volatile fatty acids in both studies were not affected by NaCl in either study ($P \geq 0.39$). Our results suggest the NaCl levels in our study may have little influence on intake and rumen fermentation.

Introduction

Water is the most important nutrient for livestock production (Petersen et al., 2015), however, its quality is often overlooked in western range settings. Many factors, such as quality, can influence cattle water requirements and consumption. This includes numerous environment

and cattle components including, size, lactation status, forage base, activity, and ambient temperature (NASEM., 2016). In addition, water accounts for an average of 70% body mass in cattle (NASEM., 2016). The average water consumption for a dry cow in summer is around 45 liters a day, and is required for all of life's processes including digestion, rumen fermentation, body temperature regulation, reproduction and lactation (Meehan et al., 2015; Aiello et al., 2016; NASEM, 2016). Furthermore, quantity and quality of western water sources varies greatly between and among streams/rivers, ponds/reservoirs, springs, and tanks (Petersen et al., 2015). Quality can further be affected by geographical location, year, precipitation, season, recharge site and soil composition (Anderson and Woosley, 2005; Petersen et al., 2015).

The majority of the Western U.S. is composed of arid and semi-arid rangelands (DelCurto et al., 2000). Montana falls into this category, receiving on average 25 cm of precipitation a year (Petersen et al., 2015). High concentrations of salts in livestock drinking water are most common in these regions (Beke and Hironaka, 1991). In Montana, sodium chloride (NaCl) is a common salt in livestock drinking water, especially during drought years when solutes are concentrated due to evaporation (Petersen et al., 2015). In general, TDS levels up to 3,000 mg/L are tolerable, naive cattle may refuse the water at first, due to palatability, and diarrhea may be expected, however, it is safe (Berger and Cunha, 1993; Aiello et al., 2016). Levels between 3,000-7,000 mg/L are less tolerable, may be avoided, cause diarrhea, and should be avoided by pregnant and lactating cattle (Berger and Cunha, 1993; Aiello et al., 2016). Levels above 10,000 mg/L are toxic, should be avoided by all classes of cattle and can cause death (Berger and Cunha, 1993; Aiello et al., 2016). In a survey of livestock water sources in Montana, Petersen and coworkers (2015) reported 1.5% of samples exceeded the maximum upper limit of

3,000 mg/L of TDS in livestock drinking water, and concentrations were highest during drought years.

Furthermore, around 60% of the western United States is rangeland (Holechek, 2004). This includes Montana, where the forage base is primarily cool season grasses which are senesced for much of the year. The average protein of these senesced forages is 6-8%, and consequently are low-quality for much of the year, hindering optimal livestock performance. Thus, self-fed supplements are common on extensive range operations to improve performance by providing minerals, vitamins, and protein for grazing cattle. A salt limiting supplement containing 250,000 mg/kg of salt is most commonly used due to its affordability, availability and effectiveness at limiting intake (Cardon et al., 1951; Meyer et al., 1955; Berger and Cunha, 1993). Self-fed supplementation practices assume all cattle receive the same amount of supplement. However, salt limited supplement intake can be highly variable (among animals and across days) with daily supplement intakes often exceeding 5 kg (Wyffels et al., 2020). Thus, self-fed delivery systems utilizing salt as an intake limiter can result in high levels of salt intake that may impact the use of low-quality forages (White et al., 2019).

However, the need for salt in livestock nutrition was noted by early settlers, and further proven in the 19th century, when salt deprivation was intentionally induced leading to a reduction in animal performance (Suttle, 2010). Sodium and chloride are required in amounts averaging 0.2% of total diet (Aiello et al., 2016), and are extremely important for many bodily functions including the sodium potassium pump, hydrochloric acid production and osmolar balance of the body and rumen (Berger and Cunha, 1993; Van Soest, 1994). Simply put, salt supplementation has become a part of good cattle husbandry (Suttle, 2010). Although rare on range settings, NaCl

deficiency can occur if salt is not provided and/or excessive sweating (Aiello et al., 2016).

Deficiency is marked by excessive licking of objects and other animals, cattle are unthrifty, have a rough haircoat, and can die if persistent (Underwood and Suttle, 1999). While NaCl is required in the diet, it can also be toxic leading to neurological problems such as seizures, loss of coordination and even death (Aiello et al., 2016). However, if adequate amounts of fresh water are provided, toxicity is extremely rare.

Early water quality research evaluated the levels that noticeably reduced cattle performance. Heller (1933), Embry et al. (1959), and Weeth (1960, 1961) reported reduced forage and water intake as well as weight loss when NaCl concentrations in water were greater than 1%. Further research by Weeth and Hunter (1971), provided heifers with 4,110 ppm NaCl in drinking water. They increased water consumption by 19%, but forage consumption was unaltered suggesting no negative effects by 4,110 mg/L NaCl in drinking water. In addition, previous research suggests that NaCl in amounts less than 10,000 mg/kg of the total diet does not alter protein, cellulose, and/or gross energy digestibility (Weeth et al., 1960). However, evaluation of low-quality forage utilization, fermentation and liquid kinetics were not conducted leaving the questions of the effect on low-quality forage utilization.

Previous research has not evaluated the chronic effects of NaCl at lower levels, it has simply provided crude thresholds. Little research has been done to actually establish these thresholds for TDS and individual salts alike; and examine the impacts that increasing NaCl levels in water have on cattle performance (Tomlinson et al., 2003; Aiello et al., 2016). Furthermore, little to no research exists on the impacts of supplements containing salt and NaCl in livestock drinking water on low-quality forage intake and utilization. Therefore, the objectives

of this study were to evaluate how increasing levels of NaCl in water and supplement delivery impacts forage intake, water intake, digestibility, and rumen fermentation of beef cattle consuming high fiber, low-quality forages. We hypothesized that increasing levels of NaCl alters forage and water intake, as well as rumen fermentation.

Materials and Methods

Experimental procedures described herein were approved by the Agriculture Animal Care and Use Committee of Montana State University (2020-AA04). Animals were provided by the Montana Agricultural Experiment Station. The study was conducted during the 2020 summer period at the Bozeman Agriculture Research and Teaching (BART) farm at Montana State University in Bozeman, MT.

Eight, three-year-old ruminally-cannulated cows averaging 620 kg, were used in two 4 × 4 Latin square studies to test the effects of increasing levels of NaCl on DM intake, digestibility and rumen fermentation. Cows were randomly assigned to water treatments corresponding to a Latin square design. Each cow was penned individually and feed and water intake were measured daily. A low-quality hay (Table 1) was fed at 120% of a previous 3-day average. Water was offered *ad libitum* in bunks on weigh bars to measure individual water intake.

NaCl water treatments were: 1) control, no added NaCl, 2) 1000 mg/L NaCl, 3) 2000 mg/L NaCl, and 4) 3000 mg/L NaCl. Water treatments were mixed in food grade shuttles. When measuring the water, 1 L weighted 0.985 kg, thus, the shuttles were filled with 986.5 kg of water and mixed with the respective amount of NaCl. Either 1,000 (low), 2,000 (moderate), or 3,000 (high) g of a non-iodized stock salt were added to the corresponding storage tanks. The solution

was mixed thoroughly until homogeneous. Storage tanks and cow drinking water was frequently checked for solid salt formation within the water. If noted, the water was again mixed until homogeneous. Study 1 (square 1) consisted of 4 cows fed 0.18% of body weight (BW) canola-based supplement without NaCl. Study 2 (square 2) consisted of 4 cows fed 0.24% of BW canola-based supplement with 25,000 mg/kg NaCl. The supplement was identical with the exception of the additional salt in the second supplement. All diets were formulated to meet nutrient requirements for non-lactating beef cows (NASEM., 2016).

Each of the four digestion study periods were 22-days in length and consisted of a 14-day adaption period, where cows were allowed to acclimate to their individual pens and water treatment. This was followed by a 7-day total collection period; feces, orts, hay, supplement and water samples were collected. Orts were collected daily to determine forage intake. Fecal samples were collected to determine total tract dry-matter and neutral detergent fiber digestibility of the diet. On day 21 rumen fluid was collected for digesta kinetics. These samples were collected prior to feeding at hour 0, the cows were then pulsed dosed with Cr-EDTA of 5 g in a 150 mL aqueous solution (Udén et al., 1980), through the rumen cannula. Subsequent samples were collected at hours 4, 8, 12, 18, and 24 post feeding using a suction strainer (19-mm diameter, 1.6-mm mesh). NH_3 concentrations were measured using methods similar to those described by Sigma Technical Bulletin #640. VFA concentrations were measured using methods similar to that described by Supleco Inc. bulletin 749E (1975). Rumen liquid volume and dilution rate were estimated by regressing the natural logarithm of Cr concentration against sampling time (Warner and Stacy, 1968). On day-23 complete ruminal evacuations were conducted 4-h

post feeding. Total rumen contents were weighed and sub-samples were taken in duplicate and weighed. Rumen content was immediately placed back into the animal.

Fecal, ort, hay and rumen samples collected were dried in a forced-air oven at 55°C, for 96 hours. After drying, samples were reweighed to determine DM. Samples were then ground through a 1-mm Wiley Mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA) and analyzed for NDF using an ANKOM fiber analyzer (ANKOM). Forage intake was calculated by subtracting orts from the amount fed the previous day. Water intake was measured by subtracting remaining water from amount provided the day before. Both determined disappearances, thus intake.

Hand-fed supplement (study 1) and self-fed supplement (study 2) were analyzed as separate studies. For each study, the impacts of salt level on DM intake, digestibility and fermentation were analyzed using an analysis of variance (ANOVA) with a generalized linear model for a Latin square. Volatile fatty acid, pH, and ammonia were analyzed using an ANOVA for a repeated measures in a Latin square design. Data were log-transformed to meet the assumptions of normality and homogeneity of variance. Pre-planned linear and quadratic orthogonal contrasts were used to describe treatment effects. Statistical significance was accepted at an alpha of ≤ 0.05 and tendencies were considered between an alpha 0.05 and 1.0. All statistical analyses were performed in R (R Core Team 2020).

Results

Study 1; Hand-fed protein supplement, no salt

Total DMI (kg/d), forage intake (kg/d), and water intake (L/d) were not affected by increasing levels of NaCl in drinking water ($P \geq 0.51$; Table 3) averaging 13.23 kg/d, 12.24 kg/d and 35.89 L/d, respectively. Similarly, total DMI (g/kg BW), forage intake (g/kg BW) and water intake (ml/kg BW) were not affected by increasing levels of NaCl ($P \geq 0.57$; Table 3) averaging 19.59 g/kg BW/d, 20.15 g/kg BW/d and 59.14 ml/kg BW/d, respectively. Likewise, NDF and DM digestibility were not influenced by increasing levels of NaCl ($P \geq 0.82$; Table 3) averaging 56.19% and 56.56%, respectively.

Ruminal pH was affected by NaCl levels in water ($P \leq 0.01$; Table 3), however, no differences were observed in post hoc analysis ($P \geq 0.38$; Table 3). Ammonia (mg/dl), acetate:propionate, and total volatile fatty acids (VFA) were not affected by increasing levels of NaCl ($P \geq 0.54$; Table 3) averaging 3.43 mg/dl, 4.28 ratio and 92.24 MM, respectively. Additionally, acetic, propionic, isobutyric, butyric and isovaleric acids were not influenced by water NaCl levels ($P \geq 0.76$; Table 2).

Liquid fill (kg/d and g/kg BW/d) was unaffected by increasing NaCl levels ($P \geq 0.88$; Table 3) averaging 101.48 kg/d and 167.20 g/kg BW/d, respectively. In addition, liquid passage (%) was unaffected by increasing levels of NaCl ($P = 0.33$; Table 3) averaging 8.47%. Liquid turnover (hr) and flow rate (L/hr) were also unaffected by salt levels in water ($P \geq 0.60$; Table 3) averaging 12.31 hr/d and 14.24 L/hr/d.

Study 2; Hand-fed protein supplement with 25% salt

Total DM intake, forage intake and water intake were not affected by increasing levels of NaCl in water ($P \geq 0.36$; Table 4) averaging 14.49 kg/d, 13.12 kg/d and 45.82 L/d, respectively. When expressed on a BW basis; total DM intake, forage intake and water intake were not affected by increasing levels of NaCl in water ($P \geq 0.63$; Table 4) averaging, 23.09 g/kg BW/d, 20.94 g/kg BW/d, and 55.16 ml/kg BW/d, respectively. Additionally, DM and NDF digestibility % were not influenced by NaCl levels in water ($P \geq 0.82$; Table 1) averaging 54.73% and 54.92%, respectively.

Ruminal pH, ammonia, acetate:propionate, and total VFA were not affected by increasing levels of NaCl in water ($P \geq 0.87$; Table 4) averaging 6.52 pH, 2.96 mg/dl, 4.20 ratio, and 92.10 MM. Acetic, propionic, isobutyric, butyric and isovaleric acids were not influenced by increasing levels of NaCl ($P \geq 0.39$).

Liquid fill (kg and g/kg BW) was not changed by increasing NaCl levels ($P \geq 0.95$; Table 4) averaging 120.24 kg/d and 147.41 g/kg BW/d, respectively. In addition, liquid passage (%) was unaffected by increasing levels of NaCl ($P = 0.11$; Table 1) averaging 8.58%. Liquid turnover (hr) and flow rate (L/hr) were unaltered by salt levels in water ($P \geq 0.35$; Table 4) averaging 12.65 hr/d and 14.08 L/hr/d.

Discussion

Salt and its components play important roles within the body and are necessary for life. Salt is required to regulate and maintain osmotic pressure and acid base equilibrium with sodium being the major cation in the extracellular fluid (Suttle, 2010). Sodium also plays a key role in

the osmotic skeleton, ensuring that there is an appropriate amount of water to protect the gut, thus, when ion intake increases, so does water intake (Wilson, 1966; Michell, 1995). The sodium potassium ATPase pump sustains the osmotic skeleton by actively pumping sodium out of the cells, creating the osmotic gradient (Suttle, 2010). Sodium is also exchanged with hydrogen ions to regulate pH (Suttle, 2010). Furthermore, rumen microbe growth requires sodium, the specific functions beyond growth are unknown, still, it is necessary (Caldwell and Hudson, 1974). Chloride is essential for maintaining an acid-base balance in blood and the production of hydrochloric acid (Suttle, 2010). And both are needed for electrolyte, water and acid-base balance. In addition, with water they are needed to maintain rumen osmolarity (Van Soest, 1994). However, NaCl is an antimicrobial as it inhibits gram-negative bacterial growth by reducing available water (Feiner, 2006). In great enough amounts and for long periods of time, salt is toxic to most bacteria (Feiner, 2006), still the specific levels of salt, and how it entirely impacts the rumen microbes are not well understood.

With this in mind, cattle have been described to have knowledge for their salt requirements. Even in early cattle husbandry, salt requirements have been recognized and supplementation has been practiced (Suttle, 2010). The recommendation to satisfy beef cattle needs is 2,000 mg/kg NaCl of the total diet (Aiello et al., 2016). In addition, the use of salt limited self-fed mineral and protein supplements is common on range settings in the Western United States. Often it is recommended that salt be 1,000 mg/kg of BW to limit supplement intake (Kunkle et al., 2000). Petersen and associates (2015) suggest if cattle receive enough salt in their diet, they may refuse water containing high amounts of salt. Furthermore, they may refuse a salt containing supplement if they receive enough salt from their water. In addition, high

levels of salt intake associated with salt containing self-fed supplements have been proposed to have negative impacts on rumen fermentation (Kunkle et al., 2000). However, the interaction of salt levels in water and salt containing supplements warrant additional investigation. Research that evaluates water quality (salt level) with/without salt containing supplements is needed to optimize beef production in nutrient limited western rangeland environments.

Water in the west is usually low quality but is often overlooked. Surprisingly so, as water is required for all life processes, including digestion, and is influenced by many factors including weather, lactation and quality (Kume et al., 2010; Petersen et al., 2015). On average a dry cow in the summer will consume roughly 45 L a day, and requirements are increased when lactating (NASEM, 2016). During hot weather/drought, increased water intake is required for thermoregulation. Increased intake is required depending on the quality and NaCl levels in the drinking water, intake may be reduced, this in turn can reduce forage intake and performance (NASEM, 2016).

In summary, our results indicate levels up to 3,000 ppm NaCl in drinking water do not affect intake and digestibility. Nor does the addition of supplement containing 25,000 mg/kg salt. In fact, forage intake for both studies were right around 2% BW, which is the average forage intake of cattle (Van Soest, 1994). Our results agree with Weeth and Hunter (1971), who also recorded no adverse effects when mixed grass hay was fed with 4,110 mg/L NaCl water. Previous research by Embry et al., (1959) and Weeth et al. (1960) suggests that noticeable negative physical impacts, including intake, arise above 10,000 mg/L NaCl in drinking water. Researchers have stated that intake tended to increase with NaCl levels less than 10,000 mg/kg in the total diet (Smith and Parrish, 1950; La Manna et al., 1999). However, previous research only

included NaCl consumed from supplement and did not include NaCl from water. The total NaCl levels reported in our study were 154,431.3 mg/kg of intake for the salt square, and 107,658.87 mg/kg in the salt excluded square. Previous research did not calculate or evaluate total salt consumed in the diet and drinking water. In addition, the majority of previous research focused on cattle consuming high quality forage and/or concentrate diets. Differences in diet quality and their interaction with greater amounts of NaCl could explain the differences in forage intake. Rogers et al. (1979) noted no increase in forage intake when salt consumption was less than 1,000,000 mg daily. What's more, cattle who received a high roughage diet and 1,000,000 mg of NaCl daily had reduced forage intake compare to cattle on a high concentrate diet which were not altered by increasing NaCl levels. In addition, we reported no alteration in forage digestibility with increased levels of salt in livestock drinking water. Literature discussing the influence NaCl has on forage digestibility is conflicting. Our results agree with Cardon (1953) who reported no alteration in the digestibility of a chopped alfalfa with the addition of salt (Cardon, 1953). Additionally, White et al. (2019) noted no difference in low-quality forage digestibility with increasing levels of NaCl in the diet. However, Riggs et al. (1953) and Bandyberry et al. (1991) noted an increase in organic matter and protein digestibility, respectively, when cattle were offered a salt-limited protein supplement. Suggesting that the protein supplement may alter digestibility. Still, these conflicting results simply required further research to help us better understand salts' impact on forage utilization.

In addition, liquid kinetics were unaltered by the addition of salt. Our results conflict with some previous research, that reported greater liquid flow with the addition of NaCl. Rogers (1979), concluded that rumen fluid dilution rate increased for both roughage and concentrate

diets when hypertonic solutions (NaCl) were added directly to the rumen. Similarly, Wiedmeier (1987) and Harvey (1986) noted an increased liquid dilution rate of cattle fed elevated levels of NaCl. In addition, Rogers (1979), reported rumen fluid volume increased in steers fed a high roughage diet. Total rumen outflow was increased when NaCl was intraruminally infused in steers that consumed a high roughage diet. This is consistent with his later work which stated an increase in rumen fluid volume as well as rumen outflow (Rogers and Davis, 1982). Rogers et al (1979, 1982), noted that the total liquid flow of steers on a high roughage diet was not met with water intake, suggesting trans-ruminal water flux to create the outflow observed. Rogers et al. (1982) also suggested an increase in salivation rate to meet the amount of fluid outflow from the rumen. It has been suggested by other researchers that up to 24% of liquid volume in the rumen is attributed to water intake, indicating a large contribution from saliva (Bailey, 1961; Poutiainen, 1968). The conflicting results in our study could be explained by lower levels of salt in this study as well as mode of intake. Salt in large quantities added directly to the rumen may have a more acute effect than the intake of salt water. The salt water mix, dilutes the salt and allows the rumen to quickly maintain the osmotic balance. In addition, similar to our results, Harvey (1986), noted no alteration in digesta passage rate between the two salt levels especially on a high concentrate diet. Similarly, Cardon (1953), reported no noticeable effect in cellulolytic microbe activity, and subsequently cellulose digestion with the addition of NaCl in the rumen.

We did not compare squares against each other; however, we did notice water intake, liquid fill and liquid fill (g/kg BW) were on average were 28%, 15.6% and 13.11% greater in study 2 with a protein supplement containing 25% salt. This observation suggests that cattle consuming water containing NaCl with the addition of a salt-limited supplement may increase

water intake altering certain rumen characteristics. This is consistent with Croom and associates (1982) and White et al. (2019). Both researchers observed water intake increased greater than 10 L from control (no salt) to high salt levels. Gaughan and Mader (2009) reported an increase in water intake during summer when dietary salt was added (Gaughan and Mader, 2009). Presumably, the increase in water intake in response to increased dietary salt is to maintain electrolyte homeostasis (Croom Jr et al., 1982) as well as temperature regulation.

We reported no alteration in ruminal fermentation with increasing levels of salt. Our results agree with Cardon (1953), who reported no alteration of pH with the addition of NaCl to the diet. However, we did note pH in study 2 was 0.2 units lower than study 1. This agrees with White and company (2019), who also noted a decrease in pH with an increase in salt intake. Rogers (1982), recorded a similar pH decline when steers fed a high roughage diet were administered a high amount of salt. Wiedmeier and coworkers (1987) fed a high concentrate diet to cattle and reported an increase in ruminal pH of cows on NaCl treatments. In addition, we saw no differences in acetate to propionate ratio which conflicts Wiedmeier et al. (1987) who reported that salt tended to increase the acetate to propionate ratio. Suggesting diet quality can potentially interact with the influence NaCl has on rumen fermentation. Furthermore, VFA's were not altered with increasing salt levels. This agrees with Wiedmeier et al. (1987) who also reported no alteration by NaCl in the diet. Suggesting NaCl levels less than 3,000 ppm in the diet does not negatively effect rumen fermentation. Moreover, we noted no difference in rumen osmolarity. However, this conflicts with previous research which reported an increase in rumen osmolarity as intraruminal infused NaCl increased (Rogers et al., 1979). Similar reports were made by Rogers (1982), who also recorded an increase in rumen osmolarity as intraruminal

infusions of NaCl increased. The increase in rumen osmolarity would suggest an increase in water intake which we did not observe in our study. However, the cattle in the studies previously stated were offered greater levels of salt and were fed a high concentrate diet potentially influencing the rumen osmolarity.

Implications

Our results suggest no negative effects on intake, digestion or rumen fermentation of low-quality forages, by cattle consuming water containing up to 3,000 ppm NaCl. Suggesting these waters are safe for livestock consumption. Furthermore, we did not report an intake interaction between a supplement containing 25,000 mg/kg salt or water containing up to 3,000 mg/kg NaCl. Provided, cattle consume the recommended level of supplement. Overall, this research evaluated the subacute effects of NaCl up to 3,000 mg/kg in livestock drinking water, and the interaction with a salt-limited supplement.

Further research is warranted regarding low-quality forage consumption and the interaction of salt-limited supplement and low-quality water. Potentially evaluating greater NaCl levels in water. It would be interesting to evaluate levels up to 5,000 mg/kg in livestock drinking water. Additionally, we recognize there is great variation in intake, between animals and even across days (Williams et al., 2018). Further investigation into infrequent salt-limited supplement consumption and the interaction with a low-quality water containing up to 5,000 mg/kg could further our understanding of low-quality water and supplementation strategies.

REFERENCES CITED

- Aiello, S. E., M. A. Moses, and D. G. Allen. 2016. The Merck veterinary manual. Merck & Company, Incorporated.
- Alves, J., G. de Araujo, S. G Neto, T. Voltolini, R. dos Santos, P. Rosa, L. Guan, T. McAllister, and A. Neves. 2017. Effect of increasing concentrations of total dissolved salts in drinking water on digestion, performance and water balance in heifers. doi:10.1017/S0021859617000120
- Anderson, M. T., and L. H. Woosley. 2005. Water availability for the western United States: key scientific challenges. U.S. Geological Survey Circular 1261, Denver, Colorado USA.
- ANKOM, T. ANKOM 2000 Automated Fiber Analyzer.
- Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. *Journal of Animal Science* 89(1):245-251. doi: 10.2527/jas.2010-3014
- Bailey, C. B. 1961. Saliva secretion and its relation to feeding in cattle. 3. The rate of secretion of mixed saliva in the cow during eating, with an estimation of magnitude of the total daily secretion of mixed saliva. *Journal of Nutrition* doi:10.1079/BJN19610053
- Beke, G. J., and R. Hironaka. 1991. Toxicity to beef cattle of sulfur in saline well water: A case study. *Science of the Total Environment* 101(3):281-290. doi: 10.1016/0048-9697(91)90042-D
- Berger, L. L., and T. J. Cunha. 1993. Salt and trace minerals for livestock, poultry and other animals. Salt Institute Alexandria, Va, USA.
- Bowman, J. G. P., and B. F. Sowell. 1997. Delivery method and supplement consumption by grazing ruminants: a review. *Journal of Animal Science* 75(2):543-550. doi: 10.2527/1997.752543x
- Brandyberry, S., R. Cochran, E. Vanzant, T. DelCurto, and L. J. J. o. a. s. Corah. 1991. Influence of supplementation method on forage use and grazing behavior by beef cattle grazing bluestem range. 69(10):4128-4136. doi: 10.2527/1991.69104128x
- Caldwell, D. R., and R. F. Hudson. 1974. Sodium, an obligate growth requirement for predominant rumen bacteria. *Applied microbiology* 27(3):549-552. doi: 10.1128/AEM.27.3.549-552.1974

- Cammack, K. M., K. J. Austin, W. R. Lamberson, G. C. Conant, and H. Cunningham. 2018. Ruminant Nutrition Symposium. Tiny but mighty: the role of the rumen microbes in livestock production. 96(2):752-770. doi: 10.1093/jas/skx053
- Cardon, B. P. 1953. Influence of a High Salt Intake on Cellulose Digestion. *Journal of Animal Science* 12(3):536-540. doi: 10.2527/jas1953.123536x
- Cardon, B. P., E. Stanley, W. Pistor, and J. Nesbitt. 1951. The use of salt as a regulator of supplemental feed intake and its effect on the health of range livestock. College of Agriculture, University of Arizona (Tucson, AZ).
- Cheeke, P. R., Dierenfeld E. S. 2010. *Comparative animal nutrition and metabolism*. Cambridge University Press, United Kingdom.
- Collins, M. J. A. J. 1985. Wetting Effects on the Yield and Quality of Legume and Legume-Grass Hays 1. *Agronomy Journal*, 77(6):936-941. doi: 10.2134/agronj1985.00021962007700060024x
- Croom Jr, W. J., R. W. Harvey, M. Froetschel, and A. C. Linnerud. 1982. High levels of sodium chloride in beef cattle diets. *Canadian Journal of Animal Science* 62(1):217-227. doi: 10.4141/cjas82-022
- Croom, W. J., R. W. Harvey, D. M. Amaral, and J. W. Spears. 1985. Growth and metabolic parameters in steers fed high levels of sodium chloride and limestone. *Canadian Journal of Animal Science*, 65(3):673-681. doi: 10.4141/cjas85-080
- DelCurto, T., B. W. Hess, J. E. Huston, and K. C. Olson. 2000. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. *Journal of Animal Science* 77(E-Suppl):1. doi: 10.2527/jas2000.77E-Suppl1v
- Embry, L. B., M. Hoelscher, R. Wahlstrom, and C. Carlson. 1959. Salinity and livestock water quality. *South Dakota Agricultural Experiment Station Bulletin*
- Feiner, G. 2006. *Meat products handbook: Practical science and technology*. Elsevier.
- Flint, H. J., and E. A. Bayer. 2008. Plant cell wall breakdown by anaerobic microorganisms from the mammalian digestive tract. *Annals of the New York Academy of Sciences*, 1125(1):280-288. doi: 10.1196/annals.1419.022
- Gaughan, J., and T. Mader. 2009. Effects of sodium chloride and fat supplementation on finishing steers exposed to hot and cold conditions. *Journal of Animal Science* 87(2):612-621. doi: 10.2527/jas.2008-1125

- Grant, R., and D. Mertens. 1992. Influence of buffer pH and raw corn starch addition on in vitro fiber digestion kinetics. *Journal of Dairy Science*, 75(10):2762-2768. doi: 10.3168/jds.S0022-0302(92)78039-4
- Grim, E. 1980. Sodium: Its absorption and transport within the body. In *Sodium in Medicine and Health*. Ed. by C. Moses. Reese Press Inc. Baltimore, MD.
- Harrison, D., D. Beever, D. Thomson, and D. Osbourn. 1975. Manipulation of rumen fermentation in sheep by increasing the rate of flow of water from the rumen. *Journal of Agricultural Science*, 85(1):93-101. doi:10.1017/S0021859600053454
- Harvey, R. W., W. J. C. Jr., K. R. Pond, B. W. Hogarth, and E. S. Leonard. 1986. High levels of sodium chloride in supplements for growing cattle. *Canadian Journal of Animal Science*, 66(2):423-429. doi: 10.4141/cjas86-044
- Heller, V. G. 1933. The effect of saline and alkaline waters on domestic animals. Oklahoma: Oklahoma Agricultural and Mechanical College, Agricultural Experiment Station, 1933, Oklahoma.
- Hemsley, J., J. Hogan, and R. Weston. 1975. Effect of high intakes of sodium chloride on the utilization of a protein concentrate by sheep. II.* Digestion and absorption of organic matter and electrolytes *Australian Journal of Agricultural Research* 26(4):715-727. doi:10.1071/AR9750715
- Holechek, J., R. Pieper, and C. J. I. Herbel, Upper Saddle River, NJ. 2004. Range management: Principles and practices. Pearsen Education.
- Houtert, V. 1993. The production and metabolism of volatile fatty acids by ruminants fed roughages: A review. *Animal Feed Science and Technology*, 43(3-4):189-225. doi:10.1016/0377-8401(93)90078-X
- Kellems, R. O., & Church, D. C. (2002). *Livestock feeds and feeding* (No. 04; SF95, K4 2002.). Upper Saddle River: Prentice Hall.
- Kume, S., K. Nonaka, T. Oshita, and T. J. L. S. Kozakai. 2010. Evaluation of drinking water intake, feed water intake and total water intake in dry and lactating cows fed silages. *Livestock Science*, 128(1-3):46-51. doi:10.1016/j.livsci.2009.10.012
- Kunkle, W., J. Johns, M. Poore, and D. Herd. 2000. Designing supplementation programs for beef cattle fed forage-based diets. *Journal of Animal Science*, 77(1)
- La Manna, A., F. Owens, S. Janloo, T. Shenkoru, and S. Welty. 1999. Impact of dietary salt concentration on water intake and physiological measurements of feedlot cattle. Oklahoma State University Animal Science Research Report. P-973, 159.

- López, A., J. I. Arroquy, A. Juárez Sequeira, M. García, M. Nazareno, H. Coria, and R. Distel. 2014. Effect of protein supplementation on tropical grass hay utilization by beef steers drinking saline water. *Journal of Animal Science*, 92(5):2152-2160. doi:10.2527/jas.2013-7138
- Meehan, M. A., G. L. Stokka, and M. S. Mostrom. 2015. Livestock water requirements. NDSU Extension Service.
- Meyer, J., W. Weir, N. Ittner, and J. Smith. 1955. The influence of high sodium chloride intakes by fattening sheep and cattle. *Journal of Animal Science* 14(2):412-418. doi:10.2527/jas1955.142412x
- Michell, A. R. 1995. Physiological roles for sodium in mammals. *Sodium in Agriculture*, 91-106.
- Morris, J., and G. Murphy. 1972. The sodium requirements of beef calves for growth. *The Journal of Agricultural Science*, 78(1):105-108. doi:10.1017/S002185960008775X
- Morris, J. 1980. Assessment of sodium requirements of grazing beef cattle: a review. *Journal of Animal Science*, 50(1):145-152. doi:10.2527/jas1980.501145x
- NASEM. 2016. Nutrient Requirements of Beef Cattle. Washington, DC: The NationalAcademeies Press.
- Nelson, A. B., R. W. MacVicar, W. Archer, Jr., and J. C. Meiske. 1955. Effect of a High Salt Intake on the Digestibility of Ration Constituents and on Nitrogen, Sodium, and Chloride Retention by Steers and Wethers. *Journal of Animal Science* 14(3):825-830. doi: 10.1093/ansci/14.3.825
- Petersen, M. K., J. M. Muscha, J. T. Mulliniks, R. C. Waterman, A. J. Roberts, and M. J. Rinella. 2015. Sources of variability in livestock water quality over 5 years in the Northern Great Plains. *J Anim Sci* 93(4):1792-1801. doi: 10.2527/jas.2014-8028
- Poutiainen, E. 1968. Factors influencing the flow of fluid, saliva and some cations through the reticulo-omasal orifice of the cow. *Annales Agricultrale Fenniae*.
- Reuter, R., C. Moffet, G. Horn, S. Zimmerman, and M. Billars. 2017. Daily variation in intake of a salt-limited supplement by grazing steers. *The Professional Animal Scientist* 33(3):372-377. doi:10.15232/pas.2016-01577
- Riggs, J. K., R. W. Colby, and L. V. Sells. 1953. The Effect of Self-Feeding Salt-Cottonseed Meal Mixtures to Beef Cows. *Journal of Animal Science* 12(2):379-393. doi: 10.2527/jas1953.122379x

- Rogers, J., B. Marks, C. Davis, and J. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. *Journal of Dairy Science* 62(10):1599-1605. doi:10.3168/jds.S0022-0302(79)83467-0
- Rogers, J. A., and C. L. Davis. 1982. Effects of Intraruminal Infusions of Mineral Salts on Volatile Fatty Acid Production in Steers Fed High-Grain and High-Roughage Diets¹. *Journal of Dairy Science* 65(6):953-962. doi: 10.3168/jds.S0022-0302(82)82296-0
- Rogers, J. A., C. L. Davis, and J. H. Clark. 1982. Alteration of Rumen Fermentation, Milk Fat Synthesis, and Nutrient Utilization with Mineral Salts in Dairy Cows¹. *Journal of Dairy Science* 65(4):577-586. doi: 10.3168/jds.S0022-0302(82)82235-2
- Russell, J. B., and D. Wilson. 1996. Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? *Journal of Dairy Science*, 79(8):1503-1509. doi:10.3168/jds.S0022-0302(96)76510-4
- Schauer, C. S., G. P. Lardy, W. D. Slinger, M. L. Bauer, and K. K. Sedivec. 2004. Self-limiting supplements fed to cattle grazing native mixed-grass prairie in the northern Great Plains¹. *Journal of Animal Science* 82(1):298-306. doi: 10.2527/2004.821298x
- Sexson, J. L., J. J. Wagner, T. E. Engle, and J. W. Spears. 2010. Effects of water quality and dietary potassium on performance and carcass characteristics of yearling steers^{1,2,3}. *Journal of Animal Science* 88(1):296-305. doi: 10.2527/jas.2009-1899
- Smith, E., and D. Parrish. 1950. The influence of salt on the gains of steer calves. *Cornell Agriculture Experiment Station Bulletin*. 938.
- Smith, S., E. Lengemann, and J. Reid. 1953. Block vs. loose salt consumption by dairy cattle. *Journal of Dairy Science* 36(7):762-765. doi: doi:10.3168/jds.S0022-0302(53)91557-4
- Stanley, T., R. Cochran, E. Vanzant, D. Harmon, and L. Corah. 1993. Periparturient changes in intake, ruminal capacity, and digestive characteristics in beef cows consuming alfalfa hay. *Journal of animal science* 71(3):788-795. doi:10.2527/1993.713788x
- Stewart, C. S. 1977. Factors affecting the cellulolytic activity of rumen contents. *Journal of animal science* 33(3):497-502. doi:10.1128/AEM.33.3.497-502.1977
- Suttle, N. F. 2010. Mineral nutrition of livestock. CABI. Wallingford, UK.
- Thomson, D., D. Beever, M. Latham, M. Sharpe, and R. Terry. 1978. The effect of inclusion of mineral salts in the diet on dilution rate, the pattern of rumen fermentation and the composition of the rumen microflora. *The Journal of Agricultural Science* 91(1):1-7. doi:10.1017/S0021859600056550
- Tomlinson, D. J., M. T. Socha, C. K. Swenson, and L. M. Schugel. 2003. Variability of water composition and potential impact on animal performance. *American Association of*

- Bovine Practitioners Conference proceedings of the annual conference:246.
doi:10.21423/aabppro20035339
- Underwood, E. J., and N. Suttle. 1999. Mineral Nutrition of Livestock. CABI, Wallingford, United Kingdom.
- USDA. 2021. USDA Plant Zone Hardiness Map. [USDA Plant Hardiness Zone Map](#) (Accessed 5/9/2021 2021).
- Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of Restricted Water Intake on Feed Intake, Nutrient Digestibility and Nitrogen Metabolism in Steers. *Journal of Animal Science* 31(1):130-135. doi: 10.2527/jas1970.311130x
- Van Soest, P. 1994. Nutritional ecology of the ruminant. Second edition. Comstock publishing associates.
- Warner, A., and B. Stacy. 1968. The fate of water in the rumen: 1. A critical appraisal of the use of soluble markers. *British Journal of Nutrition*, 22(3):369-387. doi: [10.1079/BJN19680046](#)
- Webster, A. J. F. 1980. The energetic efficiency of growth. *Livestock Production Science* 7(3):243-252. doi: 10.1016/0301-6226(80)90112-8
- Weeth, H., L. Haverland, and D. Cassard. 1960. Consumption of sodium chloride water by heifers. *Journal of Animal Science*, 19(3):845-851. doi:10.2527/jas1960.193845x
- Weeth, H., and L. Haverland. 1961. Tolerance of growing cattle for drinking water containing sodium chloride. *Journal of Animal Science*, 20(3):518-521. doi:10.2527/jas1961.203518x
- Weeth, H. J., and J. E. Hunter. 1971. Drinking of Sulfate-Water by Cattle. *Journal of Animal Science* 32(2):277-281. doi: 10.2527/jas1971.322277x
- Welch, J. G. 1982. Rumination, particle size and passage from the rumen. *Journal of Animal Science* 54(4):885-894. doi:10.2527/jas1982.544885x
- White, H. C., N. G. Davis, M. L. Van Emon, S. A. Wyffels, and T. DelCurto. 2019. Impacts of increasing levels of salt on intake, digestion, and rumen fermentation with beef cattle consuming low-quality forages. *Translational Animal Science* 3(Supplement_1):1818-1821. doi:10.1093/tas/txz048
- Wiedmeier, R., M. Arambel, R. Lamb, and D. Marcinkowski. 1987. Effect of mineral salts, carbachol, and pilocarpine on nutrient digestibility and ruminal characteristics in cattle. *Journal of Dairy Science*, 70(3):592-600. doi:10.3168/jds.S0022-0302(87)80046-2

- Williams, G., M. Beck, L. Thompson, G. Horn, and R. Reuter. 2018. Variability in supplement intake affects performance of beef steers grazing dormant tallgrass prairie. *The Professional Animal Scientist*, 34(4):364-371.
- Wilson, A. 1966. The tolerance of sheep to sodium chloride in food or drinking water. *Australian Journal of Agricultural Research*, 17(4):503-514. doi:10.1071/AR9660503

Table 1. Nutrient analysis of hay offered to cannulated 3-year-old beef cows.

Dry matter, %	89.24
Nutrient composition, % DM basis	
Crude Protein	5.14
Acid detergent fiber	30.63
Neutral detergent fiber	55.88
Non-fiber carbohydrates	29.43
Total digestible nutrients	55.23
NDFD3, % NDF	43.27
Ca	0.24
P	0.17
K	1.5
Na	0.04

3Neutral detergent fiber digestibility.

Table 2. Nutrient analysis of the salt excluded (SE) and salt included (SI) supplements fed to cannulated 3-year-old beef cows.

	SE ¹	SI ¹
Dry matter, %	88.61	88.61
Nutrient composition, % DM basis		
Crude Protein	46.32	46.32
Acid detergent fiber	11.95	11.95
Neutral detergent fiber	25.28	25.28
Non-fiber carbohydrates	11.21	11.21
Total Digestible Nutrients		
NDFD ² , % NDF		
Ca	2.74	2.74
P	1.46	1.46
K	1.03	1.03
NaCl	25	0.7

¹Salt excluded supplement was fed at a rate of 0.18% of BW/d and the salt included supplement was fed at a rate of 0.24% of BW/d to meet nutrient requirements for mature cows. Includes 14% NPN equivalent.

²Neutral detergent fiber digestibility.

Table 3. Effect of increasing water NaCl levels on intake, digestibility, and rumen fill of 3-year-old cannulated cows consuming low-quality forages and salt excluding protein supplement (Study 1).

Item	Water NaCl Levels ppm ¹					P-values			
	0	1000	2000	3000	SEM	TRT ²	LIN ³	QUAD ⁴	
Forage intake, kg	12.36	12.24	12.45	11.91	0.37	0.75	0.51	0.58	
Supplement intake, kg	1.12	1.09	1.12	1.08	0.04	0.8	0.62	0.89	
Total intake, kg	13.37	13.22	13.46	12.88	0.36	0.69	0.47	0.56	
Water Intake, L	34.92	34.79	36.84	37.00	1.32	0.51	0.19	0.92	
Forage intake, g/kg BW	19.91	20.28	20.40	20.00	1.02	0.98	0.93	0.72	
Supplement intake, g/kg BW	1.80	1.80	1.80	1.80	-	-	-	-	
Total intake, g/kg BW	21.53	21.90	22.04	21.62	1.01	0.93	0.71	0.94	
Water intake, ml/kg BW	56.41	57.90	60.34	61.92	2.93	0.57	0.18	0.99	
DM digestibility, %	56.75	57.00	54.75	56.25	2.71	0.93	0.76	0.82	
NDF digestibility, %	56.50	58.00	55.00	56.75	2.22	0.82	0.83	0.96	
Liquid Fill, kg	98.25	103.06	102.94	101.66	5.87	0.93	0.71	0.62	
Liquid Fill, g/kg BW	158.79	171.55	167.12	171.31	12.86	0.88	0.58	0.75	
Liquid Passage, %	7.73	9.24	8.34	8.57	0.55	0.33	0.52	0.72	
Liquid Turnover, hr	13.01	11.04	12.60	12.62	1.09	0.60	0.94	0.38	
Liquid Flow, L/hr	13.59	16.06	14.62	12.68	2.80	0.73	0.70	0.36	
pH	6.79	6.76	6.69	6.67	0.06	0.01	0.16	0.95	
Ammonia, mg/dl	3.51	4.10	2.76	3.36	0.61	0.99	0.51	0.90	
A:P ratio	4.22	4.28	4.42	4.20	0.34	0.99	0.95	0.68	
Total VFA, MM	91.56	95.31	92.89	89.19	3.46	0.54	0.44	0.18	
Acetic, mol/100 mol	66.73	67.29	66.61	67.06	0.65	0.89	0.91	0.93	
Propionic, mol/100 mol	17.43	17.18	17.68	17.55	0.31	0.94	0.54	0.86	
Isobutyric, mol/100 mol	1.51	1.39	1.54	1.47	0.10	0.98	0.92	0.80	
Butyric, mol/100 mol	10.40	10.52	10.42	10.12	0.34	0.76	0.53	0.53	
Isovaleric, mol/100 mol	1.78	1.61	1.63	1.66	0.14	0.93	0.55	0.39	

¹Salt levels include 1). CON, no salt, 2). LOW, 1,000 ppm, 3). MODERATE, 2,000 ppm, and 4). HIGH, 3,000 ppm.

²Treatment main effect

³Linear pre-planned contrast

⁴Quadratic pre-planned contrast

Table 4. Effect of Water NaCl levels on the pH, ammonia, and VFAs of beef cattle consuming low-quality forages supplemented with or protein supplement containing 25% salt (Study 2).

Item	Water NaCl levels, ppm ¹					P - values			
	0	1000	2000	3000	SEM	TRT ²	LIN ³	QUAD ⁴	
Forage intake, kg	13.14	12.5	14.1	12.75	0.85	0.6	0.92	0.69	
Supplement intake, kg	1.51	1.50	1.50	1.50	0.09	0.99	0.96	0.93	
Total intake, kg	14.51	13.86	15.46	14.12	0.81	0.56	0.91	0.68	
Water Intake, l	43.13	44.2	46.82	49.13	2.35	0.36	0.1	0.8	
Forage intake, g/kg BW	20.77	19.41	22.74	20.82	2.34	0.80	0.75	0.91	
Supplement intake, g/kg BW	2.40	2.40	2.40	2.40	-	-	-	-	
Total intake, g/kg BW	22.93	21.50	24.92	23.00	2.33	0.84	0.92	0.36	
Water intake, ml/kg BW	68.32	68.50	75.41	80.4	7.37	0.63	0.24	0.75	
DM digestibility, %	56.32	53.21	56.6	52.79	4.11	0.86	0.71	0.93	
NDF digestibility, %	55.78	52.02	57.98	53.88	4.52	0.82	0.99	0.97	
Liquid Fill, kg	121.59	119.53	123.02	116.8	8.17	0.95	0.78	0.8	
Liquid Fill, g/kg BW	190.85	193.92	195.05	189.83	13.3	0.99	0.98	0.76	
Liquid Passage, %	9.72	8.23	9.42	6.93	0.74	0.11	0.07	0.52	
Liquid Turnover, hr	12.36	12.7	11.21	14.34	1.13	0.35	0.41	0.26	
Liquid Flow, L/hr	13.30	15.72	16.25	11.04	2.99	0.6	0.66	0.24	
pH	6.52	6.48	6.52	6.56	0.13	0.87	0.58	0.52	
Ammonia, mg/dl	2.88	2.92	2.57	3.46	0.51	0.96	0.59	0.40	
A:P ratio	3.87	4.23	4.41	4.28	0.36	0.99	0.40	0.49	
Total VFA, MM	98.24	88.44	94.29	87.41	5.86	0.97	0.09	0.67	
Acetate, mol/100 mol	67.02	67.67	67.55	67.75	0.81	0.59	0.80	0.37	
Propionic, mol/100 mol	17.69	17.38	17.11	17.74	0.34	0.91	0.93	0.17	
Isobutyric, mol/100 mol	1.38	1.38	2.06	1.60	0.29	0.98	0.32	0.43	
Butyric, mol/100 mol	10.51	10.03	9.57	10.10	0.55	0.39	0.50	0.06	
Isovaleric, mol/100 mol	1.36	1.47	1.71	1.71	0.16	0.64	0.06	0.72	

¹ Salt levels include 1). CON, no salt, 2). LOW, 1,000 ppm, 3). MODERATE, 2,000 ppm, and 4). HIGH, 3,000 ppm

²Treatment main effect

³Linear preplanned contrast

⁴Quadratic pre planned contrast

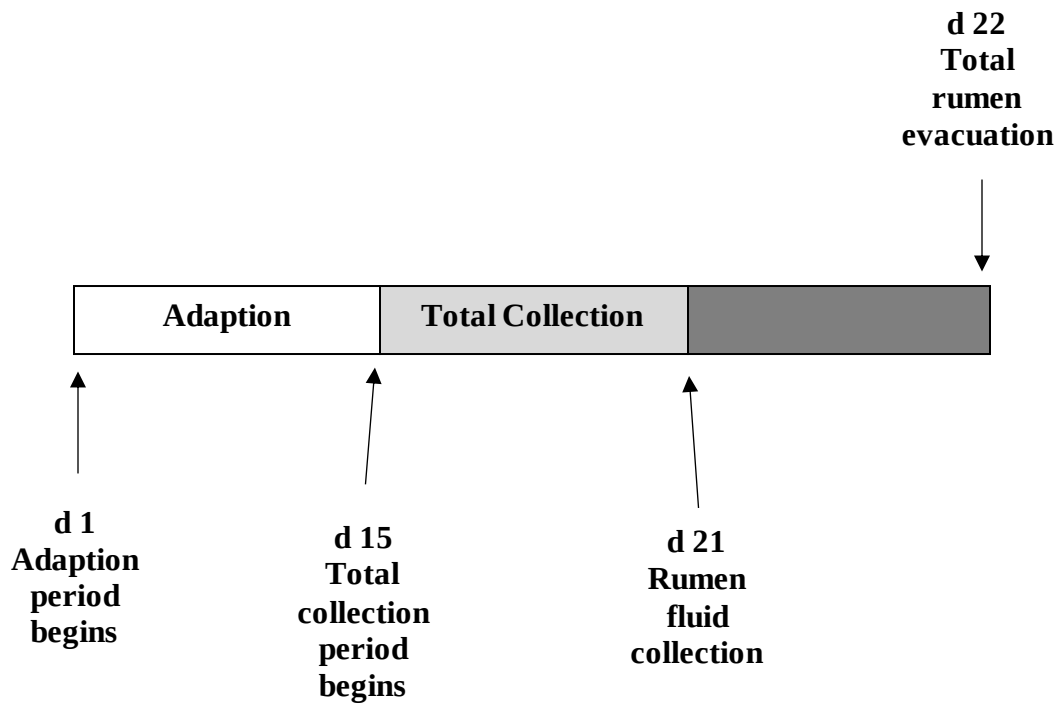


Figure 1. Study timeline

CHAPTER FOUR

CONCLUSIONS

The research discussed in chapter three assessed the impacts of increasing levels of NaCl in livestock drinking water on intake, digestion and liquid kinetics of a low-quality forage consumed by beef cattle. This is the first study to our knowledge, evaluating the chronic effects of 3,000 ppm or less NaCl in water and the interaction with a salt limited supplement. Few studies have evaluated the influence of water quality on the use of low-quality forages by beef cattle. In addition, most of the research conducted on salt limited supplements and water quality were conducted in the 1950's and 1960's (Cardon et al., 1951; Riggs et al., 1953; Weeth et al., 1960; Weeth and Haverland, 1961; Weeth and Hunter, 1971). Simply put, previous research has proposed an upper maximum tolerance of NaCl in livestock drinking water with only limited data on the effects on forage and water intake. Later studies evaluated NaCl's influence on digestion and liquid kinetics. Research discussing NaCl's influence on digestibility is conflicting. Some studies (Riggs et al., 1953; Brandyberry et al., 1991) suggest digestion improves when NaCl is added to the diet, however, Cardon (1953) reported no modifications in digestion when NaCl is added to the diet. Rogers (1979), noted an increase in fluid dilution rate. Ultimately, questions remain considering subacute NaCl effects up to 3,000 ppm in water and the interaction with self-fed salt-limited supplementation strategies. We hypothesized that increasing NaCl levels would alter forage and water intake as well as rumen fermentation and liquid kinetics.

In study 1, we reported no alteration in forage or water intake, nor digestibility, or liquid kinetics. Rumen fermentation characteristics were also not influenced by increasing levels of salt

in drinking water with the exception of ruminal pH. The change in pH, however, was modest with the lowest values averaging 6.5 units. These observations suggest that water containing NaCl levels up to 3,000 ppm does not have negative or beneficial effects on cattle. Additionally, for study 2, we reported no significance in intakes, digestibility, or liquid kinetics (Table 4). This conflicts with Smith and Parrish (1950) who suggested that NaCl levels < 1% in the total diet, increased forage intake. However, the NaCl totaled 0.45%, yet we did note alterations in forage intake. Further suggesting 3,000 ppm of NaCl in water with the addition of a supplement containing 25% NaCl do not affect cattle. However, we did notice water consumption, liquid fill (kg), and liquid fill (g/kg of BW) in study 2 was 28%, 15.6% and 13.11% greater, respectively. Suggesting that increasing NaCl in the diet can increase water intake, still the exact amounts are not well defined. Similar influences were reported by White et al. (2019) with increasing dietary NaCl levels.

Ultimately, further research is needed in regards to low-quality water and the interaction with salt-limited supplements. The researched described in this thesis evaluated the subacute effects of NaCl up to 3,000 ppm, as well as the interaction between water containing increasing NaCl levels and a salt-limited supplement. Future research could evaluate the effects of greater salt levels in the water and the interaction with a salt-limited supplement. Petersen et al. (2015), suggests that cattle have a max tolerance for NaCl, suggesting that cattle will only consume as much salt as needed. If they receive enough NaCl in their forage or supplements they may avoid waters containing greater amounts of NaCl. Conversely, if they receive enough NaCl from their water they may avoid forages or supplements containing greater levels of NaCl. We hypothesize

that increasing levels of NaCl in the water could potentially reduce supplement intake and thus may impact supplementation strategies in extensive range settings.

REFERENCES CITED

- Aiello, S. E., M. A. Moses, and D. G. Allen. 2016. The Merck veterinary manual. Merck & Company, Incorporated.
- Alves, J., G. de Araujo, S. G. Neto, T. Voltolini, R. dos Santos, P. Rosa, L. Guan, T. McAllister, and A. Neves. 2017. Effect of increasing concentrations of total dissolved salts in drinking water on digestion, performance and water balance in heifers. doi:10.1017/S0021859617000120
- Anderson, M. T., and L. H. Woosley. 2005. Water availability for the western United States: key scientific challenges. U.S. Geological Survey Circular 1261, Denver, Colorado USA.
- ANKOM, T. ANKOM 2000 Automated Fiber Analyzer.
- Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. *Journal of Animal Science* 89(1):245-251. doi: 10.2527/jas.2010-3014
- Bailey, C. B. 1961. Saliva secretion and its relation to feeding in cattle. 3. The rate of secretion of mixed saliva in the cow during eating, with an estimation of magnitude of the total daily secretion of mixed saliva. *Journal of Nutrition* doi:10.1079/BJN19610053
- Beke, G. J., and R. Hironaka. 1991. Toxicity to beef cattle of sulfur in saline well water: A case study. *Science of the Total Environment* 101(3):281-290. doi: 10.1016/0048-9697(91)90042-D
- Berger, L. L., and T. J. Cunha. 1993. Salt and trace minerals for livestock, poultry and other animals. Salt Institute Alexandria, Va, USA.
- Bowman, J. G. P., and B. F. Sowell. 1997. Delivery method and supplement consumption by grazing ruminants: a review. *Journal of Animal Science* 75(2):543-550. doi: 10.2527/1997.752543x
- Brandyberry, S., R. Cochran, E. Vanzant, T. DelCurto, and L. J. J. o. a. s. Corah. 1991. Influence of supplementation method on forage use and grazing behavior by beef cattle grazing bluestem range. 69(10):4128-4136. doi: 10.2527/1991.69104128x
- Caldwell, D. R., and R. F. Hudson. 1974. Sodium, an obligate growth requirement for predominant rumen bacteria. *Applied microbiology* 27(3):549-552. doi: 10.1128/AEM.27.3.549-552.1974

- Cammack, K. M., K. J. Austin, W. R. Lamberson, G. C. Conant, and H. Cunningham. 2018. Ruminant Nutrition Symposium. Tiny but mighty: the role of the rumen microbes in livestock production. 96(2):752-770. doi: 10.1093/jas/skx053
- Cardon, B. P. 1953. Influence of a High Salt Intake on Cellulose Digestion. *Journal of Animal Science* 12(3):536-540. doi: 10.2527/jas1953.123536x
- Cardon, B. P., E. Stanley, W. Pistor, and J. Nesbitt. 1951. The use of salt as a regulator of supplemental feed intake and its effect on the health of range livestock. College of Agriculture, University of Arizona (Tucson, AZ).
- Cheeke, P. R., Dierenfeld E. S. 2010. *Comparative animal nutrition and metabolism*. Cambridge University Press, United Kingdom.
- Collins, M. J. A. J. 1985. Wetting Effects on the Yield and Quality of Legume and Legume-Grass Hays 1. *Agronomy Journal*, 77(6):936-941. doi: 10.2134/agronj1985.00021962007700060024x
- Croom Jr, W. J., R. W. Harvey, M. Froetschel, and A. C. Linnerud. 1982. High levels of sodium chloride in beef cattle diets. *Canadian Journal of Animal Science* 62(1):217-227. doi: 10.4141/cjas82-022
- Croom, W. J., R. W. Harvey, D. M. Amaral, and J. W. Spears. 1985. Growth and metabolic parameters in steers fed high levels of sodium chloride and limestone. *Canadian Journal of Animal Science*, 65(3):673-681. doi: 10.4141/cjas85-080
- DelCurto, T., B. W. Hess, J. E. Huston, and K. C. Olson. 2000. Optimum supplementation strategies for beef cattle consuming low-quality roughages in the western United States. *Journal of Animal Science* 77(E-Suppl):1. doi: 10.2527/jas2000.77E-Suppl1v
- Embry, L. B., M. Hoelscher, R. Wahlstrom, and C. Carlson. 1959. Salinity and livestock water quality. *South Dakota Agricultural Experiment Station Bulletin*
- Feiner, G. 2006. *Meat products handbook: Practical science and technology*. Elsevier.
- Flint, H. J., and E. A. Bayer. 2008. Plant cell wall breakdown by an aerobic microorganisms from the mammalian digestive tract. *Annals of the New York Academy of Sciences*, 1125(1):280-288. doi: 10.1196/annals.1419.022
- Gaughan, J., and T. Mader. 2009. Effects of sodium chloride and fat supplementation on finishing steers exposed to hot and cold conditions. *Journal of Animal Science* 87(2):612-621. doi: 10.2527/jas.2008-1125

- Grant, R., and D. Mertens. 1992. Influence of buffer pH and raw corn starch addition on in vitro fiber digestion kinetics. *Journal of Dairy Science*, 75(10):2762-2768. doi: 10.3168/jds.S0022-0302(92)78039-4
- Grim, E. 1980. Sodium: Its absorption and transport within the body. In *Sodium in Medicine and Health*. Ed. by C. Moses. Reese Press Inc. Baltimore, MD.
- Harrison, D., D. Beever, D. Thomson, and D. Osbourn. 1975. Manipulation of rumen fermentation in sheep by increasing the rate of flow of water from the rumen. *Journal of Agricultural Science*, 85(1):93-101. doi:10.1017/S0021859600053454
- Harvey, R. W., W. J. C. Jr., K. R. Pond, B. W. Hogarth, and E. S. Leonard. 1986. High levels of sodium chloride in supplements for growing cattle. *Canadian Journal of Animal Science*, 66(2):423-429. doi: 10.4141/cjas86-044
- Heller, V. G. 1933. The effect of saline and alkaline waters on domestic animals. Oklahoma: Oklahoma Agricultural and Mechanical College, Agricultural Experiment Station, 1933, Oklahoma.
- Hemsley, J., J. Hogan, and R. Weston. 1975. Effect of high intakes of sodium chloride on the utilization of a protein concentrate by sheep. II.* Digestion and absorption of organic matter and electrolytes *Australian Journal of Agricultural Research* 26(4):715-727. doi:10.1071/AR9750715
- Holechek, J., R. Pieper, and C. J. I. Herbel, Upper Saddle River, NJ. 2004. *Range management: Principles and practices*. Pearsen Education.
- Houtert, V. 1993. The production and metabolism of volatile fatty acids by ruminants fed roughages: A review. *Animal Feed Science and Technology*, 43(3-4):189-225. doi:10.1016/0377-8401(93)90078-X
- Kellems, R. O., & Church, D. C. (2002). *Livestock feeds and feeding* (No. 04; SF95, K4 2002.). Upper Saddle River: Prentice Hall.
- Kume, S., K. Nonaka, T. Oshita, and T. J. L. S. Kozakai. 2010. Evaluation of drinking water intake, feed water intake and total water intake in dry and lactating cows fed silages. *Livestock Science*, 128(1-3):46-51. doi:10.1016/j.livsci.2009.10.012
- Kunkle, W., J. Johns, M. Poore, and D. Herd. 2000. Designing supplementation programs for beef cattle fed forage-based diets. *Journal of Animal Science*, 77(1)
- La Manna, A., F. Owens, S. Janloo, T. Shenkoru, and S. Welty. 1999. Impact of dietary salt concentration on water intake and physiological measurements of feedlot cattle. Oklahoma State University Animal Science Research Report. P-973, 159.

- López, A., J. I. Arroquy, A. Juárez Sequeira, M. García, M. Nazareno, H. Coria, and R. Distel. 2014. Effect of protein supplementation on tropical grass hay utilization by beef steers drinking saline water. *Journal of Animal Science*, 92(5):2152-2160. doi:10.2527/jas.2013-7138
- Meehan, M. A., G. L. Stokka, and M. S. Mostrom. 2015. Livestock water requirements. NDSU Extension Service.
- Meyer, J., W. Weir, N. Ittner, and J. Smith. 1955. The influence of high sodium chloride intakes by fattening sheep and cattle. *Journal of Animal Science* 14(2):412-418. doi:10.2527/jas1955.142412x
- Michell, A. R. 1995. Physiological roles for sodium in mammals. *Sodium in Agriculture*, 91-106.
- Morris, J., and G. Murphy. 1972. The sodium requirements of beef calves for growth. *The Journal of Agricultural Science*, 78(1):105-108. doi:10.1017/S002185960008775X
- Morris, J. 1980. Assessment of sodium requirements of grazing beef cattle: a review. *Journal of Animal Science*, 50(1):145-152. doi:10.2527/jas1980.501145x
- NASEM. 2016. Nutrient Requirements of Beef Cattle. Washington, DC: The NationalAcademeies Press.
- Nelson, A. B., R. W. MacVicar, W. Archer, Jr., and J. C. Meiske. 1955. Effect of a High Salt Intake on the Digestibility of Ration Constituents and on Nitrogen, Sodium, and Chloride Retention by Steers and Wethers. *Journal of Animal Science* 14(3):825-830. doi: 10.1093/ansci/14.3.825
- Petersen, M. K., J. M. Muscha, J. T. Mulliniks, R. C. Waterman, A. J. Roberts, and M. J. Rinella. 2015. Sources of variability in livestock water quality over 5 years in the Northern Great Plains. *J Anim Sci* 93(4):1792-1801. doi: 10.2527/jas.2014-8028
- Poutiainen, E. 1968. Factors influencing the flow of fluid, saliva and some cations through the reticulo-omasal orifice of the cow. *Annales Agricultrale Fenniae*.
- Reuter, R., C. Moffet, G. Horn, S. Zimmerman, and M. Billars. 2017. Daily variation in intake of a salt-limited supplement by grazing steers. *The Professional Animal Scientist* 33(3):372-377. doi:10.15232/pas.2016-01577
- Riggs, J. K., R. W. Colby, and L. V. Sells. 1953. The Effect of Self-Feeding Salt-Cottonseed Meal Mixtures to Beef Cows. *Journal of Animal Science* 12(2):379-393. doi: 10.2527/jas1953.122379x

- Rogers, J., B. Marks, C. Davis, and J. Clark. 1979. Alteration of rumen fermentation in steers by increasing rumen fluid dilution rate with mineral salts. *Journal of Dairy Science* 62(10):1599-1605. doi:10.3168/jds.S0022-0302(79)83467-0
- Rogers, J. A., and C. L. Davis. 1982. Effects of Intraruminal Infusions of Mineral Salts on Volatile Fatty Acid Production in Steers Fed High-Grain and High-Roughage Diets¹. *Journal of Dairy Science* 65(6):953-962. doi: 10.3168/jds.S0022-0302(82)82296-0
- Rogers, J. A., C. L. Davis, and J. H. Clark. 1982. Alteration of Rumen Fermentation, Milk Fat Synthesis, and Nutrient Utilization with Mineral Salts in Dairy Cows¹. *Journal of Dairy Science* 65(4):577-586. doi: 10.3168/jds.S0022-0302(82)82235-2
- Russell, J. B., and D. Wilson. 1996. Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? *Journal of Dairy Science*, 79(8):1503-1509. doi:10.3168/jds.S0022-0302(96)76510-4
- Schauer, C. S., G. P. Lardy, W. D. Slinger, M. L. Bauer, and K. K. Sedivec. 2004. Self-limiting supplements fed to cattle grazing native mixed-grass prairie in the northern Great Plains¹. *Journal of Animal Science* 82(1):298-306. doi: 10.2527/2004.821298x
- Sexson, J. L., J. J. Wagner, T. E. Engle, and J. W. Spears. 2010. Effects of water quality and dietary potassium on performance and carcass characteristics of yearling steers^{1,2,3}. *Journal of Animal Science* 88(1):296-305. doi: 10.2527/jas.2009-1899
- Smith, E., and D. Parrish. 1950. The influence of salt on the gains of steer calves. *Cornell Agriculture Experiment Station Bulletin*. 938.
- Smith, S., E. Lengemann, and J. Reid. 1953. Block vs. loose salt consumption by dairy cattle. *Journal of Dairy Science* 36(7):762-765. doi: doi:10.3168/jds.S0022-0302(53)91557-4
- Stanley, T., R. Cochran, E. Vanzant, D. Harmon, and L. Corah. 1993. Periparturient changes in intake, ruminal capacity, and digestive characteristics in beef cows consuming alfalfa hay. *Journal of animal science* 71(3):788-795. doi:10.2527/1993.713788x
- Stewart, C. S. 1977. Factors affecting the cellulolytic activity of rumen contents. *Journal of animal science* 33(3):497-502. doi:10.1128/AEM.33.3.497-502.1977
- Suttle, N. F. 2010. *Mineral nutrition of livestock*. CABI. Wallingford, UK.
- Thomson, D., D. Beever, M. Latham, M. Sharpe, and R. Terry. 1978. The effect of inclusion of mineral salts in the diet on dilution rate, the pattern of rumen fermentation and the composition of the rumen microflora. *The Journal of Agricultural Science* 91(1):1-7. doi:10.1017/S0021859600056550
- Tomlinson, D. J., M. T. Socha, C. K. Swenson, and L. M. Schugel. 2003. Variability of water composition and potential impact on animal performance. *American Association of*

- Bovine Practitioners Conference proceedings of the annual conference:246.
doi:10.21423/aabppro20035339
- Underwood, E. J., and N. Suttle. 1999. Mineral Nutrition of Livestock. CABI, Wallingford, United Kingdom.
- USDA. 2021. USDA Plant Zone Hardiness Map. [USDA Plant Hardiness Zone Map](#) (Accessed 5/9/2021 2021).
- Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of Restricted Water Intake on Feed Intake, Nutrient Digestibility and Nitrogen Metabolism in Steers. *Journal of Animal Science* 31(1):130-135. doi: 10.2527/jas1970.311130x
- Van Soest, P. 1994. Nutritional ecology of the ruminant. Second edition. Comstock publishing associates.
- Warner, A., and B. Stacy. 1968. The fate of water in the rumen: 1. A critical appraisal of the use of soluble markers. *British Journal of Nutrition*, 22(3):369-387. doi: [10.1079/BJN19680046](#)
- Webster, A. J. F. 1980. The energetic efficiency of growth. *Livestock Production Science* 7(3):243-252. doi: 10.1016/0301-6226(80)90112-8
- Weeth, H., L. Haverland, and D. Cassard. 1960. Consumption of sodium chloride water by heifers. *Journal of Animal Science*, 19(3):845-851. doi:10.2527/jas1960.193845x
- Weeth, H., and L. Haverland. 1961. Tolerance of growing cattle for drinking water containing sodium chloride. *Journal of Animal Science*, 20(3):518-521. doi:10.2527/jas1961.203518x
- Weeth, H. J., and J. E. Hunter. 1971. Drinking of Sulfate-Water by Cattle. *Journal of Animal Science* 32(2):277-281. doi: 10.2527/jas1971.322277x
- Welch, J. G. 1982. Rumination, particle size and passage from the rumen. *Journal of Animal Science* 54(4):885-894. doi:10.2527/jas1982.544885x
- White, H. C., N. G. Davis, M. L. Van Emon, S. A. Wyffels, and T. DelCurto. 2019. Impacts of increasing levels of salt on intake, digestion, and rumen fermentation with beef cattle consuming low-quality forages. *Translational Animal Science* 3(Supplement_1):1818-1821. doi:10.1093/tas/txz048
- Wiedmeier, R., M. Arambel, R. Lamb, and D. Marcinkowski. 1987. Effect of mineral salts, carbachol, and pilocarpine on nutrient digestibility and ruminal characteristics in cattle. *Journal of Dairy Science*, 70(3):592-600. doi:10.3168/jds.S0022-0302(87)80046-2

Williams, G., M. Beck, L. Thompson, G. Horn, and R. Reuter. 2018. Variability in supplement intake affects performance of beef steers grazing dormant tallgrass prairie. *The Professional Animal Scientist*, 34(4):364-371.

Wilson, A. 1966. The tolerance of sheep to sodium chloride in food or drinking water. *Australian Journal of Agricultural Research*, 17(4):503-514. doi:10.1071/AR9660503

Wyffels, S. A., A. R. Williams, C. T. Parsons, J. M.m Dafoe, D. L. Boss, T. DelCurto, N. G. Davis, and J. G. P. Bowman. 2018. The influence of age and environmental conditions on supplement intake and behavior of winter grazing beef cattle on mized-grass rangelands1. *Translational Animal Science* 2(suppl_1);S89-S92. doi: 10.1093/tas/txy046