

UTILIZING SUGAR BEETS IN STEER BACKGROUNDING, SHEEP NUTRIENT
METABOLISM, AND SILAGE

by

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DEDICATION

To my parents, John and Crystal McGregor, who have taught me to remain persistent in pursuing my goals and that it is a privilege to work. I'm very thankful for where I am in life, and I certainly would not have made it this far without their guidance and support.

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ABSTRACT

Non-harvested sugar beets are an abundant yet underutilized feedstuff for producers in Montana and Northern Plains region. A performance and metabolism study were performed to observe the effects of sugar beets on steer backgrounding performance, sheep nutrient metabolism, and rumen fermentation characteristics. Both experiments utilized four dietary treatments where sugar beets replaced 0% (0SB), 15% (15SB), 30% (30SB), and 45% (45SB) of barley on a dry matter (DM) basis. Forty eight Angus steers were used in a completely randomized design to conduct the 50 d performance study. Average daily gain (ADG), feed efficiency (G:F), and dry matter intake (DMI) weren't affected by treatment ($P \geq 0.06$). A 4 x 4 replicated Latin Square design was used to observe the effects of increasing dietary inclusion of sugar beets on nutrient metabolism and rumen fermentation characteristics of eight growing wethers. Crude fiber, DM, and nitrogen (N) digestibility weren't affected by treatment ($P \geq 0.10$), while N balance demonstrated a cubic effect ($P = 0.04$). Butyrate concentration demonstrated a treatment x time effect ($P = 0.01$), where butyrate concentrations increased with increasing sugar beets in the diet at 1300. The acetate to propionate ratio demonstrated a linear increase ($P = 0.03$) with increasing sugar beets in the diet. Overall, we concluded that sugar beets can be included up to 45% of the diet without inducing any deleterious effects on steer performance or sheep nutrient metabolism. However, the moisture content of sugar beets creates difficulty when storing this feedstuff, and we hypothesized that sugar beets may ensile well with other feedstuffs. Therefore, we carried out a study to test this hypothesis using a 3 x 2 factorial design. Treatments were hay (H), or sugar beets mixed with either hay (SBH) or soybean meal (SB) were ensiled at a rate of 50:50 (as fed) with or without a mold inhibitor. The pH of all treatments fell below 5.0 before d 90 ($P < 0.01$). All treatments increased in crude fiber and crude protein over time ($P \leq 0.03$). With these results, we conclude that sugar beets can be effectively ensiled with hay or soybean meal.

CHAPTER ONE

GENERAL INTRODUCTION

Nutrition is a major expense for livestock producers, and increasing the options for ruminant livestock feedstuffs can create opportunities for these producers to lessen this burden. Montana is a major producer of sugar beets in the Northern Great Plains (5th in the US; USDA, 2015a). Approximately 45.2 million pounds of sugar beets were left unharvested after the 2014-2015 Montana sugar beet harvest (USDA, 2015b). Sugar beets are high in energy (81% TDN; Lardy and Schafer, 2008), indicating that these non-harvested sugar beets could serve as a viable feedstuff for cattle and sheep that could potentially replace more traditional energy sources such as barley or corn.

Sugar beets differ from more traditional energy sources such as barley or corn in that the energy in sugar beets is stored in the form of sugar (8 to 22% sucrose; Yamane, 1998) rather than starch. Vallimont et al. (2004) conducted an in vitro study where cornstarch was replaced with sucrose in the DM of total mixed rations up to 7.5%, and observed that sugar can enhance fiber digestibility. Broderick and Radloff (2004) observed similar results when supplementing sugar to lactating dairy cows, where crude fiber digestibility increased when sugar exceeded 4.9% of the DM, but decreased when sugar was supplemented at 10%. Sugar may also enhance N metabolism efficiency, as Chamberlain et al. (1985) observed that sugar was more effective than starch at reducing rumen ammonia concentrations in goats receiving a silage-based diet.

According to the aforementioned literature, it seems that sugar beets may be a useful energy source. However, the seasonal availability of sugar beets may provide quantities of sugar beets that are too large for immediate use. Therefore, an effective storage method would be necessary to extend the amount of time that sugar beets can be fed. The high moisture content (75 to 80%; Lardy and Schafer, 2008) of sugar beets indicates that ensiling the sugar beets may be the most ideal storage method. Attaining a silage pH below 5 (Pitt, 1990) is the most effective way to inhibit the enzymes that degrade the nutrient quality of the feedstuff (Dewar, 1963; McKersie, 1981; Owens et al., 1999), as well as discouraging the growth of yeasts (Moon, 1983) that would encourage mold growth (Woolford, 1990). Other studies observing the effects of ensiling sugar beet pulp have observed satisfactory fermentation characteristics (Ferris and Mayne, 1994; Moore and Kennedy, 1994; Leupp et al., 2006).

Overall, it seems that unharvested sugar beets could be used for more productive purposes than we realize, rather than being left in the ground and plowed under. The following research studies that we have conducted serve to illustrate how sugar beets can be used to reap optimum benefit on livestock operations. By knowing how sugar beets can be most effectively utilized by livestock producers, we create opportunities for producers to use this feedstuff in years where it is in surplus, and perhaps lessen the burden of nutritional expenses.

CHAPTER TWO

LITERATURE REVIEW

General Sugar Beet Information

General Description of Sugar Beets

The sugar beet (*Beta Vulgaris*) is part of the amaranth family (*Amaranthaceae*), and was developed during the 1800's from the white fodder beet in Europe (Cattanach et al. 1991; Yamane, 1998). Sugar beets contain a white, fleshy root that is conical in shape, as well as a rosette of leaves that grows superior to the root portion of the plant. A sugar beet is approximately 366 centimeters (cm) in length and weighs an average of 1 to 2.26 kilograms (kg) when fully grown (American Sugarbeet Growers Association, 2015). The sugar beet utilizes a taproot system that allows the plant access to water and nutrients at depths of 152 to 244 cm into the soil (Cattanach et al. 1991). As the sugar beet plant begins to grow, cotyledons unfold, followed by successive leaves that grow in pairs throughout the growing season (Cattanach et al. 1991). Sugar beets typically grow until they are harvested or growth is halted by a hard freeze (Cattanach et al. 1991). Sugar beets are diploid, cross-pollinated plants. The vast majority of commercial sugar beets have been genetically engineered, with most of the plants being bred for resistance to the glyphosate herbicide (Yamane, 1998). The leaves of the sugar beet allow the plant to use photosynthesis for the storage of energy in the form of sucrose in the root of the plant so that it can sustain itself through the winter (Cattanach et al. 1991). Harvesting the sucrose that is stored in the root of sugar beets is the primary purpose that drives the

commercialization of sugar beets. Fifty-four percent of domestically-produced sugar comes from sugar beets (American Sugarbeet Growers Association, 2015). The remaining portion of our domestically-produced sugar comes from sugar cane, but it should be noted that the sugar harvested from sugar beets and sugar cane is identical.

Nutrient Characteristics of Sugar Beets

The weight of a harvested sugar beet usually contains 8 to 22% sucrose (Yamane, 1998). Sugar beets have a high moisture content (75 to 80%; Lardy and Schafer, 2008), high concentration of total digestible nutrients (TDN; 75-81% TDN; Lardy and Schafer, 2008), but they lack crude protein (CP; 6.8% CP; Lardy and Schafer, 2008).

The sugar content of sugar beets is what makes this a unique energy source when compared to more traditional livestock feeds such as corn or barley, which are considered starch-based energy sources. Carbohydrates are categorized based on the degree of polymerization and the type of linkage (alpha or beta; Aller et al. 2011). Sugars consist of 1 or 2 monomers, mainly consisting of glucose, fructose, and galactose (Cummings and Stephen, 2007). Sucrose is a disaccharide consisting of glucose and fructose that is the primary form of energy in sugar beets (Cummings and Stephen, 2007). Starches are polysaccharides that consist of more than 10 alpha-linked glucose molecules (Cummings and Stephen, 2007).

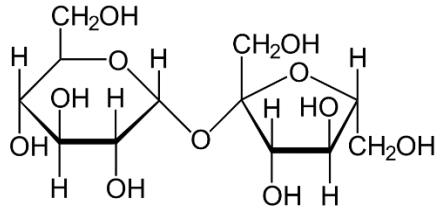
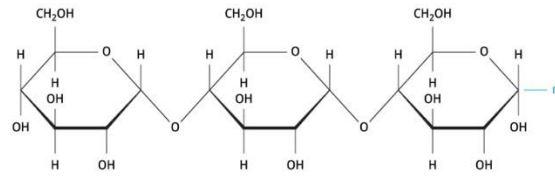
SucroseStarch

Figure 2.1. Chemical structures of sucrose and starch

Sugar Beet Production

Sugar beets are typically planted in late March and early April (American Sugarbeet Growers Association, 2015). Sugar beet seeds can be sown in a wide variety of soils ranging from heavy clay to sandy loam (Yamane, 1998). The ideal depth for sugar beet seeds to be sown is between 2 to 4 cm, with 6 to 8 cm between each seed, and rows usually contain 50 to 56 cm of space between one another (Yamane, 1998). The sugar beet plants are then harvested in late September and early October (American Sugarbeet Growers Association, 2015). The first step of the harvest is to remove the foliage using a mechanical defoliator. This is necessary to prevent new leaf growth and the loss of sucrose when sugar beets are being stored (Cattanach et al. 1991). Following defoliation, a mechanical sugar beet lifter then removes the roots of the sugar beets from the soil then loads them onto a truck (Cattanach et al. 1991). The trucks then take the sugar beets to a processing facility where the beets are stored on a flat and unpaved surface (Cattanach et al. 1991). The piling grounds used to store sugar beets helps to minimize the loss of sugar that is caused by root respiration or rot (Cattanach et al. 1991).

Sometimes sugar beets are stored in climate controlled storage buildings equipped with forced air ventilation systems (Cattanach et al. 1999).

Sugar Beet Processing

The sugar extraction process of sugar beets is illustrated in Figure 2.2. The processing of sugar beets for the extraction of sugar usually takes place from October through April (American Sugarbeet Growers Association, 2015). The sugar beets are first put into washers that facilitate the removal of any debris, then they are moved into slicing machines where the sugar beets are sliced into long strips called “cosettes” (Lardy and Schafer, 2008; Agribusiness Handbook, 2009). The cosettes then move into a large cylinder full of circulating hot water. Sugar from the cosettes then gradually diffuses into the water, much akin to the process of brewing tea (Agribusiness Handbook, 2009). After the water that contains all of the sugar from the sugar beets is separated from the cosettes, milk of lime and carbon dioxide followed by filtering can be used to remove any impurities (Agribusiness Handbook, 2009). The water is then boiled and is passed through a number of evaporator pans to convert it into syrup. Tiny sugar crystals are added to the pans to promote crystal formation which creates a substance commonly referred to as “massecuite” (Agribusiness Handbook, 2009). At this point, the leftover syrup can be used by livestock producers as molasses. Lastly, the massecuite is centrifuged to separate the sugar from the syrup and then it is dried (Agribusiness Handbook, 2009). After being separated from the hot water mixture, the cosettes are transported to a pulp press, which squeezes out excess water (Lardy and Schafer, 2008).

The cossettes produced from this process can then be used by livestock producers as beet pulp.

→ Sugar production diagram

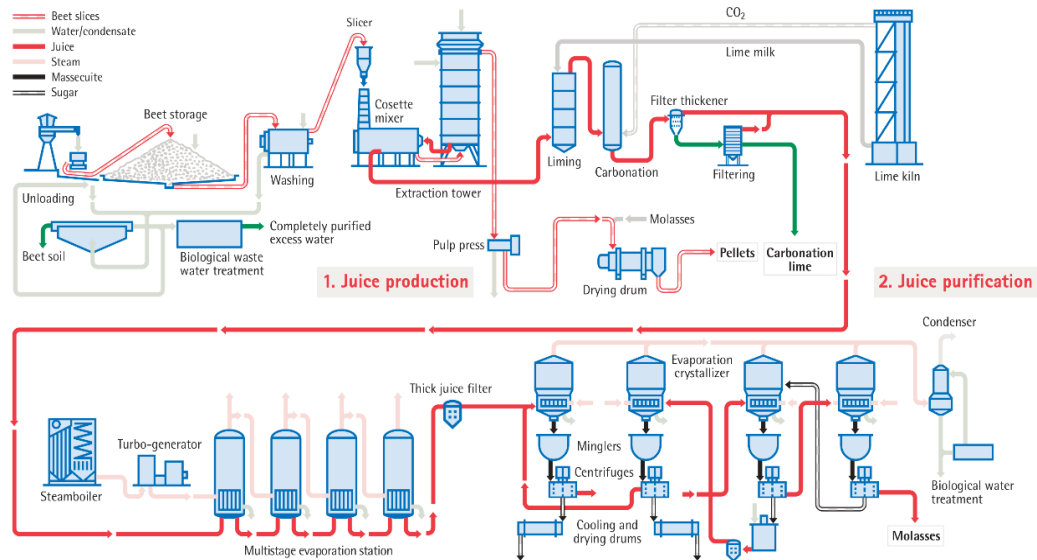


Figure 2.2. The sugar extraction process from sugar beets
<http://www.kissner.com/sugar-processing/>

Optimal Growing Conditions for Sugar Beets

Sugar beets are a biennial crop that is typically grown during the summer in the cool parts of temperate zones (Yamane, 1998; Agribusiness Handbook, 2009). Sugar beets are sometimes grown as a winter crop in the warm regions of temperate zones, but this increases the occurrence of parasites and diseases affecting the sugar beet crop (Yamane, 1998; Cattanach et al., 1991). Sugar beets are best suited for areas of long day length and a 5 month growing season (Cattanach et al., 1991; American Sugarbeet Growers Association, 2015). Optimum yields are reached when the climate remains mild throughout the growing period, and turns cold during the last period of growth (Yamane,

1998). The most ideal daytime temperatures for growing sugar beets is between 15.5 to 27°C, and optimal night temperatures are from 4.4 to 10°C (Cattanach et al., 1991). The ideal soil pH for growing sugar beets ranges from 6.0 to 8.0, and they do not do well in highly acidic soils (Cattanach et al., 1991). Lastly, a well-distributed precipitation of about 61 cm is ideal in the pursuit of optimal sugar beet yields (Yamane, 1998).

Montana Sugar Beet Industry

The majority of sugar beets in Montana are grown in the eastern part of the state and processed in Billings or Sidney. The average highest temperature in Billings during the sugar beet growing season is 30.4°C, with the lowest average temperature being 1.5°C (US Climate Data, 2017). Billings receives an average of 30.5 cm in annual precipitation in the form of rain, with most of this precipitation occurring during the sugar beet growing season (Jensen and Neill, 1902). Soils in Billings, MT includes clay, loam, gravelly loam, and sandy loam (Jensen and Neill, 1902). These environmental conditions allow Montana to be a major producer of sugar beets in the Northern Great Plains (5th in the U.S.; USDA, 2015a). Montana has recently experienced surpluses in the supply of sugar beets. Approximately 45.2 pounds of sugar beets were left unharvested during the 2014-2015 sugar beet harvest (USDA, 2015b).

Due to the substantial energy content, these non-harvested sugar beets could be used to replace more traditional sources of energy for livestock production when the price of these traditional energy sources such as barley and corn is on the rise. Considering this information, our objective is to determine how sugar beets can be used by livestock

operations to produce optimal results by evaluating the effects of sugar beets on steer backgrounding performance, sheep nutrient metabolism, as well as the preservation characteristics and nutrient profile of silage mixture.

Sugar Beet Impacts on Performance

Feedlot Performance

Feed intake is the primary dietary factor that directs the level and efficiency of ruminant animal performance (Allison, 1985). Intake is controlled by two general factors: 1) the limited capacity of the rumen, and 2) the metabolic requirement of the animal. The fact that the limited capacity of the rumen controls feed intake was illustrated by Campling and Balch (1961), where cannulated cows were used to demonstrate that intake increases when recently ingested feed is subsequently removed, and intake decreases when recently digested hay was put into the rumen. The limited capacity of the rumen may limit intake when bulky, high fiber feeds are being fed.

The effect of the metabolic requirement of the animal on feed intake was illustrated by Egan (1977), where acetic acid was infused into the rumen and/or casein infused into the duodenum of sheep on a wheat hay-straw diet, and intake decreased as a result of energy and protein infusion. The metabolic requirement of the animal may limit intake with concentrate-based diets, which are energy dense and not bulky enough to have DMI limited by rumen fill. Another factor that can influence intake are taste preferences among individuals. Nombekela et al. (1994) conducted a preference study with six multiparous Holstein cows, and compared their preferences for sweet, sour,

bitter, and salty diets. Four out of six of the cows preferred the sweet diet, and the calculated probability that a cow would choose the sweet diet out of the four diets was 59% (Nombekela et al., 1994). These two studies are particularly important to be considered when interpreting performance results from feeding sugar beets, due to the high sucrose content of sugar beets and their effects on volatile fatty acid production profiles in the rumen, to be discussed later.

Results regarding the effect of sugar beets on DMI are variable. Arrizon et al. (2012) observed no changes in DMI when dried shredded sugar beets replaced steam-flaked corn. Average daily gain was also unaffected, but Arrizon et al. (2012) observed a decrease in feed efficiency. This could be due to an improper energy to protein ratio in the diets that included sugar beets, which is to be discussed in chapter 3. Olfaz et al. (2005) observed a linear decrease in DMI as sugar beet pulp replaced grass hay in the diet, but observed an increase in ADG and feed efficiency. It is possible that adding sugar beet pulp to a grass-based diet increased fiber digestibility (Huhtanen, 1998; Arrizon et al., 2012), which may have improved feed efficiency in this case. The increase in feed efficiency may have allowed the animals to reach their metabolic requirement much quicker, resulting in a decrease in DMI.

Carcass Characteristics

The aforementioned experiments demonstrated that dried shredded sugar beets or sugar beet pulp can be used in ruminant diets without inducing any deleterious effects on performance, but maintaining the quality of the end product is still of primary importance when selecting dietary components for ruminant livestock. Both Olfaz et al. (2005) and

Arrizon et al. (2012) observed no deleterious effects on hot carcass weight or dressing percentage when replacing grass hay with sugar beet pulp or replacing steam-flaked corn with dried shredded sugar beets, respectively. In addition, Arrizon et al. (2012) also observed no effects on fat thickness, longissimus muscle area, or marbling score. Moreover, Olfaz et al. (2005) observed no effect on flavor, juiciness, or tenderness, but cooking loss was significantly reduced as sugar beet pulp was included in the diet. Olfaz et al. (2005) also observed an increase in palmitic (C16:0) and linoleic (C18:2) fatty acids in the longissimus muscle, while stearic (C18:0), oleic (C18:1), and arachidonic fatty (C20:4) acids decreased. Chemical analysis of sugar beet pulp by Asadollahi et al. (2017) demonstrated that the majority of fatty acids present are palmitic, linoleic, and oleic acid. It would make sense for sugar beet pulp to increase palmitic and linoleic fatty acids in the study performed by Olfaz et al. (2005), especially if the addition of sugar beet pulp increased the rate of passage, allowing palmitic and linoleic acids to escape biohydrogenation. This theory is supported by the decrease in stearic acid, which is a potential product of the biohydrogenation of linoleic acid (Ward et al., 1964; NRC, 2016). Furthermore, feeding sugar beets is commonly associated with decreased propionate production (Voelker and Allen, 2003; Arrizon et al., 2012), perhaps due to the fiber content of sugar beets, and bacteria that utilize fiber typically produce acetate (Lana et al., 1998). Propionate is a precursor of odd-numbered fatty acids, which are associated with lower melting points (Garton et al., 1972). A decrease in propionate would allow for an increase in even-numbered fatty acids, thus increasing the melting point of fatty acids in the meat.

Sugar Beet Impacts on Nutrient Metabolism

Volatile Fatty Acids (VFA)

Survival of ruminants can be attributed to the symbiotic relationship between the animal and the microorganisms found in the rumen. The animal provides food and suitable habitat for the microorganisms, and the microorganisms produce the enzymes necessary to digest feed that is indigestible to mammals, then produce by-products that can be used by the animal (Hungate, 1966; NRC, 2016). The rumen microorganisms use carbohydrates to obtain the adenosine triphosphate (ATP) necessary for their own growth by the process of fermentation (Pirt, 1965; Moran, 2005). However, not all of the energy contained in plant carbohydrates is extracted by fermentation. Most of the remaining energy is assimilated into the by-products of fermentation (Van Houtert, 1993). The most important by-products are volatile fatty acids, which provide the animal with a majority of its energy requirements (Bergman et al., 1965; Van Houtert, 1993). The three main volatile fatty acids that are produced are acetate, butyrate, and propionate (NRC, 2016). The proportions in which these volatile fatty acids are produced are largely dependent upon the type of microorganisms that utilize specific types of diets (Moran, 2005). Acetate producing bacteria are associated with forage-based diets, and propionate producing bacteria are associated with concentrate-based diets (Lana et al., 1998; Lage et al., 2017). Butyrate producing bacteria, however, are favored when fiber and energy are present in a balanced manner (Plöger, 2012).

Butyrate. Butyrate has been found to play a key role in the growth and differentiation within the rumen, enhancing the absorptive capabilities of the organ (Plöger, 2012). Butyrate has also been shown to improve barrier function of gastrointestinal epithelia, which can discourage the onset of certain diseases associated with weak barrier function (Mariadason et al., 1997; Peng et al., 2009; Plöger, 2012). Butyrate is metabolized by ruminal epithelium (NRC, 2016), and may be converted into ketone bodies (acetoacetate and β -hydroxybutyrate) which can be used as an energy source by the animal (Van Houtert, 1993). However, these ketone bodies are not the most suitable energy source for growing steers, as it has been demonstrated that increased butyrate at the expense of propionate production can result in the mobilization of body fat to be used in beta oxidation, as well as the oxidation of amino acids to make up for the lack of available energy (Huhtanen et al., 1998).

Propionate. Once propionate is produced, it is absorbed through the rumen wall, and is carried by the portal system to the liver, where propionate is metabolized to produce glucose (Van Houtert, 1993). A substantial portion of the energy required for weight gain and for the mammary system to generate lactose is derived from propionate (Moran, 2005). Propionate is used to form around 27 to 54% of the glucose that is in the ruminant animal (NRC, 2016).

Acetate. A very small amount of acetate is converted into ketones, but most of it is transferred to the liver through portal circulation (NRC, 2016). Acetate is essential for the production of milk fat and subcutaneous fat (Smith and Crouse, 1984; Moran, 2005;

Choi et al., 2014). Intramuscular adipose tissue preferentially uses glucose as a substrate for fat synthesis, whereas subcutaneous adipose tissue preferentially uses acetate as a substrate for fat synthesis (Smith and Crouse, 1984). However, Choi et al. (2014) observed that acetate incorporation into intramuscular fat depots was greater in Angus steers at 16 months of age compared to the steers at 12 months of age.

Potential effect of sugar beets on VFA production. Results regarding the effects of sugar beets on the production of volatile fatty acids are rather consistent. Arrizon et al. (2012) observed increases in acetate and butyrate, and decreases in propionate when dried shredded sugar beets replaced steam-flaked corn. Similarly, Voelker and Allen (2003) observed increases in acetate and butyrate, and a decrease in propionate when pelleted beet pulp replaced high-moisture corn. Lastly, Rooke et al. (1991) also observed increases in acetate and butyrate when molassed sugar beet feed replaced barley in a silage based diet. However, Huhtanen (1988) observed decreases in butyrate when unmolassed sugar beet pulp replaced barley in a silage based diet, but the addition of molasses tended to increase butyrate production. These results indicate that the presence of sugar favors butyrate production. Furthermore, in vitro studies regarding the inclusion of sugar in the rumen environment have also observed increases in butyrate production (Vallimont et al., 2004; Ribeiro et al., 2005). Considering these VFA production patterns as a result of feeding sugar beets or sugar beet by-products, it seems as though sugar beets can be characterized as a forage-based energy source, rather than a concentrate-based energy source (Lana et al., 1998; Lage et al., 2017). It seems that this VFA production pattern would not be ideal for a feedlot situation, as the decreased propionate

production would not support the increased weight gain that is desired in a feedlot setting. However, this VFA production pattern may be more ideal for replacement heifers and breeding cows on range. Not only does butyrate support milk fat production (Huhtanen et al., 1998) to help provide energy to a nursing calf, but it has also been demonstrated that excessive weight gain during pregnancy can make replacement heifers and cows more susceptible to calving problems (Drennan, 1979).

Fiber

Fiber is the primary nutrient consumed by ruminants, as they contain the microorganisms necessary to hydrolyze and ferment carbohydrate polymers present in plant cell walls that are indigestible to most animals (Krause et al., 2003). Fiber can be classified as either neutral detergent fiber (NDF) or acid detergent fiber (ADF), and comprises the cell walls of plants. Neutral detergent fiber is made up of hemicellulose, cellulose, and lignin, while ADF is made up of cellulose and lignin (NRC, 2016). Lignin is considered to be the least digestible of the aforementioned fiber components, making ADF less digestible than NDF. When these components of the cell wall, lignin in particular, can be digested, this allows access to the inner contents (carbohydrates and protein) of the cell wall by ruminal microorganisms.

It has been observed that increases in fiber digestibility may result in increased DMI, milk production, and steer performance (Beauchemin et al., 1995; Dado and Allen, 1996). There are a number of factors that are responsible for having an effect on fiber digestibility, and these factors are typically related to creating an environment that allows rumen fibrolytic microorganism populations to increase and their ability to attach to

feedstuffs to carry out digestion of that feedstuff. Increasing rate of passage decreases fiber digestibility due to the decreased amount of time available for the microorganisms to attach to the feed in the rumen (Allen and Mertens, 1988). Additionally, decreasing pH has been shown to have a negative effect on fiber digestibility (Terry et al., 1969; Mertens and Loften, 1980), due to the decreasing number of cellulolytic bacteria as pH decreases (Stewart, 1977). A reduction in pH is typically associated with high starch diets, and could be caused by the production of lactic acid by starch digesting bacteria and/or a decrease in saliva production due to a reduction in time spent ruminating (Allen and Mertens, 1988).

Potential effects of sugar beets on fiber digestibility. Contrary to the increase in acetate concentrations in the rumen, previous research has consistently observed that sugar beets may enhance fiber digestibility. Arrizon et al. (2012) observed a linear increase in the total tract digestibility of NDF as dried shredded sugar beets replaced steam-flaked corn. Similarly, Huhtanen (1988) observed an increase in both NDF and ADF as sugar beet pulp replaced barley. It is likely that these results are due to the sugar content of sugar beets, given their different chemical structure and components compared to starch (Cummings and Stephen, 2007), and may promote a unique population of rumen microorganisms (Valdez et al., 1977). This is also supported by a study conducted by Vallimont et al. (2004), who observed that sucrose had a positive effect on NDF digestibility when it replaced starch in vitro. However, it is interesting to note that none of these studies observed any effect of sugar beets on pH as fiber digestibility was

enhanced, indicating that the observed improvements in fiber digestibility occurred by mechanisms independent of pH.

Protein

Animals require protein for milk and meat production. For ruminants, the actual microorganisms present in the rumen will flow into the intestine and serve as a major protein source for the ruminant. The bacteria themselves are composed of roughly 50% protein (Nocek and Russell, 1988), and makes up more than half of the amino acids used by the animal (Seo et al., 2013). In addition, the amino acid profile of microbial protein is ideal for milk and meat production (NRC, 2000). Therefore, maximizing microbial protein synthesis should be a priority for ruminant animal production.

Rumen microorganisms require a N source (ammonia, amino acids, or peptides) in order for microbial protein synthesis to occur, and energy is required for the microorganisms to capture the N (Nocek and Russell, 1988). However, it is important to note that the microorganisms must meet a maintenance energy requirement before microbial protein synthesis can occur (Pirt, 1965). It has been suggested that a proper ratio of carbohydrate to protein has the potential to maximize microbial protein synthesis and improve performance (Cole and Todd, 2008; Seo et al., 2013). However, a seemingly appropriate carbohydrate to protein ratio may not always be ideal due to the variability of solubility and availability of different carbohydrate and protein sources (Moore et al., 1991).

Nocek and Russell (1988) compared isonitrogenous and isocaloric diets on their effect on microbial protein yield. The diets compared included a slow carbohydrate-slow protein (SC-SP), fast carbohydrate-slow protein (FC-SP), fast carbohydrate-fast protein (FC-FP),

and slow carbohydrate-fast protein (SC-FP) diets. The terms fast and slow refer to their degree of degradability in the rumen environment (Nocek and Russell, 1988). This study observed that the FC-SP and FC-FP diets had the greatest amount of microbial protein synthesized, which illustrates that the availability of energy to rumen microorganisms can be a major constraint on microbial protein production (Nocek and Russell, 1988). The Agriculture Research Council (Agricultural Research Council, 1980) recommends that 1.25 grams (g) of ruminally degradable nitrogen should be paired with each megajoule of metabolizable energy. If degradable protein is deficient, the digestibility of carbohydrates decreases (Nocek and Russell, 1988), possibly due to less microorganisms being available to digest carbohydrates. If there are not enough carbohydrates available for the microorganisms to capture protein, then ammonia will accumulate and N will be lost through urine or feces (Nocek and Russell, 1988). Therefore, increased ammonia concentrations would indicate an inefficient use of N and additional biological issues.

Potential effect of sugar beets on nitrogen metabolism. Studies regarding the effect of sugar on N utilization have generated interesting results. Sugar beets are different than more traditional energy sources in regards to the fact that sugar beets store energy in the form of sucrose rather than starch (Evans and Messerschmidt, 2017). Therefore, it is reasonable to believe that sugar beets may affect N metabolism. Huhtanen (1988) and Rooke et al. (1991) observed the effect of sugar beet pulp on N metabolism in silage based diets, which are generally associated with high ammonia content. Interestingly, Huhtanen (1988) observed that sugar beet pulp diets decreased N balance and digestibility compared to barley, but the addition of molasses increased the

amount of microbial N entering the small intestine. Rooke et al. (1991) observed that molassed sugar beet feed decreased rumen ammonia concentrations while increasing microbial N entering the small intestine when compared with barley. The two aforementioned studies seem to demonstrate that the presence of sugar itself enhances the efficiency of N utilization, perhaps by quickly providing energy to the rumen bacteria for maintenance and converting ammonia to microbial protein. This is further illustrated by Chamberlain et al. (1985) who observed that sugar was more effective than starch in decreasing rumen ammonia concentrations in small ruminants.

Storing Sugar Beets

An effective sugar beet preservation method is warranted due to the seasonal availability of sugar beets, which leads to quantities of sugar beets that are too large for immediate use. The high moisture content of sugar beets creates challenges when it comes to storage, and the drying of sugar beets prior to storage can be rather labor and cost intensive. The practical alternative to drying would be to ensile the sugar beets.

Silage Making Process

The goal of ensiling forage is to store forage for a period of time so that its nutritional value coming out of storage is similar to when it was put into storage. Silage is created by storing feed in an anaerobic environment with adequate moisture (60-65% moisture; Lardy and Schafer, 2008) and water-soluble carbohydrates. The beginning of this process is the aerobic phase, where the little oxygen that is left is eliminated by the respiration of the crop and aerobic microorganisms, such as yeasts and enterobacteria

(Elferink et al., 2000). Nutrient degrading enzymes are also present and active during the aerobic phase. The next step is the fermentation phase, where oxygen is absent, allowing for anaerobic bacteria to proliferate and start fermenting soluble carbohydrates into organic acids (Elferink et al., 2000). The bacteria of primary importance are lactic acid producing bacteria (Cai et al., 1999). Once sufficient acid has been produced to bring the pH below 5, the activity of the various enzymes and bacteria begins to cease at this point, promoting silage preservation. A review written by Muck (1987) states that the amount of lactic acid bacteria that is necessary for an immediate decline in pH is roughly 10^8 colony forming units (cfu) per gram of DM. Once the pH is below 5, this initiates the stable phase (Elferink et al., 2000), where the activity of nutrient degrading enzymes and bacteria remains minimal. The stable phase continues until the silage becomes exposed to oxygen again, which initiates the feed-out phase (Elferink et al., 2000). This allows for aerobic activity to occur once again, and promotes the proliferation of yeasts and fungi. Organic acids may assist in inhibiting the growth of yeasts and fungi for a short period of time (Moon, 1983; Muck, 2004). Specific management strategies used to prolong silage stability during the feed-out phase will be discussed later on.

Factors that need to be minimized in order to maximize preservation during the ensiling process are plant respiration, clostridial activity, plant enzyme activity, and aerobic microbial activity. When there is oxygen present, the crop being ensiled continues to use the oxygen and soluble carbohydrates through respiration, which produces carbon dioxide, water, and heat (Muck, 1988). If the silo is properly sealed, the loss of soluble carbohydrates and DM is insignificant because respiration by the plant

will eliminate the oxygen that is present, which induces the production of acids via anaerobic activity (Muck, 1988). If the silo is improperly sealed, plant respiration will continue and the energy value of the crop will decrease substantially. This would also allow for the growth of aerobic microorganisms such as yeasts and fungi, leading to ample deterioration of the silage.

Clostridia are anaerobic microorganisms that can lead to DM loss in silage. Clostridia can be saccharolytic or proteolytic. Saccharolytic clostridia primarily convert carbohydrates and various organic acids to butyric acid, carbon dioxide, and hydrogen (Muck, 1988). Proteolytic clostridia convert amino acids into ammonia and amines (Muck, 1988). These chemical reactions do indeed lead to substantial DM loss, but the production of butyric acid, ammonia, and amines is the main concern as the production of these substances can lead to decreased intake by ruminants (Conrad et al., 1977; Wilkins et al., 1971).

Factors Affecting Protein Content of Silage

Substantial hydrolysis of protein may occur in ensiled forages, especially at the beginning of the process that produces an accumulation of soluble non-protein N (NPN) in the silage (Ohshima and McDonald, 1978). Alfalfa, a legume known for its protein content, contains N that is 20-30% soluble NPN when it is put into the silo, with the rest of the N being CP (Muck and Dickerson, 1988; Muck, 1988). However, soluble NPN may make-up 40-85% of the total N present after the alfalfa has been ensiled (Muck 1988). The conversion of CP to soluble NPN during the ensiling process is carried out by plant enzymes classified as proteases (Kemble, 1956). This is an issue as it has been

suggested that substantial protein degradation in silage can result in reduced DMI, reduced N utilization efficiency, and reduced overall performance by the animals consuming the silage (Charmley and Veira, 1990). In addition, it has been suggested that the end-products of protein degradation (ammonia, amines, amino acids) may impede a rapid decline of pH of the silage (Voss, 1966). The primary factors that affect protein degradation during the ensiling process are pH, individual species characteristics, DM content of the silage, and temperature.

It has been well established that a rapid reduction of pH is the most effective way to minimize protein degradation (Finley et al., 1980; McKersie, 1981). Although final pH may be a good indicator of the quality of fermentation, the only sure way to minimize protein degradation is a rapid decrease in pH (Muck, 1988). It is interesting to note that the activity of various protein degrading enzymes are maximized at different pH values. For example, the activity of proteases in white clover are maximized between pH 5.9 and 6.3 (Brady, 1961), and the activity of amino acid and peptide degrading enzymes in alfalfa is maximized at pH values 6.5 and 5.2, respectively (McKersie, 1985). McKersie (1985) demonstrated that proteolysis in ensiled alfalfa, red clover, and birdsfoot trefoil is generally much slower at a silage pH of 4 as opposed to a pH of 6. Pitt (1990) suggested that rapidly attaining and maintaining a silage pH in the range of 3.8 to 5.0 is best for minimizing protein degradation in general. Considering that the fermentation of carbohydrates leads to the production of organic acids, the amount of fermentable substrate is the primary factor that determines the degree of pH decline (Owens et al., 1999). The amount of available fermentable substrate in forage can be manipulated by

the time of day in which the forage was harvested. It has been observed that concentrations of available carbohydrates, like sugar and starch, are lowest in the morning and increases through the afternoon (Holt and Hilst, 1969; Lechtenberg et al., 1971), due to the time spent exposed to the sun allows the plants to conduct photosynthesis and accumulate non-structural carbohydrates.

Individual forage species characteristics have also demonstrated potential to have an effect on the rate of protein degradation during the ensiling process. It has been observed that more soluble NPN is produced when ensiling alfalfa than when ensiling red clover or birdsfoot trefoil (Papadopoulos and McKersie, 1983), which indicates greater protein degradation in the alfalfa silage. It has been suggested that the protein in red clover is more protected from degradation than alfalfa following harvest (Owens et al., 1999). Species also differ in their buffering ability, which Owens et al. (1999) and a review written by Muck (1988) defines as the amount of acid needed to reduce forage pH from 6 to 4 per unit of dry matter. The buffering ability in legumes is typically greater than that of grasses (Pitt, 1990), and alfalfa has the greatest buffering ability among the legumes (Owens et al., 1999). As a result, pH values are usually lower in red clover silages than alfalfa silages (Owens et al., 1999).

Dry matter concentration of the silage mixture can also have an effect of protein degradation. Muck (1987) observed that protein degradation in alfalfa silage decreased as dry matter increased from 27 to 64%, with all treatments being ensiled at the same temperature (30°C). However, Muck and Dickerson (1988) conducted a study where alfalfa was ensiled at either 40 or 55% DM and ensiled at 15, 25, or 35°C for 40 d.

Table 2.1. Nutrient composition of three legumes (NRC, 2000)

Nutrient	Legumes		
	Alfalfa	Red Clover	Birdsfoot Trefoil
DM, %	23.4	19.6	19.3
TDN ¹ , %	62	69	66
CP ¹ , %	18.9	20.8	20.6
Crude Fiber ¹ , %	26.5	23.2	21.2
NDF ¹ , %	47.1	40	46.7
ADF ¹ , %	36.8	31	-

¹Percentage on a DM basis.

As a result, proteolysis increased with increasing temperature between 15 and 25°C, but did not increase as much between 25 and 35°C for both dry matter levels. This demonstrates that although dry matter content may influence proteolysis at a given temperature, the effect of temperature variation may be a stronger determining factor in the DM range that was tested. Muck and Dickerson (1988) suggest that reducing silage temperature may help maximize the amount of crude protein available at the end of ensiling. This is especially important during the first few days of ensiling as it has been observed that most proteolysis takes place during the first 2 to 5 days of the ensiling process (Ohshima and McDonald, 1978; McKersie and Buchanan-Smith, 1982; Muck, 1987).

Factors Affecting Fiber Content of Silage

As previously discussed, lactic acid is the primary acid required to reduce pH, which is necessary for the preservation of the silages nutritional components (McKersie, 1985). Lactic acid producing bacteria require fermentable non-structural carbohydrates to produce lactic acid (Owens et al., 1999). The amount of fermentable substrate in forage is often underestimated, as the hemicellulose contained in the plant cell wall can

be converted into sugars during the ensiling process that can be used for lactic acid production (Dewar et al., 1963). Hemicellulose decomposition occurs by three different processes: 1) active hemicellulases present in the herbage, 2) bacterial activity, and 3) hydrolysis by organic acids produced during fermentation (Dewar et al., 1963). The factors that determine the extent of hemicellulose decomposition are similar to those that determine the extent of protein degradation; pH, time, and temperature. Dewar et al. (1963) found that the optimum pH for hemicellulose degradation is 6.0, and slows down substantially at pH 4.0. Additionally, Dewar et al. (1963) observed that hemicellulose degradation was still occurring at pH 4.0 when hemicellulose prepared from *Lolium perenne* (perennial ryegrass) was incubated with enzymes extracted from *Lolium perenne*, *Lolium italicum* (Italian ryegrass), and *Dactylis glomerata* (cocksfoot), but at a much slower rate and most likely due to acid hydrolysis rather than enzymatic activity. Morrison (1979) also observed that acidic conditions can result in hemicellulose degradation. Conversion of hemicellulose to sugar was greatest at the 3-d mark of ensiling, but enzymatic degradation of hemicellulose appeared to halt after d 7 (Dewar et al., 1963). Moreover, Dewar et al. (1963) also observed the effect of temperature at a set pH (6.0) on the activity of hemicellulose degrading enzymes and found that *L. perenne* enzyme activity was greatest at 37°C, *L. italicum* enzyme activity was greatest at 30°C, and *D. glomerata* enzyme activity was greatest at 43°C. However, Dewar et al. (1963) concluded that temperature was not as strong of a determining factor of hemicellulose degradation as pH or time in this instance. It should be mentioned that although NDF

concentrations do decrease as a result of degrading hemicellulose, this would have very minimal effect on the concentration of the indigestible portion of NDF (Muck, 1988).

It is also possible for fiber content to increase in forage as it is ensiled. Although it is possible to observe increases in fiber concentration as a result of a decrease of non-fiber constituents (Buckmaster et al., 1989; Gunn et al., 2013), lignin content may increase as a result of Maillard reactions. Maillard reactions occur as a result of heating forages, which is associated with the fermentation process involved in making silage (Van Soest and Mason, 1991). The Maillard reaction is when sugar components, primarily hemicellulose and sucrose, are degraded to phenolic products. Amino acids or ammonia are degraded in the process, and the newly created phenolic products bind with the remnants of the N source (Mason et al., 1990; Van Soest and Mason, 1991). This results in the production of lignin polymers with high N content (Van Soest, 1965), which increases the concentration of indigestible N. Goering et al., (1973) subjected orchardgrass to various temperatures for 24-h in Erlenmeyer flasks with a moisture content of 53%, and observed that the amount of acid-detergent insoluble N was greatest in samples incubated at or above 60°C, but the data implies that a substantial amount Maillard reactions may still occur at temperatures between 40 and 60°C stored for periods longer than 24-h. Additionally, Gunn et al. (2013) observed an increase in ADF when modified wet distillers grains were ensiled with soybean hulls, suggesting that this may be a result of Maillard reactions, due to the fact that soybean hulls do not promote a very dense mixture. This allows for oxygen to be trapped between particles which promotes the heating that is associated with Maillard reactions (Pitt, 1990).

Aerobic Stability of Ensiled Forages

Aerobic stability is a measure of how much time it takes for silage to start generating heat after the silo is opened to feed animals, which is associated with aerobic chemical reactions that lead to the degradation of silage quality (Muck, 2004). The spoilage and heating of silages when exposed to oxygen is generally associated with yeasts (Woolford, 1990). Management practices towards improving aerobic stability typically focus on inhibiting the growth of yeast. Although the presence of lactic acid is an effective yeast inhibitor, acetic and propionic acid has been demonstrated to be more effective (Moon, 1983; Cai et al., 1999). Thus, the aforementioned management practices usually involve inoculating the silage with a strain of bacteria that produces lactic, acetic, or propionic acid. Heterofermentative lactic acid bacteria, that produce both lactic and acetic acid, have demonstrated to be more effective at improving aerobic stability than homofermentative lactic acid bacteria that only produce lactic acid (Muck, 2004). It has been demonstrated that inoculants can often be ineffective in improving aerobic stability (Muck and Kung, 1997). A review written by Muck (1988) suggests that in order for an inoculant to be effective, it must grow faster than the lactic acid bacteria already present in the forage.

The Potential Role of Sugar Beets in Silage Fermentation

Ample research has been published regarding the use of sugar beet pulp in silage mixtures consisting of grass, forage maize, dry rolled corn, wheat midds, and dry corn gluten feed (Ferris and Mayne, 1994; Moore and Kennedy, 1994; Hamelers et al., 1999; Leupp et al., 2006), but this research is mostly focused on using sugar beet pulp as an

absorbent to decrease effluent production. Effluent is a liquid that seeps out of the silo during the fermentation process that can lead to dry matter loss from the silage (Moore and Kennedy, 1994), and is a major source of water pollution (Ferris and Mayne, 1994). This body of research generally agrees that the inclusion of sugar beet pulp in silage mixtures is effective at reducing effluent production (Ferris and Mayne, 1994; Moore and Kennedy, 1994; Hameleers et al., 1999)

Certain fermentation characteristics were also measured as part of these research studies including pH, acid production, and soluble non-protein N production. Sugar beet pulp consistently generated lower pH values as opposed to ensiling grass alone (Ferris and Mayne, 1994; Moore and Kennedy, 1994). A study conducted by Leupp et al., (2006) observed that including wet sugar beet pulp produced consistent pH values across a range of dry matter values (25-50% DM) after being ensiled for 47 days, indicating that wet sugar beet pulp had a strong influence on pH. It is assumed that sugar beet pulp is effective in reducing pH due to the high content of water soluble carbohydrates in sugar beets, providing more fermentable substrate for lactic acid bacteria. In the case of Ferris and Mayne (1994), the pH drop was not rapid, as pH values for the sugar beet pulp treatments were higher than the control on d-14, but generated the lowest pH values by d-56. These authors suggested that the water soluble carbohydrates in the sugar beet pulp was not available until the beet pulp was soaked in effluent. This conflicts with observations made by Leupp et al., (2006), likely due to the fact that Leupp et al., (2006) used wet sugar beet pulp rather than a dried sugar beet pulp. The collection of reviewed literature generally demonstrates that the inclusion of sugar beets in a silage mixture

supports a rapid decrease in pH, as long as moisture is available to facilitate the availability of the sugar to the acid-producing bacteria.

The acid production profiles as a result of including sugar beet pulp in silage mixtures were also measured. It has consistently been observed that the inclusion of sugar beet pulp increases lactate production and decreases acetate production (Ferris and Mayne, 1994; Moore and Kennedy, 1994; Hamelers et al., 1999). Although aerobic stability was not measured in these studies, it is possible that this acid production profile could have detrimental effects on the aerobic stability of silage as acetate is a stronger inhibitor of yeasts than lactate (Moon, 1983). Perhaps it would be appropriate to use an inoculant that promotes the production of acetic acid when including sugar beets in silage mixtures.

Soluble N production was also measured in these studies as a measure of CP degradation, and sugar beet pulp effectively decrease soluble N production in studies conducted by Ferris and Mayne (1994) and Moore and Kennedy (1994). This may relate in the reduction in pH that has been observed in the same research, which would help inhibit proteolysis.

Sugar Beet Feeding Strategies

Considering the results from the previous research studies, it is reasonable to believe that the addition of sugar beets to diets for ruminant livestock will increase butyrate production, enhance the efficiency of N utilization by rumen microorganisms, and could potentially increase fiber digestibility. This is likely to be attributable to the

high sucrose content and the absence of starch in sugar beets. Given the unique qualities of this underutilized energy source, sugar beets must be fed in a strategic manner in order to reap optimal benefit when using them in a livestock operation. Things that must be considered are the unique fermentation characteristics of sugar when compared to starch, the relationship between sugar and fiber digestibility, the necessity for rumen degradable protein, the high moisture content of sugar beets, shipping costs, animal safety, and storage.

Unique Fermentation Characteristics of Sugar

After reviewing relevant scientific literature, it is apparent that sugar can induce different ruminal fermentation patterns when compared to starch. This is likely attributable to their different chemical structure and composition (Cummings and Stephen, 2007). Replacing starch-based energy sources with sugar-based energy sources has consistently demonstrated to favor butyrate production, and decrease propionate production. It has been demonstrated that this type of VFA production pattern will raise plasma concentrations of non-esterified fatty acids (NEFA), blood concentrations of β -hydroxybutyrate and acetoacetate, and decrease plasma glucose concentrations (Huhtanen et al., 1998). This indicates a mobilization of fat stores to be used as energy in response to low available glucose. This can also lead to the utilization of amino acids in gluconeogenesis (Malette et al., 1969), resulting in an inefficient use of nitrogen. These factors would not favor steer backgrounding performance. However, the actual amount of increase in butyrate and decrease in propionate would have to be quite substantial to have a biologically significant effect on performance.

Sugar beets should be fed at conservative levels. An abundance of a readily fermentable energy source in the rumen can induce rapid fermentation, which would cause a shift in fermentation products from acetate, propionate, and butyrate to lactate production (Russell, 1998). Bloat is also a concern regarding feeding excessive amounts of sugar beets, as it is rapidly fermented in the rumen environment. The article “A Review of Bloat in Ruminants” (Cole et al., 1945), mentions a number of experiments where sugar significantly increases gas production in the rumen. However, it is also noted in this article that starch is capable of generating the same amount of rumen gas as sugar, but requires a longer time to become fermented (Cole et al., 1945). The extra time that starch requires to be fermented allows the gas to build up over time, making starch more likely to cause bloat in ruminants.

Relationship between Sugar Beets and Fiber Digestibility

Results from Huhtanen (1988) and Arrizon et al. (2012) indicate that sugar beets harbor the potential to enhance fiber digestion. Huhtanen (1988) observed an increase in crude fiber digestibility when unmolassed sugar beet pulp replaced barley in a silage based diet. Additionally, Arrizon et al., (2012) observed a linear increase in NDF digestibility when dried shredded sugar beets replaced steam-flaked corn at rates of 0, 20, and 40% of the dry matter in the total mixed ration. These studies also observed increased fiber intake as sugar beets were added to the diet. The presence of sufficient fiber in the rumen may have had an influence on fiber digestibility in these studies, as Belanche et al. (2012) observed that fiber-rich diets enhanced the synthesis of cellulolytic microorganisms when compared to starch-based diets. Increased fiber digestibility

observed in the aforementioned studies could also be associated with the sugar content of sugar beets. Broderick and Radloff (2004) observed a quadratic relationship between sugar supplementation and crude fiber digestibility in lactating dairy cows, where crude fiber digestibility increased when sugar exceeded 4.9% of the DM, but decreased when sugar was supplemented at 10% of the DM. Vallimont et al., (2004) replaced cornstarch with sucrose in the dry matter of total mixed rations for continuous culture fermenters at rates of 0, 2.5, 5, and 7.5%, and observed a quadratic response for NDF digestibility. These results indicate that the amount of sugar present must reach a certain threshold, somewhere between 5 and 7.5% to have an effect on fiber digestibility. It is interesting to note that none of these studies observed an effect of the inclusion of dried shredded sugar beets, sugar beet pulp, or sugar on pH, indicating that the effect of these treatments on fiber digestibility occurred through mechanisms that are independent of pH.

Nitrogen Source

As previously mentioned, sugar beets do not contain adequate protein (6.8% CP; Lardy and Schafer, 2008). This protein deficit must be accounted for when balancing diets that include sugar beets in order to avoid hindering rumen microbial synthesis. Previously mentioned studies have indicated that the inclusion of sugar in the diet for ruminants is an effective strategy for reducing ammonia concentrations in the rumen (Chamberlain et al., 1985; Huhtanen, 1988; Rooke et al., 1991). This means that it may be appropriate to pair sugar beets with a highly rumen degradable protein source like soybean meal, alfalfa, or dietary components that are associated with high rumen ammonia concentrations like silage (Chamberlain et al., 1985).

Effects of Moisture Content on Digestibility

The high moisture content of sugar beets must also be considered. There has been evidence that suggests that a high moisture diet can increase passage rate, and this could be a result of a high moisture diet (Trenkle, 1992). This could present a problem as increased passage rates of feed through the rumen can hinder the digestibility of that feed (Allen and Mertens, 1988). Animals usually compensate for this by increasing their intake to meet their nutrient requirements (Balch, 1950). Although this is a factor that should be considered, it has been demonstrated that animals will adjust their water intake based on their dry matter intake (Meyer et al., 2004). In theory, animals fed sugar beets would drink less water when compared to animals receiving diets containing a higher dry matter content.

Logistical Issues

The high moisture content of sugar beets also presents an entirely different problem due to the fact that the additional weight of the excess moisture will increase the shipping cost of this feedstuff. In order to feed sugar beets to gain financial benefit, the operation in which sugar beets are to be used must be within a reasonable distance to a sugar beet provider. In addition, the physical nature of the sugar beet increases the chances of animals choking. It is suggested that whole beets to be broken up prior to feeding. Using either a wood-chipper or an extended mixing time with a conventional mixer wagon has been shown to be able to adequately break up whole beets (Lardy and Schafer, 2008). Lastly, it may be necessary that sugar beets are washed before feeding. The residue left on sugar beets after harvesting can contain an unpredictable profile of

minerals, which reduces the control that the livestock manager would have over the nutrient profile of the diet.

Hypotheses

Considering the amount of unutilized sugar beets available in Montana and their potential to be used as an energy source by livestock operations, we carried out 3 research studies to help us determine how livestock operations can use sugar beets to generate optimal results; a steer backgrounding performance study, a sheep nutrient metabolism study, and a sugar beet silage fermentation study. Based on the previous literature we have based our research on the following hypotheses:

1. Replacing barley with sugar beets in backgrounding rations for steers will not negatively impact steer performance.
2. Replacing barley with sugar beets in rations for growing wethers will not result in any deleterious effects on nutrient metabolism and will alter ruminal fermentation patterns.
3. Adding sugar beets to a hay silage mixture will result in adequate silage fermentation.

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CHAPTER THREE

EFFECTS OF SUGAR BEETS ON STEER BACKGROUNDING PERFORMANCE,
SHEEP NUTRIENT METABOLISM, AND RUMINAL CHARACTERISTICS

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ABSTRACT

A performance and metabolism study were performed to evaluate the effects of sugar beets on steer backgrounding performance, sheep nutrient metabolism, and rumen fermentation characteristics. In both experiments, four dietary treatments were used where sugar beets replaced 0% (0SB), 15% (15SB), 30% (30SB), or 45% (45SB) of barley on a DM basis. Forty eight Angus steers were used in a completely randomized design to conduct the 50 d performance study. The MIXED procedure of SAS was used for the statistical analysis in both trials. Neither ADG nor G:F were effected by treatment ($P \geq 0.33$). However, there was a quadratic tendency for DMI ($P = 0.06$), where 0SB was reduced and 15SB was increased, with 30SB and 45SB being intermediate. In the metabolism study, a 4 x 4 replicated Latin Square design was used to observe the effects of increasing dietary inclusion of sugar beets on the nutrient metabolism and ruminal fermentation characteristics of eight growing wethers. A quadratic tendency was observed for ADF digestibility ($P = 0.10$), with 0SB and 45SB wethers being greater than 15SB and 30SB wethers. A cubic affect was observed for nitrogen (N) balance ($P = 0.04$). Ruminal ammonia and acetate concentrations demonstrated a linear tendency ($P \leq 0.09$) to increase with increasing sugar beets in the diet. Propionate concentration decreased linearly ($P = 0.05$) with increasing sugar beets in the diet. The acetate to propionate ratio increased linearly ($P = 0.03$) with increasing sugar beets in the diet. Butyrate concentration demonstrated a treatment \times time effect ($P = 0.01$), where butyrate concentration increased with increasing sugar beets in the diet at 1300. Ruminal pH was not affected ($P \geq 0.39$) by treatment at 0700 h, but a quadratic effect was observed for pH

at 1300 h ($P = 0.05$), with 15SB having the greatest pH and 45SB having the least pH.

Our results allow us to conclude that replacing barley with sugar beets up to 45% of the diet dry matter will have no deleterious effects on steer backgrounding performance or sheep nutrient metabolism, but will alter rumen fermentation patterns.

Key words: steer, performance, sheep, nutrient metabolism, ruminal characteristics, sugar beets

INTRODUCTION

Montana is a major producer of sugar beets in the Northern Great Plains (5th in the US; USDA, 2015a). During the 2014-2015 sugar beet harvest, approximately 45.2 million pounds of sugar beets were not harvested (USDA, 2015b). Feedstock opportunities exist considering the energy content of sugar beets (81% TDN; Lardy and Schafer, 2008), as the non-harvested sugar beets could provide a readily available feedstuff for cattle and sheep producers that could potentially replace more traditional feedstuffs such as barley or corn. Sugar beets differ from traditional feedstuffs due to their moisture content (70-80% moisture; Lardy and Schafer, 2008) and how they store energy in the form of sugar rather than starch (12-20% sugar; Agribusiness Handbook, 2009). In addition, sugar beets contain considerably less protein than barley and corn (barley 14.0% CP, corn 9.8% CP; NRC, 2000; sugar beets 6.8% CP; Lardy and Schafer, 2008).

Many studies have observed no deleterious effects on steer backgrounding performance or nutrient metabolism when sugar beets or sugar beet pulp replace more

traditional energy sources (Huhtanen et al., 1988; Olfaz et al., 2005; Arrizon et al., 2012). In addition, other studies have observed many differences between the effects of sugar and starch on ruminal fermentation patterns (Vallimont et al., 2004; Ribeiro et al., 2005).

Based on energy density, sugar beets may provide an excellent alternative to more traditional energy sources. Due to the chemical nature of sugar beets, we hypothesized that feeding increasing levels of sugar beets would have no deleterious effects on steer feedlot growth or sheep nutrient metabolism. Therefore, the objective of this study was to evaluate the effects of sugar beets on steer backgrounding performance and sheep nutrient metabolism.

MATERIALS AND METHODS

All procedures were approved by the animal care and use committee of Montana State University (#2015-AA09 & #2016-AA09).

Experiment One: Backgrounding trial

Animals and Diets.

Forty-eight Angus steers (260.7 ± 3.4 kg) were used in a completely randomized design for a 50 d study. Steers were weighed on consecutive days on d -1 and 0. Steers were stratified by BW and assigned to 1 of 8 pens (6 steers per pen) equipped with GrowSafe (GrowSafe Systems Ltd., Airdrie, AB Canada) units to allow for individual feed intake measurement starting on d 0. On d 0, pens were allotted to one of the four dietary treatments (n = 12 steers/treatment; 2 pens/treatment: Table 3.1): 1) **0SB**: control diet with no sugar beets and 45% barley; 2) **15SB**: 15% sugar beets and 30% barley; 3)

30SB: 30% sugar beets and 15% barley; and 4) **45SB**: 45% sugar beets and 0% barley. Sugar beets directly replaced rolled barley on a DM basis. All dietary treatments were formulated to meet or exceed the nutrient requirements of a 295-kg steer gaining 0.91 kg/d (NRC, 2000). Steers had continuous access to water and shelter. Sugar beets were processed through a commercial wood chipper to reduce the particle size. Steers were weighed on consecutive days at the beginning of the trial (d -1 and 0), mid-point (d 26 and 27), and end (d 49 and 50) of the trial. Individual DMI and G:F of each steer was calculated. Two steers were removed from the study due to non-treatment related illness. Ration samples were collected weekly, composited by treatment by period, and dried in a forced-air drying oven at 60° C for 48 h to determine DM.

Statistical Analysis

The MIXED procedure of SAS was used for the statistical analysis of all performance data (SAS 9.4; SAS Inst. Inc., Cary, NC). The dietary treatment was the fixed effect included in the model with a random effect of pen nested within treatment. Dry matter intake data was analyzed utilizing repeated measures with the fixed effects of dietary treatment, day, and the interaction. Four days of dry matter intake data were not calculated due to equipment failure. Individual animal is the experimental unit. Pre-planned comparisons of linear, quadratic, and cubic contrasts were utilized to partition treatment effects. Significance was determined at $P \leq 0.05$, and tendencies were determined at $P \leq 0.10$. To partition day effects and treatment \times day interactions, LS Means was utilized ($P \leq 0.05$).

Experiment Two: Metabolism Trial

Animals and Diets

A 4 × 4 replicated Latin Square design was used to evaluate the effects of four diets varying in sugar beet concentration on the digestibility of DM, NDF, ADF, N, N balance, as well as ruminal fermentation patterns of wethers. Wethers were weighed and allotted into one of four dietary treatments on d 0 (n = 2 wethers/treatment; 2 crates/treatment: Table 3.3): 1) **0SB**: control diet with no sugar beets and 45% barley; 2) **15SB**: 15% sugar beets and 30% barley; 3) **30SB**: 30% sugar beets and 15% barley; and 4) **45SB**: 45% sugar beets and 0% barley. All dietary treatments were formulated to meet or exceed the nutrient requirements of growing wethers (30 kg; NRC, 2007). Due to the protein content provided by sugar beets relative to barley, soybean meal was added to the total mixed ration (TMR) as sugar beet concentration increased in order to make the diets isonitrogenous. Water was added to each dietary treatment to equilibrate moisture content among treatments. Each experimental period was 20 d in length with 4 d between periods (d 1 to 5; to remove wethers from metabolism crates). All wethers were kept in a single pen with ad libitum access to hay and water d 1 to 5. On d 5, wethers were assigned to a dietary treatment and placed in metabolism crates in a temperature controlled enclosed room for a 10-d adaptation period to metabolism crates and diets, and a 5-d total collection. Wethers were on a 12 h light, 12 h dark schedule.

Sampling and Laboratory Analysis

Total mixed ration samples were collected d 15 through d 19 and ort samples were collected d 16 through d 20. Ort and TMR samples were dried in a 60° C forced air-

drying oven for 48 h for DM analysis. Total fecal output was collected and weighed on d 16 through d 20 with 7.5% of the total fecal sample collected, weighed, and placed in a 60° C forced-air drying oven for 96 h for DM analysis. Total urine output was collected on d 16 through d 20. Exactly 100 mL of 6 *N* HCl was added daily to urinals to maintain urine pH < 3. A 25% subsample of the total urine weight was collected and composited by individual lamb. Total mixed ration, ort, and fecal samples were ground to pass a 1 mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Ort samples were composited by lamb within period and TMR samples were composited by period. Feed, ort, and fecal samples were analyzed for NDF (AOAC, 2005) and ADF (AOAC, 2005) by using an Ankom 2000 Fiber Analyzer (Ankom Co., Fairport, NY). Alpha-amylase and sodium sulfite were used in the NDF procedure. Nitrogen concentrations were also measured (AOAC, 2010).

Blood samples were collected on d 15 through d 19, 4 hours post-prandially via jugular venipuncture into 16 × 100 mm blood collection tubes (no. 367988; BD Vacutainer, Franklin Lakes, NJ) and refrigerated at 4° C for 4 h. Blood samples were centrifuged at 2500 × *g* for 20 minutes at 4° C. Serum was collected into 5-mL polypropylene tubes. Samples were then stored at -20° C until analysis. Serum urea nitrogen (SUN) concentrations were determined by using a commercial colorimetric kit (Teco Diagnostics, Anaheim, CA) with intra- and interassay CV less than 12%.

Rumen fluid was extracted from all sheep via oral lavage on d 19 of each period at 0700 (pre-prandial) and at approximately 1300 (post-prandial). Rumen fluid pH measurements were taken immediately after extraction, then samples were stored at -

20°C. Rumen samples were analyzed for ammonia concentration (RAN) using methods similar to those described by Sigma Technical Bulletin #640, Chaney & Marback (1962), Horn & Squire (1967), and Weichselbaum et al., (1969). Rumen samples were also analyzed for individual VFA concentrations using a gas chromatography procedure similar to that described by Baumgardt (1964), Supleco Inc. bulletin 749E (1975), Byers (1979), and Fritz & Schenk (1979).

Statistical Analysis

Data were analyzed as a replicated Latin Square, with lamb serving as the experimental unit. Nutrient metabolism data were analyzed using the MIXED procedure of SAS (SAS 9.4; SAS Inst. Inc., Cary, NC). The model included the fixed effects of dietary treatment, period, and replicate. The period and dietary treatment interaction as well as the replicate and treatment interaction served as random effects. Day served as the repeated measure used to analyze daily DMI and SUN concentrations using the variance components covariance structure, selected due to the lowest Akaike's information criteria. Fixed effects for SUN and daily DMI were dietary treatment, day, and the interaction. Rumen fluid analysis was conducted with the fixed effects of dietary treatment, time of collection, and the interaction. Time of collection served as the repeated measure with the variance component covariance structure. Linear, quadratic, and cubic orthogonal contrasts of sugar beet inclusion rate served to partition dietary treatment effects. Significance was set at $P \leq 0.05$, with tendencies set at $P \leq 0.10$.

RESULTS AND DISCUSSION

Experiment One: Backgrounding trial

Average daily DMI demonstrated a quadratic tendency ($P = 0.06$; Table 3.2) where 15SB resulted in the greatest daily DMI, and 0SB resulted in the lowest daily DMI. The increase in daily DMI between 0SB and 15SB could be attributable to dietary moisture content. As moisture content increases in the diet, passage rate of the feed through the digestive tract may increase, thus hindering the digestibility of that feed (Trenkle, 1992). Animals will typically increase their intake to make up for the decrease in digestibility (Balch, 1950). This result may also be due to differences in palatability between diets. Nombekela et al. (1994) conducted a study using six multiparous Holstein cows and compared their preferences between sweet, sour, bitter, and salty diets. Four out of six of the cows preferred the sweet diet, and the probability that the cow would choose the sweet diet over the other three diets was 59%. We also observed that daily DMI started to decrease when there was more than 15% sugar beets in the diet. This result is similar to results generated by other studies where DMI decreased when wet sugar beet pulp was included in the diet at concentration's greater 20% (Olfaz et al., 2005; Lardy and Schafer, 2008). Olfaz et al. (2005) observed decreases in DMI when the TMR for Karayaka male lambs included 40 and 60% sugar beet pulp, compared to the control with 0% sugar beet pulp.

Mid-point BW, final BW, and ADG were not affected ($P \geq 0.16$) by dietary treatments. Although statistically insignificant, there was a numerical increase in ADG as sugar beets increased in the diet. This observation is emphasized in order to show that

the inclusion of sugar beets up to 45% in the diet had no deleterious effects on steer performance, in light of our hypothesis. Arrizon et al. (2012) also generated results indicating that replacing 20 or 40% of steam-flaked corn with dried shredded sugar beets in total mixed rations for steers on a dry matter basis would have no deleterious effects on ADG. However, Olfaz et al., (2005) observed significant increases in body weight gain when sugar beet pulp was added up to 60% of grass hay based TMR's for growing male Karayaka sheep. Although we did not observe an increase in BW or ADG, this may, in part, be due to the increased passage rate due to the increased moisture content of the sugar beet diets.

Feed efficiency was not affected ($P \geq 0.12$) by treatment in the current study. Contrary to our results, Arrizon et al. (2012) observed a linear decrease in feed efficiency as dried shredded sugar beets increased in the diet up to 40% of the dry matter. This could be due to the different protein sources used between the current study and Arrizon et al. (2012). The current study used soybean meal as a protein source, and Arrizon et al. (2012) used alfalfa hay and distillers grains as a protein source. The protein in soybean meal and alfalfa hay is made up of mostly degradable intake protein (DIP) (soybean meal 65% DIP, alfalfa hay mid-bloom 84% DIP; NRC, 2000), but distiller's grains contain much less DIP (distillers grains + solubles 27.2% DIP; NRC, 2000). Microbial protein synthesis contributes to a majority of the amino acids that are absorbed in the duodenum of the small intestine, and also contains an amino acid profile that is favorable for meat and milk production (NRC, 2000). Rumen microorganisms require N for microbial synthesis (Nocek & Russell, 1988). Due to lesser DIP component of distiller's grains as

a protein source, it is possible that less N was available for microbial protein synthesis, thus resulting in a decrease in feed efficiency in the study conducted by Arrizon et al., (2012).

The results generated by this study allows us to conclude that sugar beets can be fed up to 45% in total mixed rations for backgrounding steers with no deleterious effects on steer backgrounding performance.

Experiment Two: Metabolism trial

The nutrient metabolism results are reported in table 3.4. Daily DMI and DM digestibility were not affected by treatment ($P \geq 0.25$). Similar to the current study, Arrizon et al., (2012) did not observe any differences in organic matter digestibility when dried shredded sugar beets replaced steam-flaked corn in TMR's for steers at rates of 0, 20, and 40% on a DM basis. Contrary to the current study, Huhtanen (1988) observed a decrease in DM digestibility when sugar beet pulp replaced barley in a silage based diet. This may be due to the greater fiber content of the sugar beet pulp diets compared to barley diets used by Huhtanen (1988).

There was no treatment effect on NDF digestibility ($P \geq 0.33$). However, ADF digestibility demonstrated a tendency to be effected quadratically by treatment ($P = 0.10$) with 15SB and 30SB producing the lesser values, and 0SB and 45SB producing the greater values. Our results differ from those observed by Arrizon et al., (2012), who reported increased NDF digestibility when dried shredded sugar beets replaced steam flaked corn. The results of the current study also differ from results observed by Huhtanen (1988), who reported increased NDF and ADF digestibility when sugar beet

pulp replaced barley in a silage based diet. We observed that the values for ADF digestibility and intake follow a very similar pattern in the current study (Table 3.4). This may relate to results generated by Belanche et al (2012), where it was observed that fiber rich diets consistently increased the synthesis of cellulolytic microorganisms when compared to starch rich diets in both high and low protein diets. This relationship is also apparent in results generated by Arrizon et al., (2012) and Huhtanen (1988), where the intakes of NDF and ADF increased as dried shredded sugar beets or sugar beet pulp increased in concentration in the diet, resulting in increased fiber digestibility.

There was a linear tendency ($P = 0.07$) for RAN concentrations to increase as sugar beets increased in the diet. This is likely due to the increase in soybean meal as sugar beets were added to the diet. The protein in soybean meal is much more soluble in the rumen environment than the protein contained in barley (barley grain 49% RUP; NRC, 2016). Increasing ammonia concentrations indicates an abundance of soluble protein in the diet and in certain instances inefficient use of N due to bacteria requiring more energy in order to use the excess ammonia for microbial protein synthesis (Nocek & Russell, 1988), and the possible inefficient use of energy required to excrete urinary nitrogen (Russell, 2002). It's well established that including sugar in a TMR for ruminant animals typically decreases RAN concentrations (Chamberlain et al., 1985; Huhtanen, 1988; Rooke et al., 1992). It is important to note that previous research used grass silage based diets, which are usually associated with soluble protein and subsequently high RAN concentrations (Chamberlain et al., 1985). Huhtanen (1988) and Rooke et al., (1992) observed a decrease in RAN when sugar beet pulp or molassed sugar

beet feed replaced barley in a silage based diet. Chamberlain et al. (1985) also demonstrated that supplementing sugar may be more effective than starch in decreasing RAN concentrations in goats receiving a silage based diet.

There was no effect on the excretion of nitrogen through the feces or urine ($P \geq 0.18$), and no effect on serum urea nitrogen ($P \geq 0.22$). Nitrogen balance demonstrated a cubic treatment effect ($P = 0.04$), with 30SB having the highest nitrogen balance and 15SB having the lowest. As previously discussed, rumen microorganisms require N to carry out microbial protein synthesis, and energy is required by the microorganisms in order to utilize N (Nocek & Russell, 1988). It has been suggested that feeding carbohydrates and protein in synchrony can result in improvements in N utilization and animal performance (Cole & Todd, 2008). Although the diets contained similar amounts of energy and protein, the solubility of the protein source was different as sugar beet concentrations changed in the diet due to the added soybean meal. It seems that available N may have been lacking in the 15SB treatment, and available N may have been in excess in the 45SB treatment, as reflected by their respective ammonia levels.

As a result of increasing concentrations of sugar beets in the dietary treatments in the current study, we observed a linear tendency for ruminal concentrations of acetate to increase ($P = 0.09$), a linear decrease in propionate ($P = 0.05$), a linear increase in the acetate to propionate ratio ($P = 0.03$), and a linear increase in butyrate ($P = 0.01$) that occurred post-prandially. Dietary treatment did not affect concentrations of valerate, isobutyrate, or isovalerate ($P \geq 0.25$). The increase that was observed regarding the acetate to propionate ratio indicates that sugar beets produce an effect that would be

characterized as a forage energy source, rather than a concentrate energy source (Lana et al., 1998). These results are consistent with Voelker and Allen (2003) and Arrizon et al. (2012) where it was observed that concentrations of acetate and butyrate increased, while propionate decreased when pelleted beet pulp or dried shredded sugar beets replaced high moisture corn or steam-flaked corn, respectively. Increasing butyrate concentrations may be attributable to the sugar content of sugar beets, as Vallimont et al. (2004) observed a linear increase in butyrate concentrations when sucrose replaced corn starch at rates of 0, 2.5, 5, and 7.5% in TMR's for continuous culture fermenters. Ribeiro et al. (2005) also observed an increase in butyrate concentrations when sucrose supplements were added to alfalfa hay at rates of 0, 4, and 8%. Results from Huhtanen et al. (1988) also observed a tendency for increasing acetate concentrations when sugar beet pulp replaced barley in silage based diets, but observed divergent results as propionate demonstrated a tendency to increase while butyrate significantly decreased when sugar beet pulp replaced barley.

Ruminal pH at 0700 h was not affected by treatment ($P \geq 0.39$). This result is complimentary to those observed by Huhtanen (1988) and Arrizon et al., (2012) where no treatment effect was observed for pH when sugar beet pulp or dried shredded sugar beets replaced barley or steam flaked corn, respectively. However, dietary treatment imposed a quadratic effect on pH at 1300 as sugar beets increased in the diet ($P = 0.05$).

Measurements of pH at 1300 h were greatest for 15SB and was least for 45SB. It is important to note that pH measurements were above 6 amongst all treatments, indicating that microbial synthesis was not limited by pH (Russell & Dombrowski, 1980).

The results from this study demonstrates that sugar beets can replace barley up to 45% without having any deleterious effects on nutrient metabolism. We also conclude that VFA production patterns can be altered by the addition of sugar beets to total mixed rations for growing wethers.

IMPLICATIONS

Results generated by the current study support our hypotheses, leading us to make the following conclusions; 1.) Sugar beets fed up to 45% of the dry matter has no deleterious effects on steer backgrounding performance when compared to barley. 2.) Sugar beets fed up to 45% of the dry matter has no deleterious effects on the digestibility of fiber or nitrogen when compared to barley. 3.) Sugar beets are capable of altering rumen fermentation patterns when compared to starch based energy sources. We believe that the results from our sheep metabolism study can be extrapolated to cattle as well, given the similarity between their respective digestive systems and the similar diets between studies. We believe that sugar beets are a safe energy source to be used by livestock producers, and can be financially rewarding in some cases. Also, this provides another avenue by which sugar beet producers can sell sugar beets, thus enhancing the financial sustainability of sugar beet growing operations.

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Table 3.1. Ingredient and nutritional composition of diets fed to backgrounding steers (DM basis)

Item	Dietary Treatment ¹			
	0SB	15SB	30SB	45SB
Ingredient, %				
Sugar beets ²	—	15.0	30.0	45.0
Rolled barley	45.0	30.0	15.0	—
Chopped hay	45.0	41.0	36.9	32.75
Soybean meal	6.25	10.40	14.75	19.0
Mineral premix ³	0.90	0.90	0.90	0.90
Calcium carbonate	1.25	1.10	0.85	0.75
Salt	0.25	0.25	0.25	0.25
Deccox	1.35	1.35	1.35	1.35
Nutritional Composition ⁴				
DM, %	87.4	74.4	64.7	57.3
TDN, %	66.6	65.5	64.5	63.4
CP, %	16.0	15.6	15.4	15.1
Ca:P	2.63	2.65	2.57	2.64

¹Dietary treatments were: 0SB: control diet with no added sugar beets; 15SB: 15% sugar beets substituted for barley; 30SB: 30% sugar beets substituted for barley; and 45SB: 45% sugar beets substituted for barley on a DM basis.

²Sugar beets were processed through a wood chipper to reduce the particle size to reduce the risk of choking.

³Mineral premix: 13.6% Ca, 10% P, 15.6% NaCl, 1.0% Mg, 0.1% K, 2,500 mg/kg Cu, 35 mg/kg Se, 8,500 mg/kg Zn, 440,529 IU/kg vitamin A, 44,053 IU/kg vitamin D, and 881 IU/kg vitamin E.

⁴Calculated nutrient composition of the diets.

Table 3.2. Effects of increasing sugar beets on backgrounding performance of steer calves.

Item	Dietary Treatment ¹				SEM	<i>P</i> – value	Contrasts ²		
	0SB	15SB	30SB	45SB			Linear	Quadratic	Cubic
BW, kg									
d 1	259.8	261.6	260.3	261.1	7.08	1.00	0.94	0.95	0.87
d 28	299.7	302.9	302.8	304.9	8.52	0.98	0.68	0.95	0.88
d 50	324.0	334.8	339.3	341.7	10.54	0.63	0.27	0.67	0.92
ADG, kg/d									
d 1 to 27	1.42	1.48	1.52	1.57	0.14	0.89	0.44	0.99	0.98
d 28 to 50	1.42	1.39	1.59	1.60	0.17	0.72	0.36	0.92	0.59
d 1 to 50	1.38	1.44	1.55	1.58	0.12	0.55	0.16	0.90	0.78
DMI, kg/d									
d 1 to 27	6.24	6.65	5.94	5.70	0.42	0.25	0.11	0.36	0.34
d 28 to 50	8.33	9.12	9.65	8.92	0.52	0.18	0.21	0.10	0.62
d 1 to 50	7.14	7.70	7.60	7.25	0.28	0.16	0.80	0.06	0.69
G:F									
d 1 to 27	0.23	0.22	0.24	0.27	0.02	0.41	0.20	0.27	0.79
d 28 to 50	0.16	0.15	0.17	0.18	0.02	0.72	0.43	0.59	0.64
d 1 to 50	0.19	0.18	0.20	0.22	0.02	0.33	0.12	0.41	0.71

¹Diets will be formulated to meet or exceed nutrient requirements of a 295-kg steer gaining 0.91 kg/d (NRC, 1996). Treatments were 0SB: 45% barley and 45% chopped hay; 15SB: 15% sugar beets substituted for barley on a % DM basis; 30SB: 30% sugar beets substituted for barley; and 45SB: 45% sugar beets substituted for barley

²n = 12

³*P* -value for the *F*-test of the mean.

⁴*P*-value for linear, quadratic, and cubic effects of increasing sugar beets in the diet.

Table 3.3. Ingredient and nutritional composition of diets fed to growing wethers (DM basis).

Item	Dietary Treatment ¹			
	0SB	15SB	30SB	45SB
Ingredient, %				
Sugar beets ²	—	15.00	30.00	45.00
MSU barley	45.00	30.00	15.00	—
Grass hay	46.00	41.00	36.90	32.80
Soybean meal	5.50	10.40	14.80	19.00
NaCl	0.25	0.25	0.25	0.25
Decoquate	1.35	1.35	1.35	1.35
Calcium carbonate	1.00	1.10	0.85	0.75
Mineral premix	0.90	0.90	0.90	0.90
Nutritional Composition ⁴				
DM, %	28.33	24.97	22.59	20.72
TDN, %	66.80	65.80	64.80	63.60
CP, %	15.80	15.70	15.40	15.10
Ca:P	2.30	2.50	2.40	2.47

¹Dietary treatments were: 0SB: control diet with no added sugar beets; 15SB: 15% sugar beets substituted for barley; 30SB: 30% sugar beets substituted for barley; and 45SB: 45% sugar beets substituted for barley on a DM basis.

²Sugar beets were coarse ground with a flail chopper designed for woody biomass, to reduce choking hazard.

Table 3.4. Nutrient metabolism characteristics of growing wethers fed increasing concentrations of sugar beets in the diet.

Item	Dietary Treatment ¹				SEM ²	Orthogonal Contrasts ³		
	0SB	15SB	30SB	45SB		Linear	Quadratic	Cubic
Initial BW, kg	36.65	36.65	36.65	36.65	0.00	1.00	1.00	1.00
Daily DMI, g/kg BW	29.12	26.01	28.03	30.43	2.51	0.61	0.30	0.68
Daily NDF intake, g/kg BW	12.48	9.57	10.50	11.14	0.85	0.41	0.04	0.27
Daily ADF intake, g/kg BW	7.80	5.96	6.88	7.13	0.60	0.68	0.09	0.20
Daily nitrogen intake, g/kg BW	0.68	0.63	0.90	0.74	0.07	0.10	0.33	0.02
Total tract digestibility, %								
DM	70.34	67.23	71.29	71.4	0.20	0.44	0.44	0.25
NDF	57.07	50.70	52.71	53.41	35.02	0.57	0.33	0.54
ADF	51.64	40.41	48.64	50.58	39.11	0.77	0.10	0.14
Nitrogen	74.83	72.66	74.95	72.22	1.88	0.37	0.85	0.19
Daily nitrogen excretion, g								
Fecal	6.57	6.16	6.37	7.51	0.70	0.36	0.29	0.92
Urine	12.23	12.31	12.03	14.41	1.02	0.18	0.27	0.51
Serum urea nitrogen, mg/dL	5.65	5.03	4.39	4.87	0.53	0.22	0.31	0.63
Nitrogen balance, g/kg	0.16	0.13	0.28	0.14	0.05	0.63	0.24	0.04

¹Dietary treatments were: 0SB: control diet with no added sugar beets; 15SB: 15% sugar beets substituted for barley; 30SB: 30% sugar beets substituted for barley; and 45SB: 45% sugar beets substituted for barley on a DM basis.

²Greatest SEM presented (n = 8).

³P-value for linear, quadratic, and cubic effects of increasing sugar beet concentration in the diet.

Table 3.5. Ruminal characteristics of growing wethers fed increasing concentrations of sugar beets in the diet.

Item	Dietary Treatment ¹				SEM	<i>P</i> -value	Orthogonal Contrasts ³		
	0SB	15SB	30SB	45SB			Linear	Quadratic	Cubic
Ammonia, mg/dL ⁴					2.81	0.59	0.07	0.14	0.27
0700	22.61	22.27	24.86	26.37					
1300	27.19	20.80	27.49	31.35					
VFA, mol/100 mol ⁴									
Acetate					3.12	0.85	0.09	0.60	0.89
0700	79.68	81.00	83.35	85.13					
1300	76.90	81.38	83.71	82.54					
Propionate					3.16	0.35	0.05	0.90	0.85
0700	23.93	23.65	20.55	20.03					
1300	29.73	25.22	21.82	18.87					
Butyrate					2.20	0.01	0.62	0.67	0.80
0700	15.03	13.21	13.49	11.13					
1300	15.33	15.49	17.37	21.39					
Valerate					0.24	0.43	0.26	0.63	0.51
0700	1.48	1.18	1.50	1.40					
1300	1.54	1.27	1.09	0.97					
Isobutyrate					3.00	0.36	0.39	0.95	0.45
0700	2.17	2.66	2.63	3.00					
1300	0.75	0.75	0.50	0.56					
Isovalerate					3.82	0.34	0.25	0.85	0.52
0700	2.72	3.31	3.48	3.83					
1300	0.75	0.89	0.52	0.68					
A:P ratio ⁵					0.64	0.14	0.03	0.90	0.92
0700	3.74	4.17	4.43	4.66					
1300	2.83	3.52	4.27	5.42					
pH ³					0.15	0.75	0.10	0.08	0.39
0700	7.45	7.59	7.32	7.29					
1300	6.73	6.99	6.84	6.51					

Table 3.5 continued

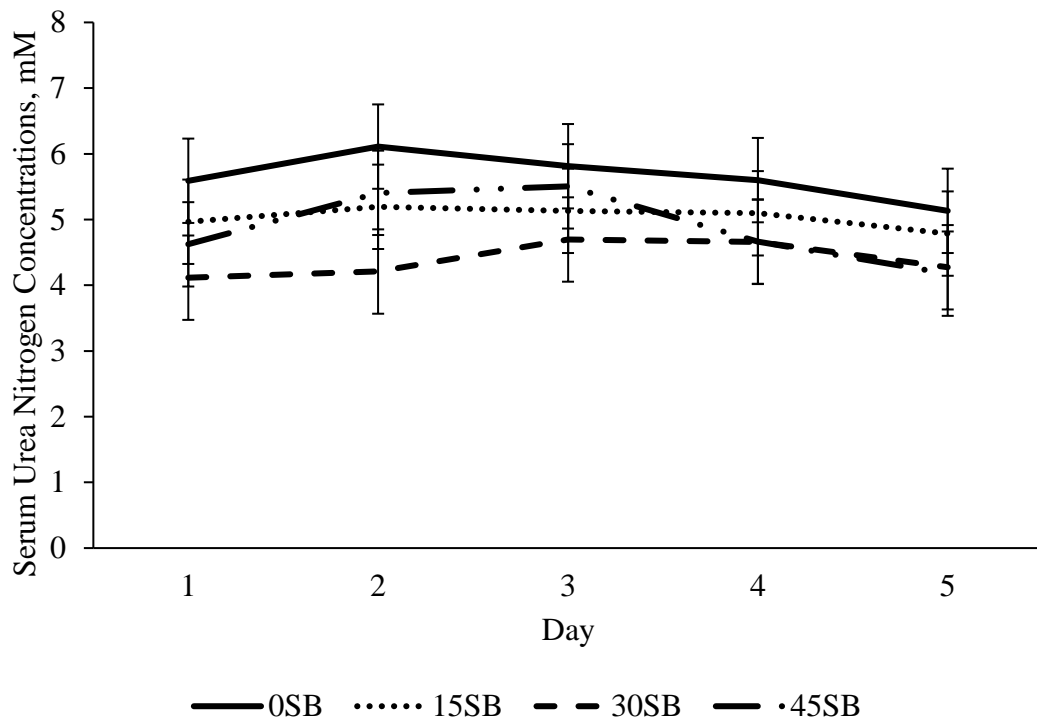
¹Dietary treatments were: 0SB: control diet with no added sugar beets; 15SB: 15% sugar beets substituted for barley; 30SB: 30% sugar beets substituted for barley; and 45SB: 45% sugar beets substituted for barley on a DM basis.²*P*-value for the treatment × time interaction.

³*P*-value for linear, quadratic, and cubic effects of increasing sugar beet concentration in the diet.

⁴Rumen fluid extraction and pH measurements took place at 0700 and at 1300 on d 15 each period.

⁵A:P ratio = Acetate to propionate ratio.

Figure 3.1. Effects of increasing sugar beet concentrations on wether serum urea nitrogen concentrations. Treatment \times day: $P = 0.95$; Day: $P = 0.11$; and treatment: $P = 0.42$.



CHAPTER FOUR

THE EFFECT OF ENSILING SUGAR BEETS ON PRESERVATION
CHARACTERISTICS, NUTRIENT PROFILE, AND IN SITU DISAPPEARANCE

Contributions of Authors and Co-Authors

Author: I. R. McGregor

Contributions: Main author and lead scientist responsible for data collection, sample analysis, data interpretation, and writing this article

Co-Author: J. G. P. Bowman

Contributions: Aided in experimental design

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Contributions: Critical in experimental design, data collection, data interpretation, and revisions of this article

Manuscript Information Page

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ABSTRACT

Non-harvested sugar beets represent an abundant and yet underutilized feedstuff for livestock producers in Montana and Northern plains region. The moisture content of sugar beets may create opportunities for improving storage and ensiling options. The objective of this project was to determine if sugar beets could be ensiled with hay or soybean meal with or without a liquid mold inhibitor and the impact of ensiling sugar beets on nutrient composition, pH, and aerobic stability. A 3 x 2 factorial experiment where hay (control; H) or sugar beets mixed with either hay (SBH) or soybean meal (SB) were ensiled at a rate of 50:50 (as fed) without the mold inhibitor. The mold inhibitor was included to create three additional treatments: hay (HT) sugar beets:soybean meal (SBT), and sugar beets:hay (SBHT). Water was added to each mini-silo to achieve an optimum dry matter (35%). Temperature sensors were included in each replicate to monitor internal temperature. Data were analyzed using the Mixed procedure of SAS. All treatments decreased in pH over time ($P < 0.01$), with the lowest pH value being generated by the SB treatment. Concentrations of DM decreased between d 0 and d 90 for treatments H, HT, SBT, and SBH ($P < 0.01$). Concentrations of NDF increased between d 0 and d 90 for treatments SB and SBT ($P \leq 0.01$), and increased between d 90 and d 180 for treatments H, HT, SBH, and SBHT ($P \leq 0.01$). Concentrations of ADF also increased among all treatments ($P \leq 0.05$). Concentrations of CP increased from d 0 to d 90 for HT and SB treatments ($P \leq 0.01$), increased from d 90 to d 180 for the SBT treatment ($P \leq 0.02$), increased from d 0 to d 180 for the SBH treatment ($P \leq 0.03$), and decreased from d 90 to d 180 for the SB treatment ($P \leq 0.01$). The SBT treatment was

the only treatment to decrease in in-situ disappearance with additional days of ensiling ($P = 0.03$). This data suggests that sugar beets may be ensiled with hay or soybean meal, with or without a liquid mold inhibitor, without negatively impacting nutrient quality or preservation characteristics of the ensiled mixture.

INTRODUCTION

Montana was the 5th largest producer of sugar beets in the United States in 2015 (USDA, 2015a). Approximately 45.2 million pounds of sugar beets were left unharvested after the 2014-2015 Montana sugar beet harvest (USDA, 2015b). This typically results in the sugar beets being left in the field and plowed under.

With this many sugar beets being left in the field, and their substantial energy content (81% TDN; Lardy and Schafer, 2008), sugar beets make an excellent alternative energy source for ruminant livestock. Previous research has indicated that whole shredded sugar beets can replace barley up to 45% of the dry matter in total mixed rations without having any deleterious effects on steer backgrounding performance or sheep nutrient metabolism (McGregor et al., 2016, 2017). However, the seasonal availability of sugar beets may provide quantities of sugar beets that are too large for immediate use. Challenges exist when storing sugar beets due to their high moisture content. Drying sugar beets can be labor intensive, but ensiling may be a more practical alternative to prevent deterioration.

Sugar beets contain a substantial amount of available energy (Lardy and Schafer, 2008), which has been demonstrated to decrease the pH of a silage mixture (Owens et al.,

1999). A rapid decline in pH is the most effective way of inhibiting the enzymes that degrade protein, energy, and fiber throughout the ensiling process (Dewar, 1963; McKersie, 1981; Owens et al., 1999). Therefore, the objective of this study was to determine if sugar beets could be ensiled with hay and soybean meal with or without a liquid mold inhibitor, and the impact of ensiling sugar beets on nutrient composition, pH, and aerobic stability. We hypothesized that sugar beets can be effectively ensiled with other feedstuffs without inducing deleterious effects on nutrient quality or preservation characteristics.

MATERIALS AND METHODS

Treatments & Storage

A 3 x 2 factorial experimental design was utilized in our study with the following treatments: hay without the mold inhibitor (H); hay with the mold inhibitor (HT); sugar beets mixed with hay, without the mold inhibitor (SBH); sugar beets mixed with hay, with the mold inhibitor (SBHT); sugar beets mixed with soybean meal, without the mold inhibitor (SB); sugar beets mixed with soybean meal, with the mold inhibitor (SBT). All feed ingredients were mixed at a rate of 50:50 (as fed). Sugar beets were coarse ground with a flail chopper designed for woody biomass. A liquid mold inhibitor (Ultra CURB[®]; Kemin Industries, Inc.) was added (0.001 kg/kg silage mixture) to the treatments that included the mold inhibitor. Treatments were mixed using a horizontal auger feed mixer (Model 84-8, Roto-Mix[®], Dodge City, KS), and water was added to each mixture to achieve an optimum dry matter concentration for ensiling (35%), and to ensure consistent

moisture content among treatments. Mini-silos were created by lining a 3.8-liter bucket with three 45-liter plastic bags. Approximately 4.6 kg of each treatment was placed in each mini-silo, with a HOBO Pendant® temperature data logger (UA-002-64, Onset Computer Corp., Bourne, MA) placed in the center. A pneumatic air-pump (Air Cadet®, Cole-Parmer Instrument Company, Chicago, IL) was used to remove oxygen from the sample, then bags were closed and the lid secured. There was also a HOBO Pendant® temperature data logger placed outside of the mini-silos in order to record the ambient temperature outside of the mini-silos. Each HOBO pendant temperature data logger was set to record temperature every 15 min.

Sampling & Laboratory Analysis

Samples were collected from the freshly mixed treatments on d 0. Mini-silos were opened and visually inspected for mold on d 90 and 180 of the ensiling process. Each treatment was allocated to 3 buckets per time-point (n = 36). Samples of 2,000 g were collected from each bucket at each time point and stored at -20°C for further analysis. Five-hundred g of each sample were later placed in a 60°C forced air oven for 48 h to determine DM concentrations. Samples were ground to pass a 2 mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and composited by treatment by sample day. These dried samples were then analyzed for NDF (AOAC, 2005) and ADF (AOAC, 2005) by using an Ankom 2000 Fiber Analyzer (Ankom Co., Fairport, NY). Alpha-amylase and sodium sulfite were used in the NDF procedure. Nitrogen concentrations were also analyzed (AOAC, 2010).

Fresh 50 g samples from each bucket were thawed and composited by treatment by day. A 50 g sample from each treatment was individually homogenized with 500 mL of deionized water using a Waring blender for 2 min. The resulting homogenized mixture was then filtered through two layers of cheesecloth and analyzed for pH, as described by Cherney et al. (2004).

HOBO Pendant® temperature data loggers were placed at a depth of 10 cm in the remaining silage for 10 days following the opening of the mini-silos in a climate controlled (19°C) room, and recorded temperature measurements in 15 min increments. Lids were left off of the mini-silos to mimic the period of time where silos are open and its contents are exposed to oxygen during feeding. Minimum and maximum temperatures, as well as how many hours transpired between the minimum and maximum temperatures was recorded. The rate of change in temperature was calculated ($\Delta^{\circ}\text{C}/\text{h}$).

In Situ Disappearance

Four cannulated heifers (BW = 595 ± 35 kg) were used to determine the digestible DM content of each silage treatment at each time-point of the ensiling process. Samples were dried in a forced air oven at 60°C for 48 h and ground to pass a 2 mm screen using a Wiley mill. Five grams of each sample was placed into 10 x 20 cm Dacron bags (Ankom Technology, Macedon, NY) in duplicates. Bags were soaked in 39°C water for 15 min prior to placing bags in the rumen of each cow. The number of hours that each treatment stayed in the rumen are as follows: H and HT bags were analyzed at 0, 6, 12, 24, 48, 72, and 96 h; SBH and SBHT bags at 0, 2, 4, 6, 12, 24, 48, 72, and 96 h; SB and SBT bags at 0, 2, 4, 6, 12, 24, and 48 h; and a hay standard was included at 0, 2, 4, 6, 12, 24, 48, 72,

and 96 h. Zero h bags were soaked for 15 min in 39°C water. Each bag was removed at their respective time-points and immediately placed in ice water to inhibit microbial activity. The bags were then rinsed until the runoff ran clear, dried at 60°C for 48 h in a forced air oven, then the bags were weighed and disappearance from each bag was calculated.

Statistical Analysis

The MIXED procedure of SAS (SAS 9.4; SAS Inst. Inc., Cary, NC) was used for the statistical analysis of aerobic stability and change in nutrient composition over time as a 3 x 2 factorial. Individual bucket served as the experimental unit. Treatments were in triplicates for each time-point observed, with day serving as the fixed effect. Mold inhibitor and replication served as the random effects. In situ disappearance results were also analyzed using the MIXED procedure of SAS with the interaction of inoculant treatment x day x hour serving as the fixed effect. Individual bag served as the experimental unit, with two bags for every hour per treatment. Cow and silage opening date served as the random effects. Repeated measures was used to determine treatment differences with the spatial exponential covariance structure, with the subject of heifer x mold inhibitor x silage opening day. Significance was set at $P \leq 0.05$, with tendencies set at $P \leq 0.10$.

RESULTS AND DISCUSSION

Measurements of pH are represented in Table 4.1. The pH of all treatments fell below 5.0 by d 90 ($P < 0.01$). However, on a numerical basis, it should be noted that H

and HT treatments produced higher pH values, SB and SBT treatments produced the lowest pH values, with SBH and SBHT treatments being intermediate. The SB treatment also demonstrated the most rapid pH decline among all un-treated silages (Figure 4.1). This observation is in agreement with Ferris and Mayne (1994) as well as Moore and Kennedy (1994), who observed that ensiling unmolassed sugar beet pulp with perennial ryegrass decreased pH as the unmolassed beet pulp was added to the silage mixture. Additionally, Leupp et al., (2006) demonstrated that wet sugar beet pulp has a strong influence on pH, as the pH remained constant among various levels of DM when ensiled with dry pelleted beet pulp, dry rolled corn, wheat middlings, and dry corn gluten feed. This is likely due to the addition of water soluble carbohydrates in the form of sucrose when sugar beets are included in the mixture, as acid-producing bacteria can use sucrose as a substrate to produce organic acids (Muck, 1988). This explanation seems valid seeing as though similar results have been observed with sugar cane (Alli et al., 1982). Owens et al. (1999) also observed a similar pattern when it was observed that increasing starch in a silage mixture decreased pH. Rapidly attaining a silage pH below 5.0 is important for feed preservation when making silage (Pitt, 1990), as this inhibits the activity of enzymes that degrade protein (McKersie, 1981), fiber (Dewar et al., 1963), available energy (Muck, 1988; Owens et al., 1999), and helps inhibit mold growth once the silage mixture is exposed to oxygen (Moon, 1983). Our observations indicate that including sugar beets in a silage mixture may assist in attaining a low pH and quality fermentation.

Nutrient composition data is represented in Table 4.1. Concentrations of DM decreased from d 0 to d 90 for treatments H, HT, SBT, and SBH ($P < 0.01$). This can be attributable to filling the mini-silo's too slowly, or perhaps a less than perfect seal, as both of these conditions can lead to excessive plant respiration (Muck, 1988) and the colonization of aerobic microorganisms that can cause mold growth (Woolford, 1990). This explanation is further validated by the fact that mold was visually observed in the H and SBT treatments at d 180, but not statistically different between treatments. Excessive plant respiration can lead to the loss of fermentable carbohydrates, leaving less substrate available for acid production (Muck, 1988), which may explain why the SBT treatment generated higher pH values than the SB treatment on d 90 and d 180.

Concentrations of NDF for treatments H, HT, SBH, and SBHT remained similar ($P \geq 0.07$) from d 0 to d 90, but significantly increased from d 90 to d 180 ($P \leq 0.01$). Conversely, concentrations of NDF for treatments SB and SBT significantly increased from d 0 to d 90 ($P \leq 0.01$), but remained similar from d 90 to d 180 ($P \geq 0.06$). It is possible for phenolic products to form as a result of Maillard reactions when the temperature of the silage exceeds 40°C (Goering et al., 1973), which would be represented in both NDF and ADF fractions (NRC, 2016). However, the maximum internal temperature among all of the silages during the ensiling process was 12°C. Due to these circumstances, it seems likely that any increase in fiber concentration in this instance would be due to the loss of non-fiber constituents, similar to what was observed by Gunn et al., (2013) when modified wet distillers grains with solubles were ensiled with marginal-quality feedstuffs. The immediate increase in NDF of the SB and SBT

treatments was likely due to the abundance of sugar present, which is a readily fermentable carbohydrate that would be utilized rapidly. The delayed increase of NDF of the H, HT, SBH, and SBHT treatments may be due to the hay portion of these mixtures, as hemicellulose would be the primary carbohydrate used by bacteria to produce organic acids, and was not fermented as rapidly as the sugar provided by sugar beets (Dewar et al., 1963). It is reasonable to believe that the utilization of hemicellulose would lead to a decrease in NDF. However, hemicellulose is just one component of NDF, other than cellulose and lignin which are also components of ADF (NRC, 2016). An increase in the proportion of cellulose and lignin could result in an increase in NDF, and this is supported by the observation that ADF also increased in treatments H, HT, SBH, and SBT ($P \leq 0.05$). Concentrations of ADF also increased for SB and SBT treatments ($P \leq 0.04$), also likely due to the sugar that was present being fermented rapidly, thus attributing the increase in ADF concentration to a loss in non-fiber constituents.

Concentrations of CP did not change with time in H and SBHT treatments, increased between d 0 and d 90 for the HT treatment ($P \leq 0.02$), increased between d 90 and d 180 for the SBT treatment ($P \leq 0.02$), gradually increased from d 0 to d 180 for the SBH treatment ($P \leq 0.03$), and the SB treatment demonstrated an increase in CP between d 0 and d 90 ($P \leq 0.01$), then decreased between d 90 and d 180 ($P \leq 0.01$). The primary factors that affect CP levels during the ensiling process are pH (McKersie, 1981), individual species characteristics (Owens et al., 1999), DM concentration (Muck, 1987), and storage temperature (Muck & Dickerson, 1988). Ambient temperatures and DM concentrations were all similar among treatments throughout the ensiling process, and all

pH values fell within the ideal range to inhibit proteolysis (3.8 – 5.0; Pitt, 1990).

Increases in CP concentration during the ensiling process are also likely due to a decrease in compounds that do not contain nitrogen, similar to what was observed by Gunn et al., (2003). Although proteolysis is strongly inhibited in an acidic environment (McKersie, 1981), it is still possible that it could occur at a low rate, which may explain the decrease in CP concentrations between d 90 and d 180 of the SB treatment.

Aerobic stability is the amount of time it takes for silage to begin to heat up after the silage is exposed to oxygen (Muck, 2004), which is associated with the presence of aerobic microorganisms (Woolford, 1990). There seems to be confusion regarding the measurement of aerobic stability among relative literature. Muck (2004) measured aerobic stability by observing how long it takes for the internal temperature of the silage to reach 2°C above ambient temperature after exposing the silage to oxygen. Gunn et al., (2013) measured aerobic stability by observing how long it takes for the internal temperature of the silage to obtain an increase in 2°C after exposing the silage to oxygen. For this study, we decided to represent aerobic stability by recording the minimum and maximum temperatures during the 10 day period after opening the mini silo's, then calculated a rate of temperature change ($\Delta^{\circ}\text{C}/\text{h}$) to represent aerobic stability. All temperature data is represented in Table 4.2. The Ultra CURB® liquid mold inhibitor did not reduce the rate of temperature change during the 10 days following the opening of the silo's for any treatment ($P > 0.05$), nor was the rate of temperature change different ($P > 0.05$) between treatments. It is possible that the naturally occurring bacteria established a healthy population more rapidly than the bacterial population that was intended to be

established by using Ultra CURB®. This is considered to be one of the primary reasons as to why mold inhibiting inoculants do not always improve aerobic stability (Muck and Kung, 1997).

In-situ results are represented in Table 4.3 and in Figure 4.2. Absolute rate of in-situ disappearance did not differ between d 0, 90, and 180 for treatments H, HT, SBH, and SBHT. However, SBT demonstrated a decrease in rate of in-situ disappearance between d 90 and d 180 ($P = 0.03$), and SB demonstrated a tendency to decrease rate of in-situ disappearance between d 90 and d 180 ($P = 0.09$) (Table 4.3). Additionally, treatments H and HT had greatest absolute disappearance for d 0 silages, and SB and SBT treatments had greater absolute disappearance for d 0 and d 90 of ensiling, with the lowest absolute disappearance for d 180 for all of these treatments (Figure 4.2). Any decrease in in-situ disappearance is likely attributable to the increase in fiber concentration that was observed throughout the ensiling process. Despite the observed decrease in in-situ disappearance, SB and SBT demonstrated the greatest disappearance rates at all time-points relative to other treatments. This is not surprising, as the in vitro dry matter digestibility (IVDMD) of sugar beet pulp is approximately 75%, which is much greater than the IVDMD of hay (approximately 54%; Sanson, 1993). The SBH and SBHT treatments numerically demonstrated slightly higher disappearance rates than the H and HT treatments at d 90 and d 180. The observed disappearance values indicates that if hay were added to a sugar beet silage mixture, the animal would still receive the benefit of sugar beets as an immediate source of energy, but the addition of hay may slow down passage rate and allow for the energy from the sugar beets to be used by rumen

microbes over a longer period of time rather than rapidly exiting the rumen. By providing energy to rumen microbes over a longer period time this may increase the extent at which the hay is digested. The hay portion of the silage will be ruminated and masticated until it achieves a particle size that allows for it to exit the rumen, and if the rumen microbes have a readily available energy source, the microorganisms will have the ability to further digest the hay while it is in the rumen.

IMPLICATIONS

In conclusion, our data implies that sugar beets can be ensiled with hay or soybean meal without inducing any deleterious effects on nutrient composition or preservation characteristics. This gives livestock producers the opportunity to buy large quantities of sugar beets when it is financially advantageous, and have an effective storage method so that the sugar beet supply can be fully utilized.

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Table 4.1. Change in nutrient composition and pH of silage treatments over time

Item ¹	Day of ensiling ²			SEM	P - value
	d 0	d 90	d 180		
H					
DM	34.81 ^a	33.07 ^b	33.46 ^b	0.26	0.01
CP ³	9.63	9.99	9.92	0.13	0.27
NDF ³	61.78 ^a	63.39 ^a	69.26 ^b	0.86	0.01
ADF ³	44.98 ^a	49.03 ^{ab}	52.67 ^b	1.64	0.04
pH	6.20 ^a	4.77 ^b	4.77 ^b	0.03	0.01
HT					
DM	33.39 ^a	30.33 ^b	31.52 ^c	0.32	0.01
CP	10.84 ^a	11.69 ^b	12.09 ^b	0.12	0.01
NDF	57.35 ^a	59.58 ^a	66.78 ^b	0.97	0.01
ADF	42.69 ^a	47.25 ^{ab}	51.72 ^b	1.65	0.02
pH	6.20 ^a	4.67 ^b	4.67 ^b	0.03	0.01
SB					
DM	36.17	37.32	36.07	1.17	0.64
CP	28.10 ^a	30.48 ^b	27.78 ^a	0.18	0.01
NDF	10.29 ^a	15.59 ^b	15.43 ^b	0.48	0.01
ADF	7.70 ^a	9.92 ^b	9.15 ^{ab}	0.66	0.08
pH	6.67 ^a	4.27 ^b	4.33 ^b	0.05	0.01
SBT					
DM	41.40 ^a	34.09 ^b	35.35 ^b	0.87	0.01
CP	31.91 ^a	32.60 ^a	33.94 ^b	0.14	0.09
NDF	7.48 ^a	17.45 ^b	14.78 ^b	0.60	0.01
ADF	5.99 ^a	9.89 ^b	9.33 ^b	0.55	0.01
pH	6.50 ^a	4.43 ^b	4.40 ^b	0.04	0.01
SBH					
DM	45.08 ^a	38.91 ^b	39.05 ^b	0.82	0.01
CP	9.99 ^a	10.52 ^b	10.79 ^b	0.14	0.05
NDF	55.82 ^a	54.11 ^a	60.88 ^b	1.10	0.02
ADF	42.05 ^a	44.50 ^b	43.78 ^{ab}	0.50	0.03
pH	5.97 ^a	4.50 ^b	4.40 ^b	0.05	0.01
SBHT					
DM	43.62	43.28	41.65	0.84	0.22
CP	17.22	17.34	17.13	0.12	0.63
NDF	42.87 ^a	43.40 ^a	50.17 ^b	0.91	0.01
ADF	32.17 ^a	33.19 ^{ab}	34.84 ^b	0.71	0.09
pH	6.20 ^a	4.57 ^b	4.47 ^b	0.04	0.01

Table 4.1 continued

¹ Silage treatments were H: hay; HT: hay with Ultra CURB®; SB: sugar beets and soybean meal; SBT: sugar beets and soybean meal with Ultra CURB®; SBH: sugar beets and hay; SBHT: sugar beets and hay with Ultra CURB®.

²n = 3 for each treatment per time period.

³Percentage on a DM basis.

^{a,b,c} Means without common superscript within row differ ($P < 0.05$)

Table 4.2. Summary of temperature data for the 10 days after opening mini-silos

Day ²	Silage Mixtures ¹					
	H	HT	SBH	SBHT	SB	SBT
d 90						
Min, °C	-8.24	-8.19	-8.24	-8.46	-8.54	-8.53
Max, °C	1.96	1.82	8.73	8.80	1.72	1.70
$\Delta^{\circ}\text{C}/\text{h}^3$	0.10	0.10	0.14	0.15	0.13	0.13
d 180						
Min, °C	1.40	0.54	-0.09	0.24	2.66	2.17
Max, °C	11.99	9.76	8.73	8.80	12.14	12.10
$\Delta^{\circ}\text{C}/\text{h}$	0.15	0.13	0.12	0.13	0.14	0.12

¹Silage treatments were H: hay; HT: hay with Ultra CURB®; SB: sugar beets and soybean meal; SBT: sugar beets and soybean meal with Ultra CURB®; SBH: sugar beets and hay; SBHT: sugar beets and hay with Ultra CURB®.

²n = 3 for each treatment per time period.

³Difference between Min and Max divided by the number of hours that transpired.

^{a,b} Means without common superscript within row differ ($P < 0.05$).

Table 4.3. Effects of ensiling on the absolute rate of in situ disappearance and density

Item	H	HT	SBH	SBHT	SB	SBT	
<i>Absolute rate of disappearance, % DM disappeared/h</i>							
d 0	0.702	0.714	0.686	0.814	1.907 ^{ab}	1.968 ^e	
d 90	0.668	0.673	0.715	0.788	1.986 ^a	1.981 ^e	
d 180	0.647	0.653	0.699	0.783	1.860 ^b	1.745 ^f	
	SEM	0.020	0.022	0.021	0.012	0.033	0.051
	<i>P</i> -value ²	0.23	0.17	0.64	0.23	0.09	0.03
<i>Density, kg/m³</i>							
d 0	-	-	-	-	-	-	
d 90	261.81	270.01	544.01 ^e	548.36	267.67	254.34	
d 180	261.83	273.80	578.84 ^f	545.10	272.21	253.77	
	SEM	6.340	6.147	9.071	8.987	4.306	5.202
	<i>P</i> -value ²	1.00	0.67	<0.01	0.72	0.38	0.94

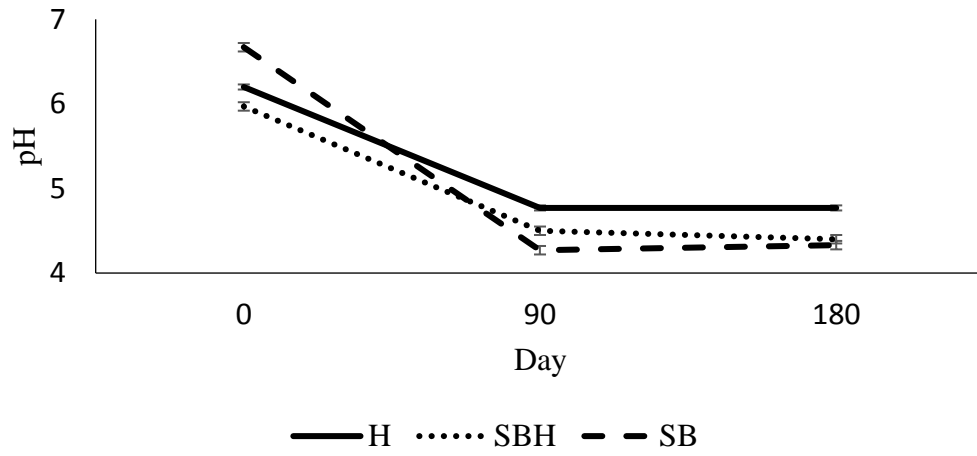
¹ Silage treatments were H: hay; HT: hay with Ultra CURB®; SB: sugar beets and soybean meal; SBT: sugar beets and soybean meal with Ultra CURB®; SBH: sugar beets and hay; SBHT: sugar beets and hay with Ultra CURB®

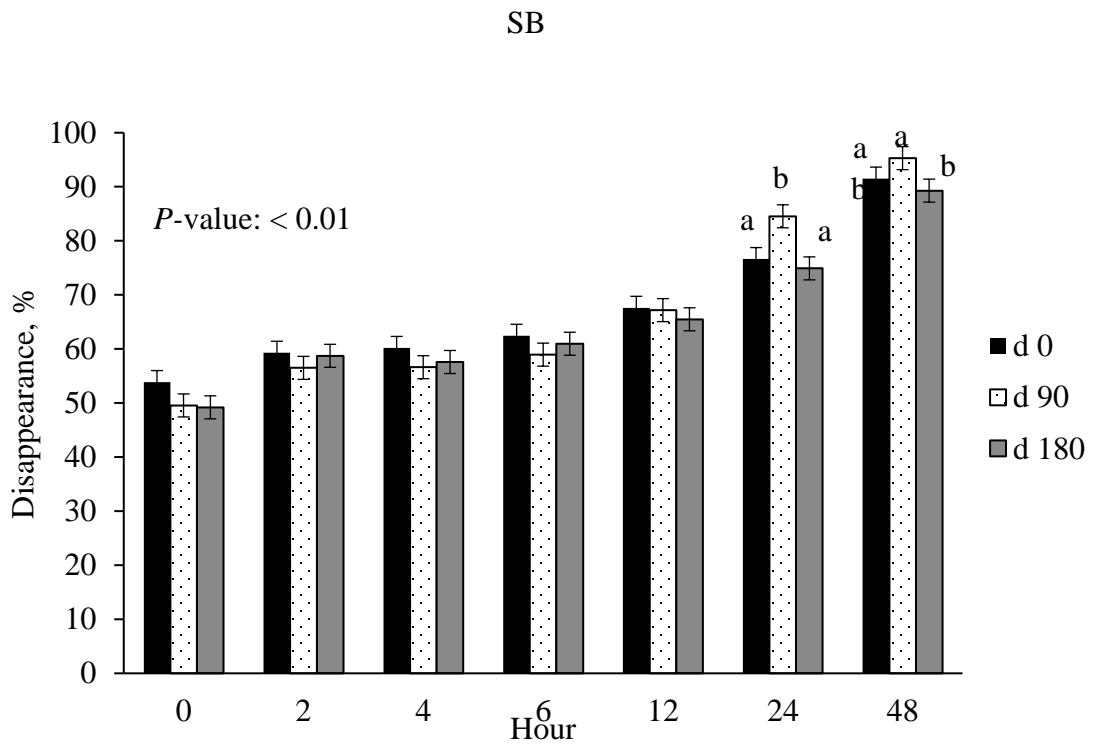
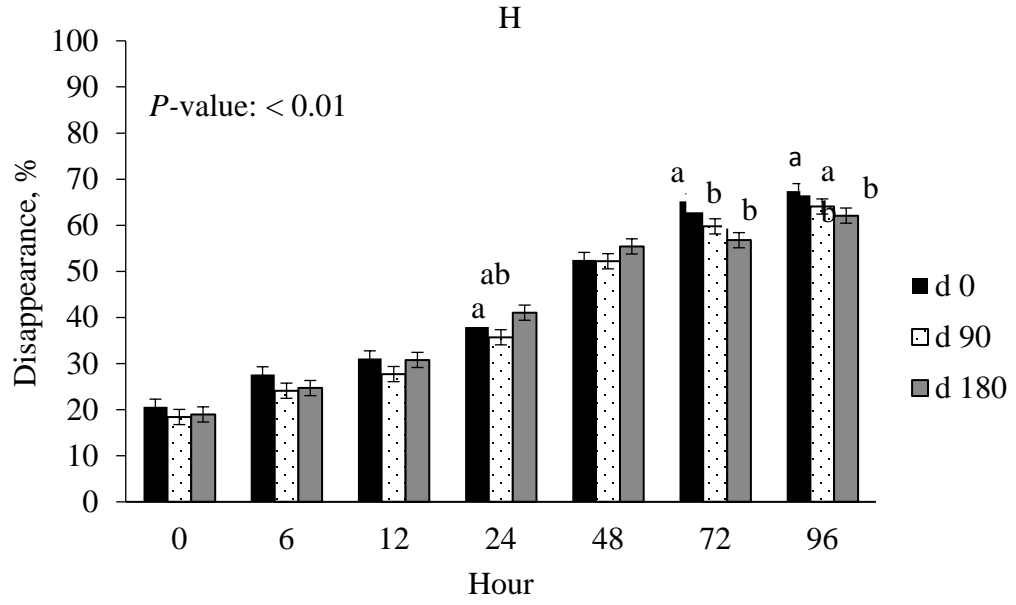
²*P*-value for day within ensiling mixture and ultra

^{a,b}Means without a common superscript within column tend to differ ($P < 0.10$)

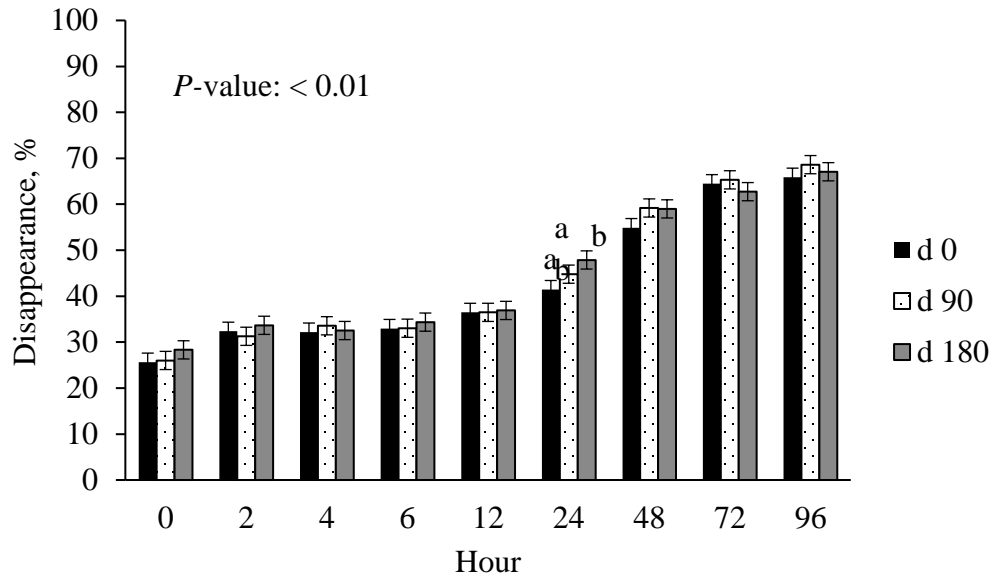
^{e,f}Means without a common superscript within column differ ($P < 0.05$)

Figure 4.1. The effect of sugar beets on the change in pH throughout the ensiling process. Day: $P < 0.01$.

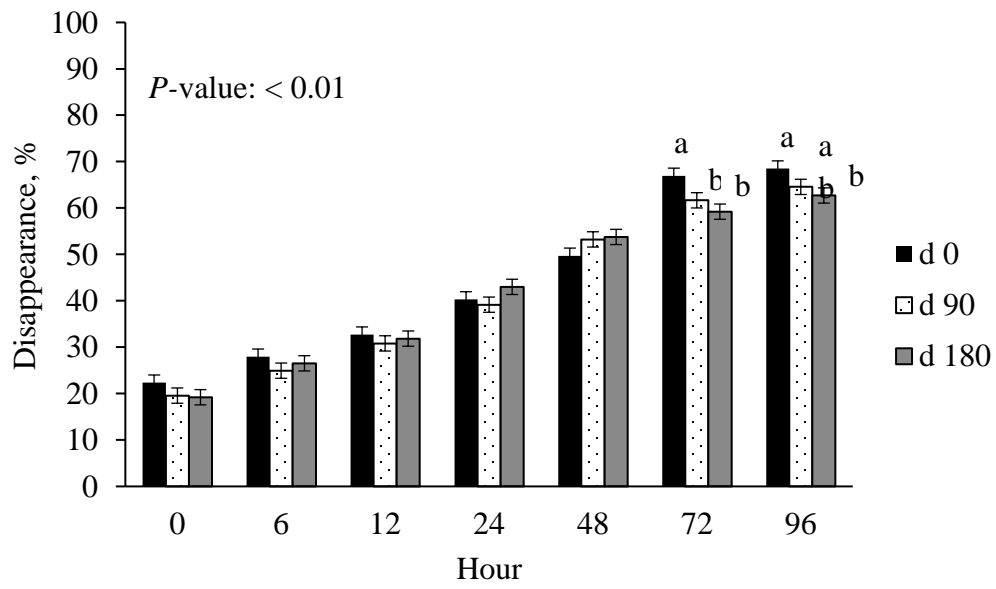




SBH



HT



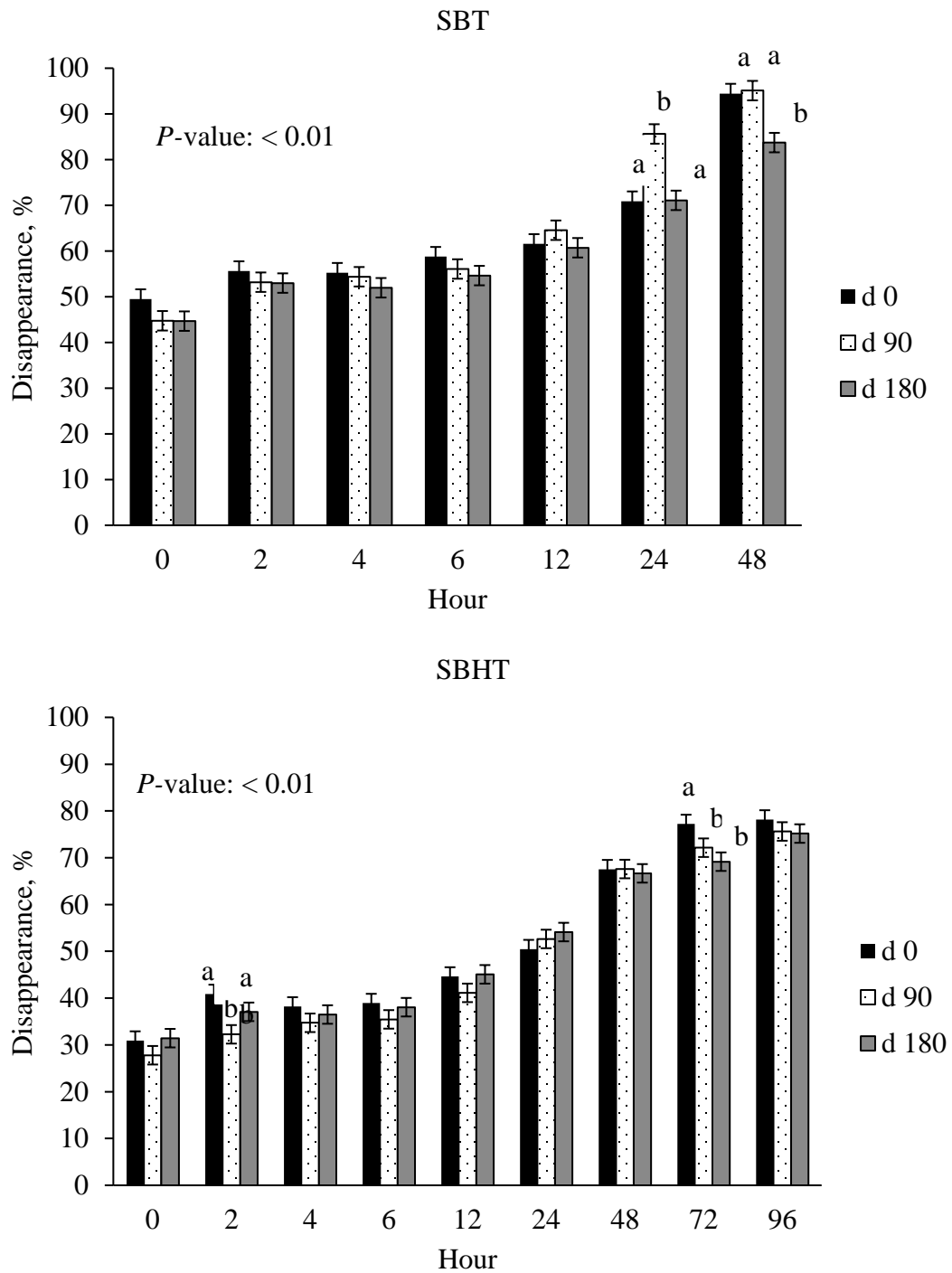


Figure 4.2. Impacts of ensiling sugar beets, liquid mold inhibitor, and day on *in situ* disappearance. ^{a,b}Means within the hour without a common superscript differ ($P < 0.05$). Ultra x day x hour: P -value < 0.01.

CHAPTER FIVE

CONCLUSIONS

Steer Backgrounding Trial

Dry matter intake demonstrated a tendency to be affected quadratically as sugar beets increased in the diet, where intake increased from 0SB to 15SB, then decreased as sugar beets were included in excess of 15% of the dry matter of the diet. It seems that the increase between 0SB and 15SB could be attributable to a combination of palatability (Nombekela et al., 1994) and moisture content (Balch, 1950), because high-moisture content may speed up the rate of passage, giving less time for the digestion of that feedstuff by rumen microorganisms, so the animal would have to eat more to meet its metabolic requirement. However, that does not explain the decrease in intake when sugar beet inclusion exceeded 15%. Several factors have been discussed that may affect dry matter intake such as rumen fill and the metabolic requirement of the animal. The animal may have to eat more to meet its metabolic requirement on a high-moisture diet. However, it is not likely that the animal will eat so much that it puts stress on the rumen wall to the point of discomfort. In fact, it has been suggested in previous literature that there may be a certain point of moisture content that the extra weight of the feed stimulates stretch receptors in the rumen wall inducing satiety (Voelker and Allen, 2003). Therefore, it is possible that the added moisture content of whole sugar beets included in the diet, between 15-30%, surpasses the point at which moisture content would start limiting intake, rather than increasing it.

Numerical increases in ADG and G:F were observed in this study. One issue with this study is that data was only recorded for 50 days. Perhaps if this study was recorded over a longer period of time, such as 70 days, statistical differences may have been observed. Numerically, ADG increased linearly as sugar beets were added to the diet, and the 45SB diet had 0.2 kg more gained per day than the 0SB diet. A similar increase was observed with G:F. A number of aforementioned research studies have mentioned increased fiber digestibility (Huhtanen, 1988; Arrizon et al., 2012) and enhanced protein utilization (Chamberlain et al., 1985; Rooke et al., 1992) as a result of the inclusion of sugar beets or molasses in the diet, thus validating the assumption that a combination of these factors may have played a role in this scenario.

Overall, due to the lack of statistical evidence, we can't make the conclusion that replacing barley with sugar beets can enhance performance, even though this could have been the case if this trial took place over a long period of time. However, with these results, we are able to conclude that replacing barley with sugar beets may not induce any deleterious effects on steer performance. This is still important, as times of surpluses in sugar beet supply may create financially advantageous opportunities to replace barley with sugar beets in a ruminant livestock ration. Our conclusion indicates that by doing this, similar performance will be observed, but money could be saved on the feed supporting this similar plane of performance.

Sheep Metabolism Trial

We observed that increasing sugar beets in the diet induced a linear tendency for ammonia concentrations to accumulate, and a significant cubic pattern for nitrogen balance with 15SB generating the lowest value and 30SB generating the highest value. This conflicts with other research that demonstrates that sugar may be more effective than starch at reducing ammonia levels and enhancing nitrogen efficiency (Chamberlain et al., 1985; Huhtanen, 1988; Rooke et al., 1992). Although the dietary treatments were isonitrogenous, our results are confounded by the various degrees of protein degradability in the rumen environment as soybean meal increased with increasing sugar beets, due to the low protein content of sugar beets relative to barley. Given that 30SB generated the highest nitrogen balance of all treatments, including the control diet in particular, it is reasonable to believe that if the protein content was equal in rumen degradability across treatments, we may have observed similar results as Chamberlain et al. (1985), Huhtanen (1988) and Rooke et al. (1992).

We expected to see an increase in fiber digestibility as sugar beets increased in the diet, as that has been what was seen in similar research studies (Huhtanen, 1988; Arrizon et al., 2012). Sugar beets serve as a fermentable fiber source, and it is possible that this aspect of sugar beets would attract bacteria that ferment fiber. However, in our dietary treatments, the proportion of hay in the diet decreased as sugar beets were added to the diet. Belanche et al., (2012) demonstrated that fiber rich diets enhance populations of bacteria that are cellulolytic in nature. This certainly makes a lot of sense, since fiber is an energy source for these bacteria, and it is not likely that any organism would be likely

to populate an area that does not have a proper feed source. In studies conducted by Huhtanen (1998) and Arrizon et al. (2012), fiber digestibility increased as sugar beets increased in the diet, as well as an increase in fiber intake. Perhaps we may have observed a statistically significant increase in fiber digestibility if the proportion of hay was similar across dietary treatments.

Given our statistical evidence, we can't conclude that replacing barley with sugar beets may enhance fiber digestibility and nitrogen utilization, even though that seems to be what has been observed by the number of aforementioned research studies. However, we are able to conclude that replacing barley with sugar beets may not induce any deleterious effects on fiber digestibility or nitrogen utilization.

This study demonstrated that replacing barley with sugar beets is capable of altering rumen fermentation patterns, possibly attributable to the microbial population that is attracted to an environment where fermentable fiber and sucrose are present, and starch tends to produce more acetate and butyrate than propionate. This is a VFA production profile that has been observed by a number of other similar research studies (Rooke et al., 1992; Voelker and Allen, 2003; Arrizon et al., 2012). This VFA production pattern seems that it would not favor performance, as this VFA production pattern has been observed to result in the oxidation of body fat and amino acids to provide energy due to the lack of glucose induced by decreased propionate production (Huhtanen et al., 1998). However, it is interesting that performance studies, such as Arrizon et al. (2012) and our previous performance study demonstrated that replacing a starch based energy source with sugar beets will not induce deleterious effects on

performance. Is this decrease in propionate that has come up as statistically significant in the aforementioned research studies biologically significant? Or is the effect of decreased propionate overcome by increases in fiber digestibility and nitrogen utilization? It is very hard to tell. It seems that these observations speaks to the multitude of factors that play a role in just about every biological system, and that an individual observation that may indicate that sugar beets may be inferior in supporting animal performance may not be the case in reality when all factors are taken into account.

Silage Fermentation Trial

We observed decreases in DM content among all treatments except for SB and SBHT treatments. Loss of some DM is unavoidable, due to available energy being utilized for acid production (Owens et al., 1999). However, the DM loss in SBT and SBH treatments was excessive, and likely due to the possibility that the silos were not properly sealed for these treatments, rather than an effect induced by the feed ingredients being ensiled or the presence of the liquid mold inhibitor. The loss of DM seems to have contributed to the higher proportions of fiber and protein content that was observed throughout the ensiling process among most treatments.

Sugar beets seem to enhance preservation characteristics, as indicated by the SB and SBT treatments generating the lowest pH values. This is likely due to the abundance of sugar in sugar beets that can be rapidly utilized as a fermentable substrate. This is illustrated by the immediate increase in proportions of fiber, as opposed to hay-

containing treatments that did not significantly increase in fiber proportion until after d 90.

It should be pointed out that all of the d 90 buckets were frozen solid at the time of sampling. Lower temperatures have been observed to inhibit enzyme activity (Muck and Dickerson, 1988). So, what kind of results could we have seen if these buckets didn't experience freezing temperatures? The potential effect of increased temperatures, and perhaps increased enzyme activity, likely would not produce different patterns of change in the nutrient profile, but may make the differences that we observed more extreme. One interesting observation was that the liquid mold inhibitor didn't enhance the aerobic stability of any of the silage treatments, contrary to the purpose behind the design of this product. Heating of silage is associated with aerobic microorganism activity and the degradation of silage nutrient quality (Woolford, 1990), and the colder temperatures may have lessened some of this heat production during the feed-out phase of this trial. Perhaps these colder temperatures enhanced the aerobic stability of these silage mixtures to the point where there was very little room for improvement by using a liquid mold inhibitor. It is reasonable to believe that if there were higher temperatures during the feed-out stage, improvements in aerobic stability may have been observed as a result of using the liquid mold inhibitor.

In conclusion, any decrease in nutrient quality that was observed in this study was not a result of the inclusion of sugar beets themselves. Therefore, we are able to conclude that sugar beets can be effectively ensiled with hay or soybean meal without

inducing deleterious effects on the nutrient profile or preservation characteristics of the silage.

Overall Conclusions

Based on our results, we are able to make the following conclusions:

1. Sugar beets can be fed up to 45% in the dry matter of a total mixed ration and have no deleterious effects on steer backgrounding performance, or sheep fiber or nitrogen digestibility.
2. Replacing barley with sugar beets is capable of altering rumen fermentation patterns.
3. Sugar beets can be ensiled with hay or soybean meal without inducing deleterious effects on nutrient composition or preservation characteristics.

These conclusions imply that sugar beets are a viable energy source to be used by livestock producers, and this creates another avenue by which this otherwise unutilized resource can be utilized. In addition, the ability to ensile sugar beets gives livestock producers the opportunity to buy large quantities of sugar beets when it is financially advantageous, and have an effective storage method so that the sugar beet supply can be fully utilized.

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