Optimization of Forage Use in Diets Fed to Backgrounding and Finishing Cattle in The Northern Great Plains

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OPTIMIZATION OF FORAGE USE IN DIETS FED TO BACKGROUNDING AND FINISHING CATTLE IN THE NORTHERN GREAT PLAINS

BY

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABBREVIATIONS

ADF	Acid Detergent Fiber
ADG	Average Daily Gain
AFBW	Adjusted Final Body Weight
AF	As Fed
BL	Black line
BW	Body Weight
°C	Degrees Celsius
cm	Centimeter
CO_2	Carbon dioxide
CP	Crude Protein
d	Day
DDGS	Dry Distiller Grains Plus Solubles
DM	Dry Matter
DMI	Dry Matter Intake
DP	Dressing Percentage
DRC	Dry Rolled Corn
EB	Estradiol Benzoate
EBF	Empty Body Fat
EE	Ether Extract

EG	Daily Energy Gain
EM	Maintenance Energy Required
FBW	Final Body Weight
F:G	Feed to Gain
g	Gram
G:F	Gain to Feed
h	Hours
ha	Hectare
HCW	Hot Carcass Weight
HMC	High Moisture Corn
HT	Harvest Time
IN	Indiana
kg	Kilogram
KP	Kernel Processing
KP+	Treatment, Kernel Processing (Yes)
KP-	Treatment, Kernel Processing (No)
KPH	Kidney Pelvic Heart Fat
KS	Kansas
L	Liter
LAB	Lactic Acid Bacteria

LS	Liquid Supplement
m	Meter
mm	Millimeter
m^3	Cubic Meter
Mcal	Megacalorie
MDGS	Modified Distillers Grains Plus Solubles
Mg	Milligram
mL	Milliliter
ML	Milkline
n	Number
NC	North Carolina
NDF	Neutral Detergent Fiber
NE	Net Energy
NEg	Net Energy for Gain
NEm	Net Energy for Maintenance
NE_l	Net Energy for Lactation
NFC	Non-fiber Carbohydrates
NO_3	Nitrate
NJ	New Jersey
OM	Organic Matter

P	*P* - value
pH	Potential of hydrogen
peNDF	Physically Effective Neutral Detergent Fiber
REA	Ribeye Area
RF	Rib Fat
RH	Ractopamine Hydrochloride
RNC	Ruminant Nutrition Center
RY	Retail Yield
SD	South Dakota
SERF	Southeast Research Farm
SEM	Standard Error of the Mean
TBA	Trenbolone Acetate
TDN	Total Digestible Nutrients
USDA	United States Department of Agriculture
VFA	Volatile Fatty Acid
w	Mean Equivalent Body Weight
YG	Yield Grade
1D	Treatment, One Diet System
2D	Treatment, Two Diet System

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ABSTRACT

OPTIMIZATION OF FORAGE USE IN BACKGROUNDING AND FINSIHING CATTLE IN THE NORTHER GREAT PLAINS.

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The two studies in this thesis were conducted to: 1) investigate the impact of corn silage moisture content and kernel processing at harvest on growth performance, efficiency of dietary net energy utilization, and carcass traits in finishing steers when fed at 20% DM inclusion in diets containing modified distillers grains plus solubles; and 2) determine the influence of equal cumulative roughage inclusion in a single diet or two-diet system during a 210-d backgrounding-finishing period in pre-conditioned beef steers on growth performance responses, efficiency of dietary net energy (NE) utilization, and carcass traits. Experiment 1 was a 112-d finishing experiment conducted at the Southeast Research Farm (SERF) near Beresford, SD using 192 single source, Red Angus influenced steers (initial BW = 446 ± 28.3 kg). This study used 6 replicate pens (24 total pens) of 8 steers assigned to one of 4 dietary treatments (2 x 2 factorial arrangement). Factors included silage maturity at harvest time (HT) and kernel processing (KP). Treatments were arranged as a 2 x 2 factorial with the factors of HT (1/2 to 2/3 Milkline [(ML)]) or (black layer [BL]) with (KP+) or without (KP-) kernel processing. Steers were blocked by batch fraction (n = 6) and pen served as the experimental unit. The model included the effects of harvest time, processing, and their interaction. Block was included as a random factor. No harvest time × KP interaction was detected ($P \geq 0.26$) for any parameters related to the efficiency of dietary NE utilization. Comparative by harvest

time indicates that delayed harvest enhanced corn silage NEm by 6% and KP decreased apparent NEm value of corn silage by 9% compared to current feeding standards. No HT × KP interaction ($P \geq 0.08$) was detected for any carcass traits except the distribution of USDA Prime carcasses ($P = 0.04$). Steers from ML/KP- had fewer ($P = 0.05$) USDA Prime carcasses compared to ML/KP+, BL/KP-, and BL/KP+. Harvest time ($P \geq 0.07$) and KP ($P \geq 0.07$) had no appreciable influence on any carcass trait parameters. These data indicate that corn silage harvest can be delayed without detriment to growth performance and kernel processing does not enhance the apparent feeding value of corn silage when corn silage is fed as the sole roughage component of a feedlot finishing diet (i.e. 20% inclusion DM basis). Experiment 2 used 46 single source, crossbred beef steers (initial BW = 281 ± 40.4 kg) in a 210-d background-finish experiment at the Ruminant Nutrition Center (RNC) in Brookings, SD. This study used five replicate 7.6 x 7.6-meter concrete pens (10 total pens) with 4 or 5 steers assigned to one of two dietary treatments. The target cumulative roughage for both treatments was 16% over the 210-d background-finish period. Treatments included: 1) Single Diet (1D), one diet throughout the feeding period, (16% Roughage) 1.34 Mcal/kg NEg 210-d, 2) Two Diet (2D), initial growing diet, (25% Roughage) 1.25 Mcal/kg NEg for 98-d, transition diet, (16% Roughage) 1.34 Mcal/kg NEg for 14-d, finishing diet, (7% Roughage) 1.43 Mcal/kg NEg for 98-d. All steers were implanted initially (d 1) with a 100 mg trenbolone acetate (TBA) and 14 mg estradiol benzoate (EB) implant (Synovex Choice, Zoetis) and re-implanted with a 200 mg TBA and 28 mg EB implant (Synovex-Plus, Zoetis) on d 112. Fresh feed was manufactured once daily for each treatment in a single batch using a stationary mixer and bunks were managed using a slick bunk management approach. Data were analyzed as a

randomized complete block design with pen as the experimental unit. Average daily gain (ADG) tended (*P* = 0.06) to be 9.5% greater for 1D compared to 2D during the backgrounding portion and ADG was increased 11.3% (P = 0.01) for 2D compared to 1D during the finishing phase of the experiment. Cumulative ADG did not differ between treatments (1.61 vs. 1.62 ± 0.046 kg/d) for 1D and 2D, respectively. Cumulative observed dietary NEm and NEg did not differ ($P \geq 0.96$) between treatments. There were no differences ($P \geq 0.18$) detected between treatments for HCW, DP, REA, RF, USDA marbling score, KPH, yield grade, retail yield, EBF, or body weight at 28% estimated EBF. It is concluded that Northern Plains feedlot producers can feed a single growing-finishing diet to preconditioned beef steers with minimal effects on overall growth performance or carcass traits.

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Ensiled feeds are widely used in the Midwest and have become cornerstone feed ingredients throughout the United States. Silage is a high energy forage that can be fed to ruminants and act as a "buffer" in the rumen to promote ruminal health and prevent metabolic disorders such as acidosis. The state of South Dakota relies heavily on the production of silage as a versatile feedstuff that can be used in a variety of production settings in both the beef and dairy industry. The demand for silages has made South Dakota the number eight ranked state for corn silage production in the United States. Corn silage makes up the majority of the silage produced in the state and is grown on 137,593 hectares (ha) and yields nearly 5.4 total metric tons of silage annually (USDA, 2019). Sorghum silage production ranks third overall nationally where 766,571 metric tons of silage are produced on 16,187 ha (USDA, 2019). The state of South Dakota and its cattle feeders rely heavily on the production of quality silage annually to optimize both profits and land usage.

Silage use in growing and finishing cattle diets is often linked to maximal or minimal roughage inclusion. Silage may often be the predominant roughage source within a given ration. Roughages can be defined as feeds high in fiber and low in digestible nutrients when compared to nutrient dense concentrates (Morrison, 1936). Silages, hay, fodder, and straw can fit into this classification of feed. Inclusion level of roughage within a ration can vary in order to control rate of gain or promote ruminal health and fermentation stability. The objective of this research was to evaluate strategies that Northern Plains cattle feeders could implement in order to fully utilize and maximize production responses while using corn silage as well as other roughage sources in confined cattle feeding settings.

SECTION 1. CORN SILAGE AND KERNEL PROCESSING

SILAGE BACKGROUND AND HISTORY

Silage is described as anything stored in a silo, which may include bunkers, towers, or piles. The word itself is derived from the Greek word "siros" which is defined as a pit or hole sunk in the ground for storing corn (McDonald et al., 1991). More practically defined by Woolford (1984) as "the product formed when grass or other material of sufficient high moisture content, liable to spoilage by aerobic microorganisms, and is stored anaerobically". Silages generally are produced from grasses or legumes which consist of a highly digestible grass that is accompanied by a high moisture grain. This can be compared to hay from the same crop with drastic differences in digestibility, pH, and dry matter of the given feedstuff (Wilkinson et al., 2003).

Production of silage originated around 1200 BC when ancient Egyptians and Greeks stored grains and whole crops in silos for preservation. A similar technique that has been linked to silage production was also used throughout the nineteenth century in Germany in the production of sauerkraut (Schukking, 1976). By the year 1882 the United

States Department of Agriculture contained statements from 90 farmers in both the United States and Canada that had adopted the ensiling practice (Wilkinson et al., 2003). Since then, the ensiling process and technology has been adopted and further developed across the globe and has proved its value in a wide range of environments and production settings as a viable storage option for high moisture feeds that would otherwise be destroyed and deemed un-suitable to feed if not stored under anaerobic conditions. Additionally, harvesting row crops as silage allows producers to harvest large quantities of feed in a short time period. The ensiling process has been used throughout history to preserve high quality feedstuffs and will continue to serve as a critical component of the livestock feeding industry.

CORN SILAGE HARVEST

There are many factors that go into the harvest of corn silage; particle size, kernel processing, and chop height are all factors that can influence the quality of the final product; however, none may be more important than plant maturity and timing of harvest. Timing of harvest and the maturity of the corn can have a significant impact on the dry matter, tonnage yield, starch content, metabolizable energy yield per hectare, and total nutrient density of silage produced.

MATURITY

Consideration of days required to plant, days required to harvest, environment, and maturation time of the hybrid planted must all be considered to ensure harvest occurs at the ideal stage of maturity. Corn silage is unique in the fact that maximum yield and feeding quality generally occur around the same time. Harvest generally occurs each fall when total plant moisture reaches approximately 65% or 35% dry matter. Silage harvested too early will often be wet (< 30% DM) and will result in seepage and nutrient loss, while silage harvested too late will be too dry (> 40% DM) and result in reduced fiber and starch digestibility and cause issues with storage and packing (Akins, 2018). Yield (metric tons/ha) can also be impacted by harvest time as a premature harvest can result in decreased yields as the plant has not been provided the opportunity to mature and the kernels have not yet filled with starch. While harvesting too late will result in a dry silage that will have lower yields on an as-is-basis as the material contains less water but contains more DM tonnage and subsequently results in enhanced yield on a DM basis.

PLANT DRY MATTER

Plant dry matter is often determined by observation of the corn kernel milk-line which is the proportion of starch and non-starch substance within the developing corn kernel. This has been deemed both a viable and simple measurement tool for determining total plant dry matter content according to Wiersma et al. (1993). A kernel milk-line of one-half to two-thirds will often indicate ideal plant dry matter for harvest. Hunt et al. (1989a) reported that in an irrigated study in Idaho and California that maximum forage yield and quality occurred at the two-thirds milk-line stage of maturity across six dual-purpose corn hybrids when compared to both one-third and black layer maturity. There is a positive correlation between plant dry matter and plant maturity as both will increase over time until the plant reaches full maturity. The increase in dry matter can be attributed to not only the drying of the plant but to the continued deposition of starch within the corn kernel. While plant maturity increases both the dry matter and starch content of the plant material will increase by 0.5 to 1.0% per day depending on plant date, meteorological conditions, soil composition, and water distribution (Mahanna et al., 2014).

PARTICLE SIZE AND CHOP HEIGHT

Corn silage particle size and chop height are two other factors that must be determined at harvest. Particle size can be an important factor when it comes to packing the silage for storage as well as its value as an effective fiber source. Particle size will often be determined by the processor type used during harvest but can vary from 0.95 to 3.18 cm. Chop height can be used to manipulate the digestibility of the harvested forage as higher chop heights will generally result in reduced stover, decrease fiber, and increase starch concentration. Previous work has shown that chop height can directly impact yields as raising cutting height from 15 to 46 cm resulted in a yield reduction of up to 7% (Campbell et al., 2005). These are management factors that must be taken into consideration prior to harvest to ensure an optimal feedstuff is produced in an adequate amount to meet the needs of the given operation.

KERNEL PROCESSING

Kernel processing is a mechanical alteration applied to the silage at harvest that aims to increase the starch availability and utilization by further processing the kernel prior to being ensiled. This process breaks the pericarp and disrupts the starch-protein matrix, thereby promoting proteolytic activity and starch utilization (Ferraretto et al., 2018). Processing of corn silage has been shown to increase starch availability while decrease total neutral detergent fiber (NDF) of the silage (Doggett, 1998). Saylor et al. (2021) observed a greater pH decline in ensiled processed kernels when compared to intact kernels under the same conditions. Lactic acid and total acid concentrations were also greater in processed kernels compared to intact kernels. This work would suggest processed kernels would be susceptible to enhanced fermentation compared to intact kernels (Saylor et al., 2021).

STORAGE

There are numerous structures and strategies used to store silage; tower silos, bunkers, bags, and covered piles are all viable options that are used depending on infrastructure, resources, and operational needs. No matter the storage type used the objective remains the same; provide an environment for forage to be fermented and conserved while maintaining an anaerobic environment and minimizing spoilage and nutrient loss. Tower silos and bunkers are often capable of handling large quantities of silage and require the most infrastructure while bags and covered piles can be more flexible to the quantity of silage produced and require less infrastructure. Three main management events remain once the crop arrives at the silo: 1) packing of the crop; to remove excess oxygen, 2) sealing of the silo; to maintain an anaerobic environment, and 3) emptying of the silo; to prevent excess spoilage (Muck et al., 2003). These steps are a critical aspect of silage production and can greatly influence the ability of the silage to maintain nutritional integrity and minimize losses while in storage.

Storage losses are mainly associated with three mechanisms 1) air infiltration; where sugars are oxidized and converted into water and CO_2, 2) fermentation; where substrates are converted by microorganisms, and 3) effluent production by the silage under excess pressure and moisture (McGechan, 1990). These losses can occur throughout the ensiling and storage process and can vary depending on management practices (filling rate, time before sealing, integrity of seal, and feeding rate), physical composition of silage (moisture content and chop length), and storage type (silo, bunker, pile, etc.). Effective storage is critical in preserving the nutritional value of the silage pile. As losses occur the quality of the silage begins to decrease as the most valuable nutrient fractions of the silage such as sugars and proteins are more rapidly deteriorated compared to the less nutritive fractions such as lignin and cellulose (Savoie and Jofriet, 2003). Overall dry matter silage loss can range from 6 to 16% depending on silo type and management strategies (Savoie and Jofriet, 2003). The importance of the three management practices discussed previously and their impact on silage production will be discussed in further detail below.

PACKING

The process of storing a high-quality silage regardless of storage type remains very similar and relies heavily on the ability to pack the silage with an adequate filling rate and density in order to prevent the growth of aerobic organisms within the ensiled mass. This is traditionally done by driving over the silage pile repeatedly with a heavy vehicle in order to compact the silage before it is covered. When using bags filling rate and density is determined by packing speed and size of bag. Dry matter densities were reported on 168 commercial bunker silos in Wisconsin by Muck and Holmes (2019) which ranged from 106 to 434 kg/m^3. They found this variation was a result of the mass of the vehicle used to compact the silage and differences in time spent compacting. It was reported by Sun et al. (2021) that increasing the packing density (600, 650, 700, and 750 kg/m^3) decreased the silage pH, content of ammonia nitrogen, ethanol, NDF, and acid detergent fiber (ADF) of barley silage, and increased *in vitro* digestibility of dry matter, NDF, and ADF. A higher packing density was also found to decrease the abundance of *Enterobacter* and *Clostridium* and increase the concentrations of *Lactobacillus* organisms. They concluded that optimum silage quality based of the densities tested was achieved at 750 kg/m^3. Adequate compaction is critical in ensuring quality of silage is maintained and a favorable microbial population is present throughout the ensiling process.

SEALING

Once the silage has been appropriately packed it must be covered in order to establish and maintain the anaerobic environment needed for the fermentation process to occur. Plastic films that exclude oxygen have been used to protect silages stored in bunkers and piles for several decades (Dubois, 1978). Efficiently covering the pile in a timely and precise manner has proven vital in the preservation of high-quality silage. According to Bolsen et al. (1993), immediate sealing of both corn and sorghum silage preserved more dry and organic matter than silages sealed after 7 days. Unsealed silages began to deteriorate within 1 week in the first 33 cm of the pile, and spoilage of the silage progressed to 67 cm during the remainder of the storage process. This further illustrates that proper sealing and the preservation of the seal throughout the storage and feeding period is critical in maintaining silage quality and minimizing dry matter losses.

EMPTYING

An important factor in maintaining the anaerobic stability of the silage pile is maintaining a feeding rate that is adequate to minimize aerobic deterioration of the pile. The two major factors that will influence the severity of deterioration are the feed out rate, which can be described as the average depth of silage removed across the whole face per day, and the manner in which silage is removed (Muck et al., 2003). Factors such as ambient temperature, microbial population, and silage pH during the ensiling phase will impact feed out rate requirements in order to minimize deterioration (Pahlow et al., 2003). The depth and rate at which air will penetrate the face will depend greatly on the pack density of the silage. Studies have investigated oxygen levels impact on open face bunker silos and found oxygen concentrations > 10 $mL \cdot L^{-1}$ at depths of 1 m or greater behind the face in corn, grass, and alfalfa silage (Honig, 1991). In the northern United States, producers are generally advised to remove 5 to 10 $cm \cdot d^{-1}$ from tower silos, 10 to 15 $cm \cdot d^{-1}$ from bunkers, and 30+ $cm \cdot d^{-1}$ from silage stored in bags. As mentioned earlier, ambient temperatures can impact necessary feeding rate and under warmer conditions it is recommended that nearly twice as much silage is removed from bunkers at a rate of 20 to 30 $cm \cdot d^{-1}$ (Muck et al., 2003). As for the importance of the manner in which silage is removed, Honig (1991) found that silage removed from a specialized silage loader is more aerobically stable than that removed by a bucket as the bucket resulted in greater oxygen exposure to the face of the pile. These benefits of modern technology should be considered with regard to added expenditures and resources available for the given operation. Management practices and decisions can greatly influence the losses accumulated during the storage and feed out period and ultimately impact the quantity and quality of feed produced.

ENSILING PHASES AND MICROBIOLOGY

The ensiling process can be divided into four phases that vary in length and ambiance and are not precisely separated from one another as defined by Barnett (1954). The stages are generally differentiated from one another by the microbial populations present, pH, and whether an aerobic or anaerobic environment is present. The four phases can be catagorized as: 1) Aerobic Phase, 2) Fermentation Phase, 3) Stable Phase, and 4) Feed out or aerobic spoilage phase (Pahlow et al., 2003). The microorganisms that are found on the crop prior to fermentation will differ greatly from those present during the ensiling process and once the final product is produced. There are many microorganisms present on the plant crop with the most relevant being epiphytic lactic acid bacteria (LAB) as well as *enterobacteria* which are responsible for spontaneous silage fermentation (Pahlow et al., 2003).

AEROBIC PHASE

This phase will generally last several hours and can be classified by the diminishing effect of free oxygen via respiration and proteolysis of plant enzymes and microorganisms until an anaerobic environment is created. The quantity of trapped oxygen within the forage pile will determine how long this phase lasts as free oxygen fuels respiration of the plants and microorganisms which results in the breakdown of plant sugars to produce carbon dioxide, water, and heat (Bolsen et al., 1996). During this time the decomposition of proteins to amino acids and ammonia also occurs via proteolysis as described by McDonald et al. (1991). The loss of plant sugars from respiration is important for silage preservation as LAB rely on these plant sugars to produce the acids essential for whole crop ensiled-mass preservation. It has been shown that the length of this phase and nutrient losses can be minimized when silage is finely chopped, well compacted, and sealed without delay upon harvest (McDonald et al., 1991).

FERMENTATION PHASE

Initiation of the fermentation phase takes place when an anaerobic environment is created and anaerobic microorganisms such as LAB become the dominant population. Lactic acid bacteria have been defined by Axelsson (2004) as a group of gram-positive bacteria that are non-spore forming and produce lactic acid as an end product during fermentation. These bacteria can be separated by the two major types of fermentation that yield lactic acid. Homofermentative, which yield lactic acid and heterofermentative, which yield not only lactic acid but other products such as ethanol, acetate, and CO_2 (Pahlow et al., 2003).

The length of active fermentation will vary from 7 to 21 days depending on crop specific properties such as water-soluble carbohydrates, dry matter, and bacterial populations preexisting on the plant mass. Higher moisture forages (> 65% moisture) will ferment more rapidly than those ensiled at a greater dry matter (< 50% moisture). Forages ensiled at the normal moisture range (55-75%) will actively ferment for 7 to 14 days and fermentation will end when available sugars are depleted by the LAB or bacteria growth is halted by a decline in pH (Bolsen et al., 1996). The speed of this shift from an aerobic to anaerobic environment has been correlated to rate of pH decline and lactic acid production, according to Merry and Davies (1999).

Other microorganisms such as *enterobacteria*, *clostridia*, yeasts, and molds are also present and compete with LAB for the available sugars making them undesirable. *Enterobacteria* produce an array of products as a result of sugar fermentation including acetate and ethanol with lactate being a minor product. According to Spoelstra (1987) *enterobacteria* are probably responsible for reduction in NO_3 (nitrate) during ensiling resulting in the production of toxic nitrous oxide gases. *Clostridia* are generally associated with the undesirable production of butyric acid which can result in a rise in pH and an unpalatable feed product (Rooke and Hatfield, 2003). Yeasts and molds will establish a population of aerobic organisms within the silage pile while using available lactate resulting in a rise in pH and temperature (Rooke and Hatfield, 2003). The importance of establishing a dominant LAB population during the initiation of the fermentation phase is essential in order to maintain silage stability and quality throughout the ensiling process.

STABLE PHASE

As the fermentation process comes to an end, little occurs during the stable phase if the integrity of the seal is maintained, and oxygen is void in the ensiled mass. Environmental conditions will be maintained within the pile at the normal range of 24 to 32 degrees Celsius and a pH of 4.5 to 5.0 (Kung, 2011). This phase can last for an indefinite time period and will make up a majority of the total time in the ensiling process as long as fermentable substrates are present; generally, this phase will be maintained for no longer than the next harvest season (Pahlow et al., 2003). Results presented by Kleinschmit and Kung Jr. (2006) would indicate that extending the storage (stable phase) of silage results in lower concentrations of lactic acid and elevated levels of acetic acid. This would contradict findings reported previously by Grum et al. (1991) that lactic acid increases with prolonged storage time in alfalfa silages. More recent research has shown that increased ensiling time will result in increased dry matter digestibility and protein degradability when silage is fed to finishing beef cattle (Benton et al., 2005). Length of this phase will depend on inventory of feed remaining from the previous harvest season along with operational goals and management strategies.

FEED OUT OR AEROBIC SPOILAGE PHASE

When the silage pile is opened and exposed to oxygen the feed out phase begins. This exposure to oxygen will allow the growth of undesirable microorganisms such as yeasts, molds, and other aerobic bacteria to take place resulting in spoilage (Pahlow et al., 2003). Previous work has illustrated that both a rise in pH and temperature will occur during this phase as an aerobic environment is re-created (Koc et al., 2009). This rise in temperature and pH is a result of highly digestible nutrients such as sugars, lactic, and acetic acid being consumed by the aerobic organisms (Bolsen et al., 1996). As discussed earlier, proper management can limit spoilage loss, however, dry matter losses of 1.5 to 4.5% per day can be expected in affected areas according to Honig and Woolford (1980). The feed out rate of silage from the pile can play a significant role in reducing dry matter losses and the effects of spoilage on the remaining pile. Pitt and Muck (1993) determined that by removing 15.24 cm per day from the silage face dry matter losses could be reduced to 3% when silage was adequately (224 kg DM/m^3) packed. They suggested that as packing density is reduced, removal be increased in order to minimize losses. Ambient temperature is another factor often considered when looking at optimal silage removal rate. Today most suggestions for removal rate are based on temperature as noted by Jones et al. (2004) where it is recommended that 7 to 10 cm are removed daily when temperatures fall below 4 degrees Celsius and 10 to 15 cm when temperatures exceed 4 degrees Celsius. Feeding ensiled feeds at elevated levels throughout the feeding period can be done to help increase silage removal rate and mitigate problems associate with DM loss if animal performance is not compromised. Losses during this phase are inevitable, but, can be reduced with proper management and feed out strategy.

SILAGE QUALITY AND PARTICLE SIZE

When ensiling crops, it is key to maintain the quality of the crop while reducing both dry matter and energy loss. The potential obstacles that may arise during this process that could hinder the quality of the silage such as plant respiration, proteolytic activity, aerobic microorganisms, and management practices discussed earlier in the review. Assessing silage quality can be important in determining how to best utilize the feed. Knowing how factors such as silage dry matter, particle size, and maturity of the crop influence the quality of silage produced is also important as it may influence management strategies of how the silage is used. Considering the impact environmental factors such as drought and frost have on silage quality can also be relevant in certain situations especially beef cattle production in the Northern Plains.

SILAGE QUALITY

The techniques used to assess silage quality have continued to co-evolve with several other processes, according to Cherney and Cherney (2003). These processes being the development of improved harvesting and processing equipment, development of storage methods and structures, and the evolving dietary needs of animals bred for increased production potential have become better understood. Silage quality also may not relate to quality of the forage as a result of the ensiling process and the interaction between the fermentation process and nutrients in the silage (Webster, 1992). The impact that crop maturity and fermentation length have on silage quality was evaluated in recent research by Bal (2006) in terms of pH, dry matter, crude protein, and *in situ* dry matter disappearance. His work found that both crude protein and *in situ* dry matter disappearance decreased linearly as the corn plant matured while dry matter and pH increased with increasing maturity. Ensiling time also impacted crude protein and *in situ* dry matter disappearance as they increased as the silage was ensiled from 0 to 16 weeks, and pH was decreased as fermentation length was prolonged. According to this work, corn silage should be harvested at 30 to 35% dry matter and be fermented for a minimum of 8 weeks to achieve maximum feed quality (Bal, 2006).

PARTICLE SIZE

Mechanically processing silage to reduce particle size at harvest has proven beneficial in improving fermentation, packing density, and nutritive value of silages (Wilkinson, 1982). Length of cut at harvest should be considered and depends on several factors that have been outlined by Mahanna et al. (2014) including; 1) need for physically effective fiber, 2) particle size of other ingredients in the diet, 3) type of storage structure, and 4) compaction capabilities, and 5) unloading method. Compaction density in storage structures is generally increased with a shorter chop where longer chop is generally associated with increased NDF (Mahanna et al., 2014). Determining particle size of a forage or total mixed ration is traditionally done using a tool known as the Penn State Particle Separator (Heinrichs and Kononoff, 1996). The particle separator is a series of sieves varying in size in which the sample will pass through with particles on varying sizes being collected in categories of descending particle sizes. The initial sieve would collect large particles greater than 19 mm classifying them as particles that would form the forage mat in the rumen, provide buffering of rumen pH, and require substantial cud chewing to be further digested. Medium particles would be collected in the 8 to 19 mm sieve and would be classified similar to the large particles with less cud chewing and faster breakdown by the rumen's microbial population. Particles 4 to 8 mm will be classified as small particles yet have little effect on rumen buffering, regardless of chemical composition. Particles found in this sieve can be used to estimate physically effective NDF (peNDF) which can be done by adding the amount of feed on the top three sieves and multiplying by the NDF of the feedstuff (Heinrichs, 2013). Physically effective NDF is a measure to estimate the ability of fiber to stimulate chewing activity and saliva production in an effort to buffer the rumen (Mertens, 1997). The importance of peNDF will be discussed further in the roughage section of this review.

Particle size of silage when used as the primary roughage source in both beef and dairy diets has been studied extensively in terms of its impacts on rumination behavior and production. Research conducted by Gentry et al. (2016) suggests that rumen function and performance can be maintained when roughage inclusion is decreased as long as particle size of the remaining roughage is increased. That research found the ideal particle size of roughage in feedlot diets is not clearly defined but should aim to maximize intake, promote ruminal health while maintaining performance (Gentry et al., 2016). When looking at dairy cattle performance it was found that reducing the particle size of corn silage increased both dry matter intake and rumen volatile fatty acid concentrations (likely because of the increased dry matter intake (DMI)) while chewing activity was closely related to particle size. Increasing particle size had no effect on rumen pH, however, results did suggest increased sorting behavior occurred when greater proportions of large particles (> 19 mm) were present in the diet (Kononoff et al., 2003).

ENVIRONMENTAL FACTORS

Environmental factors such as frost, drought stress, and excess moisture during the growing season have been shown to influence the composition and quality of corn silage. If frost damage occurs while the corn crop is still immature, plants will appear drier than plants of undamaged corn with similar moisture content. Mature plants that experience damage from frost may die, and increased urgency to finish harvest before moisture is lower than acceptable levels (Jones et al., 2004). Crops such as corn that have experienced stress from drought have been found to have increased nitrate levels. Ensiling these silages has been shown to reduce the nitrate levels by up to one-half as the forage nitrates are converted to nitrogen gases (Dorn et al., 2002). Therefore, ensiling is the preferred method of harvest for drought stressed corn. It has been shown that drought stress has little effect on overall corn silage quality and starch degradability in the rumen, however, nutritional quality may vary with distribution of tissue proportions as a result of drought stress (i.e., grain to stover ratio) with little difference in the tissue composition (Ferreira, 2015). Excess moisture during the growing season reduces the amount of total plant carbohydrates transferred to the developing kernel and increases the amount stored in the leaves and stalk of the plant making them more readily available (Jones et al., 2004). Environmental factors have been shown to influence both crop and silage properties and can influence management decisions and practices to best utilized the compromised feedstuff.

CORN SILAGE AS A FEEDSTUFF

Corn silage is a vital forage source for cattle in both the beef and dairy industries in climates where corn is well adapted. It serves as a high energy forage source that can be used in growing and finishing cattle diets, cow and calf production, heifer development, and lactating dairy cow diets (Allen et al., 2003). The nutritional values of ensiled feeds will differ from dried or fresh feeds produced from the same crop. Nutrients are not added to the feed from the ensiling process itself, however, nutrients concentrations are more readily preserved in the high-moisture feed than that of a dry feed product such as hay. Nutrient loss in hay occurs both through the drying of the feed in the field and through handling of the dry forage when nutrient rich leaves are fragile and often lost resulting in increased dry matter losses (Pitt, 1990). Factors such as maturity (Bal, 2006) and mechanical processing (Weiss and Wyatt, 2000) have also been shown to influence the nutritive value of corn silage. Since corn silage is such a prominent feedstuff it is important to understand the nutritive value of the feed and factors that may influence this as well as how inclusion levels of silage in a diet may influence cattle performance under varying production settings.

NUTRITIVE VALUE

When comparing the nutritive value of silages to dried or fresh feeds the main differences will relate to reduced concentrations of fermentable carbohydrates and protein and increased acids and nonprotein nitrogen (Weiss et al., 2003). As mentioned previously, there are many factors that may affect the nutritive value of corn silage from plant characteristics and hybrid to management practices. With that being the purpose of this section is not to discuss exact feeding values in regard to the nutrients within corn silage but discuss a few factors that may impact these nutritional components and how they compare to dried or fresh feed derived from the same crop source.

A study of the effects of hybrid, maturity, and mechanical processing on the chemical and physical characteristics of corn silage (Johnson et al., 2002) concluded that hybrid type had significant effects on chemical characteristics of the corn silage including concentrations of ADF, lignin, and starch. Maturity affected both the dry matter and chemical composition of silages as dry matter increased linearly with crop maturity. Similar to research conducted by Hunt et al. (1989b), it was found that NDF and ADF concentrations increased as corn silage matured from one-third to two-thirds milk line. This study contradicted research by Bal (2006) that illustrated an increase in starch as maturity advanced. It was also shown that corn silage harvested at earlier maturities had increased levels of crude protein compared to corn silage of the same maturity endpoint that is harvested at a later date.

When looking at the comparison of the physical and chemical characteristics of hay and silage, one can see differences in the measurements used to gauge carbohydrate fermentation in the rumen such as pH and volatile fatty acid concentrations and proportions (Weiss et al., 2003). When looking at protein comparisons between hays and silages, differences in the nitrogen fraction available in terms of soluble crude protein are readily apparent. Silage generally has increased proportions of degradable crude protein and non-protein nitrogen compared to dried forage or pasture ground of the same biomass according to Nocek and Grant (1987). Previous work comparing corn and alfalfa silage to alfalfa hay indicated that efficiency of protein and nitrogen utilization is reduced in dairy cows fed both corn and alfalfa silage compared to alfalfa hay (Hristov and Broderick, 1996). It is suggested that these differences were a result of the production level of the animal as well as the high moisture content of the silage which resulted in greater proteolysis. This would concur with a study (Brouk and Belyea, 1993) that investigated nitrogen balance when feeding non-lactating dairy cows all forage-based diets. Nitrogen balance was found to be greatest in cows fed silage compared to those fed long or short stem alfalfa hay indicating that when nitrogen requirements of an animal are low, forage source has little effect on nitrogen utilization.

CORN SILAGE USE IN FINISHING BEEF CATTLE DIETS

As mentioned previously, corn silage is a versatile feed ingredient and is used in finishing beef cattle diets in varying proportions and can be an effective way to market home-raised feedstuff through cattle. Corn silage has intermediate net energy content compared to most grains and roughage sources found in the Midwest (NASEM, 2016), and can be used to meet performance and nutritional requirements in growing cattle diets. In finishing diets, the use of corn silage is generally limited and fed as a source of scratch factor to maintain rumen health according to a survey of feedlot consulting nutritionists.

According to that survey, corn silage was used as the primary or secondary roughage source in finishing diets by 37.5% of the respondents (Samuelson et al., 2016). Extensive research efforts have investigated the impact silage inclusion has on growth performance of growing and finishing beef cattle and also the carcass characteristics of finishing beef cattle.

Increasing inclusion rates of corn silage from 12% to 24% (DM basis) in finishing cattle diets has been shown to reduce average daily gain and gain to feed ratio by 4.4% (Rusche et al., 2020). This remains consistent with previous work and coincides with work done by Preston (1975) examining NE_m and NE_g values of diets when varying proportions of corn grain and corn silage were fed. It was found that both dietary NE_m and NE_g values linearly decreased when corn silage was substituted for whole, dry-rolled, or high-moisture corn grain. Research done at the Nebraska Experiment Station investigated feeding increased levels of corn silage and modified distillers grains plus solubles (MDGS) in finishing diets as it had been indicated previously that feeding MDGS improved ADG and feed efficiency when corn was partially replaced by corn silage in finishing diets (Burken et al., 2014). Corn silage and MDGS were included at (DM basis; corn silage:MDGS) 15:20, 15:40, 45:20, 45:40 and a control diet consisting of 5% cornstalks and 40% MDGS. It was concluded from this work that a modest reduction in ADG and a decrease in gain to feed ratio could be expected when silage inclusion increased in the diet. Cattle fed at the corn silage to MDGS ratio of 15:40 expressed decreased conversion efficiency compared to steers on the control diet. Studies have indicated that reduced final body weight and hot carcass weight can be expected when elevated levels of silage are incorporated into the diet (Burken et al., 2014; Hilscher et al., 2019). Buckhaus and Smith (2021) recently found that increasing silage inclusion level from 15 to 30% had no effect on ribeye area, rib fat, USDA marbling score, calculated yield grade, retail yield, estimated empty body fat (EBF), final BW at 28% EBF, or the distribution of USDA quality or yield grades. It was noted that dressing percentage was greater for steers fed 15% corn silage (64.52%) compared to those fed 30% corn silage (63.47%). This was attributed to decreased digestive tract fill in the steers fed 15% silage. Hot carcass weight was greater in steers fed less silage agreeing with previous work (Burken et al., 2014; Hilscher et al., 2019). Corn silage is a readily available and highly utilized feed ingredient in the Northern Plains and can be used in finishing cattle diets as a high energy roughage source. Depending on the operation's goals and resources, corn silage can be fed at various inclusion levels to best meet the animal's nutrition needs as well as to best utilize the feed ingredient. Inclusion level will depend greatly on the economic costs of the corn silage and the economic benefit of marketing a home raised feedstuff through beef production.

KERNEL PROCESSING CORN SILAGE

The use of counter-rotating rolls mounted on silage harvesting equipment to process corn kernels was established in the 1990's (Mahanna et al., 2014; Ferraretto et al., 2018). Kernel processing aims to improve the starch digestibility of corn silage by reducing kernel size and increasing surface area for ruminal microbe activity (Ovinge et al., 2018). This can be critically important in dairy rations where large high producing cows have increased DMI and consume diets containing large quantities of silage. Interest in this technology has risen as a result of increased silage inclusion in dairy rations, grain prices, and increased kernel dry matter (Mahanna et al., 2014; Ferraretto et al., 2018).

PHYSICAL AND CHEMICAL IMPLICATIONS

The effectiveness of kernel processing can be measured using a system developed by the USDA Forage Research Center (Mertens, 1997). This system is similar to the previously discussed Penn State Particle Separator as it uses a series of screens to measure particle sizes and their proportion within the feed. In the case of corn silage, the percentage of starch passing through a 4.75 mm screen is used to determine adequacy of processing where greater than 70% is deemed optimal processing, 50 to 70% adequate processing, and less than 50% is inadequately processed silage.

Kernel processing corn silage has been shown to reduce particle size by 15 to 30% (Roberge et al., 1998). It was also concluded that as silage maturity increased so did the value of processing because of increased starch digestion. Johnson et al. (2002) illustrated the magnified impact of processing with increased maturity as the amount of corn silage particles found in the bottom layer of the Penn State Particle Separator (less than 4 mm) increased from 9.6 to 11.9 to 16.3% as maturity increased from one-third milk line to two-thirds milk line to black layer. Processing corn silage decreased the amount of whole intact kernels found in a 250 g silage sample, from an average of 39 intact kernels to less than 10 (Ebling and Kung, 2004).

Kernel processing has been shown to impact the chemical composition of corn silage by reducing both NDF and ADF concentrations when compared to unprocessed silage (Rojas-Bourrillon et al., 1987; Johnson et al., 1999). In other experiments (Andrae et al., 2001) both starch digestion and dry matter intake increased when corn silage was processed, however, fiber digestibility was impaired due to processing. When dairy cattle were fed corn silage at an inclusion of 26.8% (DM basis) that had been processed at 1 mm, Johnson et al. (2002) found that an increase in starch digestibility was offset by a tendency for decreased NDF digestibility resulting in no significant change in dry matter digestibility. This would agree with work done by Rojas-Bourrillon et al. (1987) that concluded processing corn silage did not impact dry matter digestibility when fed to growing steers at a dry matter inclusion level of 90%. Limited effects of processing were observed on the chemical composition of the total mixed rations containing processed corn silage in terms of ash, NDF, ADF, hemicellulose, crude protein (CP) when compared to rations with unprocessed silage (Johnson et al., 2002). A chemical effect of kernel processing of recent significance has been observed during the fermentation process. Saylor et al. (2021) found that kernel processing resulted in a more rapid pH decline, and increased concentrations of lactic, acetic, and total acids. Increased concentrations of lactic acid would indicate that there is a strong population of LAB within the silage mass which are responsible for silage conservation via production of lactic acid (Carvalho et al., 2021). These results would indicate that kernel processing enhances fermentation during the ensiling process as a result of increased levels of exposed sugars available for microbial fermentation.

ANIMAL PERFORMANCE

Enhanced production because of kernel processing has been investigated in both beef and dairy industries (Rojas-Bourrillon et al., 1987; Bal et al., 2000; Cooke and Bernard, 2005; Ovinge et al., 2018). Cooke and Bernard (2005) found that in lactating dairy cows, reduced theoretical length of cut and kernel processing increased milk yield, milk fat, and milk protein when corn silage was fed at 38% DM. Similarly Bal et al. (2000) observed an increase in dry matter intake, milk production, and milk fat for cattle processed silage at a DM inclusion of 67%. Rojas-Bourrillon et al. (1987) investigated kernel processed corn silage when fed at dry matter inclusion rates of 60, 65, and 90% to growing steers. No differences in ADG or performance were observed at any of the inclusion levels investigated. More recent work (Ovinge et al., 2018) has been done on finishing steers and found, steers fed kernel processed silage had reduced DM intakes compared to steers fed unprocessed silage. Kernel processing appeared to have a positive impact of 2.6% on gain to feed ratio when silage was fed at a DM inclusion of 40%. This would suggest a 6.5% improvement in feeding value compared to unprocessed silage. No differences were found in any carcass trait parameters including HCW, marbling score, ribeye area, or prevalence of liver abscess. Similar results were observed by Gorocica-Buenfil and Loerch (2005) when kernel processed corn silage was fed and no differences in quality or yield grade were observed. Positive responses to kernel processing on animal growth performance have been reported in specific management situations where corn silage inclusion is greater than 40% of diet DM.

SECTION 2. ROUGHAGE IN BEEF CATTLE DIETS

Roughages can be defined as feeds high in fiber and therefore low in total digestible nutrients (Morrison, 1936). Forages such as hay, straw, fodder, pasture, and silage would fall into the roughage classification. Particle size and NDF content have been used to determine roughage value in high roughage diets (Sudweeks et al., 1981;

Santini et al., 1983). Adequate amounts of roughage are necessary in ruminant diets to avoid metabolic disorders and reduce milk fat production in dairy cattle. Roughage is generally limited in the diet due to cost per unit of energy and included at a minimum level to ensure rumen health and promote microbial protein synthesis. Smith (2021) explained that purchased forage is considerably more expensive per unit of energy when compared to cereal grains often resulting in removal of forages from diet when the diet is formulated on a least-cost formulation basis. Consequently, forage is often forced into the diet as a "functional" ingredient depending on management capabilities of the operation (Zinn and Ware, 2003). Roughage has also proven beneficial in regard to sorting and separation of the ration both in the feed batching system and the feed bunk (Buckhaus et al., 2020).

Roughage source has been found to have an effect on finishing cattle performance as explained by Mader et al. (1991). Ideal roughage source in finishing diets may depend on energy source of the diet. Roughages such as silages that are high in moisture were shown to complement high moisture corn while hay or dry roughage complements dry corn. The feeding value of roughages in feedlot diets is dependent upon the nutrient content of the roughage, characteristics of the fiber, palatability, and potential associative effects it may have on other ingredients in the diet (Zinn and Ware, 2003). It has been illustrated that the significance of roughage source may be less when the roughage is adequately processed to promote uniform mixing with other dietary ingredients (Buckhaus et al., 2020) and an adequate amount of NDF from roughage is fed (Benton et al., 2015). Over the years the impacts of roughage type and inclusion have been thoroughly investigated regarding beef cattle performance, behavior, and ruminal characteristics.

ANIMAL PERFORMANCE

Several studies have been conducted regarding roughage inclusion and its effects on performance in feedlot and finishing beef steers (Loerch and Fluharty, 1998; Hales et al., 2014; Benton et al., 2015; Gentry et al., 2016; Rusche et al., 2020). Previous research efforts have noted common observations in growth performance responses when decreased roughage concentrations in the diet reduced both DMI and ADG (Stock et al., 1990a; Shain et al., 1999; Farran et al., 2003). In research investigating inclusion rate and particle size of corn stalks when fed as the primary roughage source in finishing beef steer diets containing wet corn gluten feed (Gentry et al., 2016) found that dry matter intake was greatest for steers consuming a 5% roughage diet compared to steers fed a 10% roughage diet. Carcass adjusted final body weight was greatest for steers consuming the least amount of roughage. No differences in ADG were observed; however, steers fed the 5% roughage diet had greater carcass adjusted ADG. This would contradict previous work done by Parsons et al. (2007) examining varying DM inclusion levels of alfalfa hay (0, 4.5, and 9.2%) in diets containing wet corn gluten feed. They found that body weight and carcass adjusted final body weight increased as roughage inclusion increased. These research concluded that DMI increased as roughage inclusion increased from 0 to 9.2%. Recent work by Rusche et al. (2020) observed no differences in DMI but reported reduced ADG and G:F when corn silage inclusion was increased from 12 to 24% (DM basis) and served as the primary roughage source in finishing cattle diets. Differences in carcass traits as a result of roughage inclusion have been reported by Price et al. (1980)

where increasing roughage inclusion decreased both HCW and dressing percent. It was also noted that cattle fed low levels of roughage (20% DM) reached an optimum quality grade at a lesser carcass weight when compared to steers fed diets containing increased roughage (50 and 80% DM).

Loerch and Fluharty (1998) investigated roughage timing and inclusion strategy in growing and finishing beef steers over a 186-d period in which steers were fed: 1) 85% concentrate diet for 186 d, 2) 100% concentrate diet for 186 d, 3) 85% concentrate diet fed for 84 d followed by an 100% concentrate diet for the remaining 102 d, 4) 100% concentrate diet fed for 84 d followed by an 85% concentrate diet for the remaining 102 d. The initial 84 d of this study were considered the growing phase. In steers fed the 85% concentrate diet corn silage was used as a roughage source at a DM inclusion level of 15%. It was found that ADG was not affected during the initial 84 d by level of concentrate. Treatments fed the 85% concentrate diet for the remaining 102 d had greater DMI compared to steers fed 100% concentrate throughout the feeding period. However, steers fed 100% concentrate throughout the 186-d period had the greatest feed efficiency during the finishing phase and lowest for steers continually fed 85% concentrate. No differences in carcass quality or characteristics were noted in this trial. In a separate trial Loerch and Fluharty (1998) found that steers fed a 70% concentrate and 30% roughage diet grew 11% faster and consumed 19% more feed than steers fed a 100% concentrate diet during the initial 56 days on feed. Benton et al. (2015) reported that roughage source (alfalfa hay, corn silage, or corn stalks) had no influence on any performance measures in finishing cattle when fed at inclusion levels to contain equivalent dietary NDF. This work would indicate that similar growth performance can be expected when diets are formulated to a common NDF concentration regardless of roughage source. In agreeance with previous work, NDF concentrations should be monitored as it has proven to be a driver of DMI in feedlot and dairy cattle (Stock et al., 1990b; Shain et al., 1999; Benton et al., 2015). Roughage inclusion and subsequent timing of roughage inclusion within the feeding period can influence both growth performance and carcass characteristics.

BEHAVIOR AND RUMEN CHARECTERISTICS

Roughage inclusion has been shown to significantly impact feeding behaviors and rumen characteristics (Shain et al., 1999; Crawford et al., 2008; Faleiro et al., 2011; Campanili et al., 2017a). Increasing roughage inclusion levels in finishing cattle diets increased time spent ruminating, eating, chewing, and chewing per kilogram of dry matter consumed (Campanili et al., 2017a). This data is consistent with a study done by Faleiro et al. (2011) in which an 1.5 hour increase in rumination time was observed in heifers fed barley straw *ad libitum* compared to heifers fed no roughage. Ruminal pH has consistently been shown to decrease and become more acidic as roughage inclusion in the diet is lowered according to the studies mentioned previously (Faleiro et al., 2011; Campanili et al., 2017a). Roughage influence on ruminal pH has been described as a result of increased saliva production and increased rumination caused by greater dietary peNDF (Crawford et al., 2008). The impact of low peNDF in the diet has been reported by Smith et al. (2021) to decrease both ruminal pH and time spent ruminating in feedlot steers. Shain et al. (1999) reported that VFA concentrations in the rumen are also sensitive to roughage inclusion level as ruminal acetate concentration and acetate:propionate ratio increased when increased roughage levels were fed. Campanili et al. (2017b) reported similar findings where increased molar proportions of acetate were observed when roughage level was increased. Roughage inclusion has been shown to have a significant influence on eating behavior as well as ruminal characteristics such as pH and VFA concentrations. Roughage inclusion level directly influences eating behavior and rumen characteristics in cattle.

ENERGY METABOLISM AND NUTRIENT BALANCE

Energy metabolism and nutrient balance in steers fed decreased dietary roughage was investigated in an experiment by Hales et al. (2014). According to this study, when reported as a proportion of gross energy intake, fecal energy loss increased linearly, and digestible energy decreased linearly as dietary roughage from alfalfa hay increased. Increased levels of roughage also led to increased methane energy loss and heat production. Retained energy decreased as roughage inclusion increased because of greater fecal energy loss and ruminal digestibility of NDF when hay replaced dry-rolled corn (DRC) in the diet. This could be explained by the difference in TDN value of alfalfa hay and DRC. Rusche et al. (2020) reported no differences in NE utilization when corn silage was used as the primary roughage source in finishing cattle diets at varying inclusion levels (12 vs. 24% DM inclusion). Increased fecal organic matter output was reported by Crawford et al. (2008) when dietary roughage was increased from 3.8 to 11.4%. Similarly Zinn et al. (1994) found that an increase in dietary forage resulted in decreased organic matter (OM) digestibility. Schmitz et al. (2018) reported that dairy cattle fed a diet low in roughage and high in concentrate used energy less efficiency than those fed a diet with increased roughage. This response could have been a result of decreased fiber degradation caused by a shift from cellulolytic to amylolytic bacteria (Fernando et al., 2010) and increased passage rate as a result of lower dietary peNDF

(Poore et al., 1990). Chandramoni et al. (2000) reported that both urinary energy loss and methane production per 100 g of digestible OM were greater for sheep fed a diet with increased proportion of roughage in the diet. Efficiency of NE_m was similar amongst treatments with roughage level having no significant impact even though the reduced roughage diets contained greater metabolizable energy values. It has also been illustrated that increasing roughage in the diet could lead to increased lipolytic activity in the rumen (Latham et al., 1972). These findings illustrate that the impact of roughage on energy metabolism and nutrient balance in ruminants is not completely dependent on roughage inclusion alone as other dietary components and management techniques could alter the efficiency of energy utilization.

CONCLUSION

As discussed throughout this review the role of forages in cattle diets is very complex and important to understand. Growth performance, feeding behavior, and carcass traits can all be influenced by feeding strategy and implementation of roughage within a given diet. Forages can be fed in both grazing and confined feeding settings to cattle at various stages of production. The optimization of these roughage sources will vary from operation to operation and depend greatly on their infrastructure and equipment, roughage source, and the category of animal they are feeding. Silages have become a popular option for producers looking to maximize yields and harvest a high energy forage. The ability to create a high-quality silage will depend greatly on management decisions and will differ from one operation to the next. Overall, feeding forages to cattle gives producers in the Northern Great Plains an option in which to market homegrown forages through beef production.

LITERATURE CITED

Akins, M. 2018. Corn Silage Harvest Management Midwestforage.org:5-7.

Allen, M. S., J. G. Coors, and G. W. Roth. 2003. Corn silage. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Andrae, J. G., C. W. Hunt, G. T. Pritchard, L. R. Kennington, J. H. Harrison, W. Kezar, and W. Mahanna. 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J Anim Sci 79(9):2268-2275. doi: 10.2527/2001.7992268x

Axelsson, L. (2004) Lactic Acid Bacteria: Classification and Physiology. In: Salminen, S., Wright, A.V. and Ouwehand, A., Eds., Lactic Acid Bacteria: Microbiological and Functional Aspects, 3rd Edition, Marcel Dekker, New York, 1-67. https://doi.org/10.1201/9780824752033.ch1

Bal, M. A. 2006. Effects of hybrid type, stage of maturity, and fermentation length on whole plant corn silage quality. Turkish Journal of Veterinary and Animal Sciences 30(3):331-336.

Bal, M. A., R. D. Shaver, A. G. Jirovec, K. J. Shinners, and J. G. Coors. 2000. Crop processing and chop length of corn silage: effects on intake, digestion, and milk production by dairy cows. J Dairy Sci 83(6):1264-1273. doi: 10.3168/jds.S0022-0302(00)74993-9

Barnett, A. J. G. 1954. Silage fermentation. Q. Rev. Biol. Pages 78-81. LWW.

Benton, J. R., T. J. Klopfenstein, and G. E. Erickson. 2005. Effects of corn moisture and length of ensiling on dry matter digestibility and rumen degradable protein. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p. 31-33.

Benton, J. R., A. K. Watson, G. E. Erickson, T. J. Klopfenstein, K. J. Pol, N. F. Meyer, and M. A. Greenquist. 2015. Effects of roughage source and inclusion in beef finishing diets containing corn wet distillers' grains plus solubles. J Anim Sci 93(9):4358-4367. doi: 10.2527/jas.2015-9211

Bolsen, K. K., G. Ashbell, and Z. G. Weinberg. 1996. Silage fermentation and silage additives - Review. Asian-Australas J Anim Sci 9(5):483-494. doi: 10.5713/ajas.1996.483

Bolsen, K. K., J. T. Dickerson, B. E. Brent, R. N. Sonon, B. S. Dalke, C. Lin, and J. E. Boyer. 1993. Rate and Extent of Top Spoilage Losses in Horizontal Silos1. J Dairy Sci 76(10):2940-2962. doi: https://doi.org/10.3168/jds.S0022-0302(93)77634-1

Brouk, M., and R. Belyea. 1993. Chewing activity and digestive responses of cows fed alfalfa forages. J Dairy Sci 76(1):175-182. doi: 10.3168/jds.S0022-0302(93)77336-1

Buckhaus, E. M., D. T. Smerchek, and Z. K. Smith. 2020. Evaluation of batch fraction, corn silage inclusion level, and mixing duration on long particle distribution of finishing diets for beef cattle. 2020 Sep 2. doi: 10.12688/f1000research.25981.1

Buckhaus, E. M., and Z. K. Smith. 2021. Effects of Corn Silage Inclusion Level and Type of Anabolic Implant on Animal Growth Performance, Apparent Total Tract Digestibility, Beef Production per Hectare, and Carcass Characteristics of Finishing Steers. Animals 11(2):579.

Burken, D., B. Nuttelman, T. Klopfenstein, and G. Erickson. 2014. Feeding Elevated Levels of Corn Silage and MDGS in Finishing Diets. 2015 Nebraska Beef Cattle Report p. 66-67.

Campanili, P., J. Sarturi, M. Ballou, S. Trojan, J. Sugg, L. Ovinge, A. Alrumaih, L. Pellarin, and A. Hoffman. 2017a. Effects of silage type and inclusion level on ruminal characteristics and feeding behavior of steers fed finishing diets. J Anim Sci 95(10):4623-4637.

Campanili, P. R. B., J. O. Sarturi, M. A. Ballou, S. J. Trojan, J. D. Sugg, L. A. Ovinge, A. U. Alrumaih, L. A. Pellarin, and A. A. Hoffman. 2017b. Effects of silage type and inclusion level on ruminal characteristics and feeding behavior of steers fed finishing diets1. J Anim Sci 95(10):4623-4637. doi: 10.2527/jas2017.1510

Campbell, J. A., G. W. Roth, H. Marvin, and G. A. Varga. 2005. Impacts of Increasing Chop Height on Yield and Forage Quality of Corn Silage. 2005 The Northeast Branh of the ASA-SSA.

Carvalho, B., G. Sales, R. Schwan, and C. Ávila. 2021. Criteria for lactic acid bacteria screening to enhance silage quality. Journal of Applied Microbiology 130(2):341-355.

Chandramoni, S. B. Jadhao, C. M. Tiwari, and M. Y. Khan. 2000. Energy metabolism with particular reference to methane production in Muzaffarnagari sheep fed rations varying in roughage to concentrate ratio. Animal Feed Science and Technology 83(3):287-300. doi: https://doi.org/10.1016/S0377-8401(99)00132-7

Cherney, J. H., and D. J. R. Cherney. 2003. Assessing Silage Quality. Pages 141-198 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Cooke, K. M., and J. K. Bernard. 2005. Effect of Length of Cut and Kernel Processing on Use of Corn Silage by Lactating Dairy Cows. J Dairy Sci 88(1):310-316. doi: https://doi.org/10.3168/jds.S0022-0302(05)72689-8

Crawford, G. I., C. D. Keeler, J. J. Wagner, C. R. Krehbiel, G. E. Erickson, M. B. Crombie, and G. A. Nunnery. 2008. Effects of calcium magnesium carbonate and roughage level on feedlot performance, ruminal metabolism, and site and extent of digestion in steers fed high-grain diets1,2. J Anim Sci 86(11):2998-3013. doi: 10.2527/jas.2007-0070

Doggett, C. 1998. Evaluation of the effect of corn hybrid and processing on digestion of whole plant silage, grain and stover. Thesis, University of Idaho.

Dorn, T., B. Anderson, and R. J. Rasby. 2002. Drought-stressed corn. Historical Materials from University of Nebraska-Lincoln Extension:64.

Dubois, P. 1978. Plastics in agriculture / by P. Dubois ; translated and edited by C. A. Brighton. Applied Science Publishers, London.

Ebling, T. L., and L. Kung, Jr. 2004. A comparison of processed conventional corn silage to unprocessed and processed brown midrib corn silage on intake, digestion, and milk production by dairy cows. J Dairy Sci 87(8):2519-2526. doi: 10.3168/jds.S0022-0302(04)73376-7

Faleiro, A., L. González, M. Blanch, S. Cavini, L. Castells, J. R. de la Torre, X. Manteca, S. Calsamiglia, and A. Ferret. 2011. Performance, ruminal changes, behaviour and welfare of growing heifers fed a concentrate diet with or without barley straw. Animal 5(2):294-303.

Farran, T., G. E. Erickson, and T. J. Klopfenstein. 2003. Evaluation of buffering agents in feedlot diets for cattle. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p 226.

Fernando, S. C., H. Purvis, F. Najar, L. Sukharnikov, C. Krehbiel, T. Nagaraja, B. Roe, and U. Desilva. 2010. Rumen microbial population dynamics during adaptation to a high-grain diet. Applied and Environmental Microbiology 76(22):7482-7490.

Ferraretto, L. F., R. D. Shaver, and B. D. Luck. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J Dairy Sci 101(5):3937-3951. doi: https://doi.org/10.3168/jds.2017-13728

Ferreira, G. 2015. Understanding the effects of drought stress on corn silage yield and quality. In: 24th Tri-State Dairy Nutrition Conference, Fort Wayne, Indiana, USA, 20-22 April, 2015. p 91-99.

Gentry, W. W., C. P. Weiss, C. M. Meredith, F. T. McCollum, N. A. Cole, and J. S. Jennings. 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. J Anim Sci 94(11):4759-4770. doi: 10.2527/jas.2016-0734

Gorocica-Buenfil, M. A., and S. C. Loerch. 2005. Effect of cattle age, forage level, and corn processing on diet digestibility and feedlot performance1. J Anim Sci 83(3):705-714. doi: 10.2527/2005.833705x

Grum, D., W. Shockey, and W. Weiss. 1991. Electrophoretic examination of alfalfa silage proteins. J Dairy Sci 74(1):146-154.

Hales, K., T. Brown-Brandl, and H. Freetly. 2014. Effects of decreased dietary roughage concentration on energy metabolism and nutrient balance in finishing beef cattle. J Animal Sci 92(1):264-271.

Heinrichs, J. 2013. The Penn state particle separator. Penn State Extension, University Park, PA. DSE 186:1-8.

Heinrichs, J., and P. Kononoff. 1996. Evaluating particle size of forages and TMRs using the Penn State Particle Size Separator. Department of Dairy and Animal Sci. The Pennsylvania State University

Hilscher, F. H., D. B. Burken, C. J. Bittner, J. L. Gramkow, R. G. Bondurant, M. L. Jolly-Breithaupt, A. K. Watson, J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2019. Impact of corn silage moisture at harvest on performance of growing steers with supplemental rumen undegradable protein, finishing steer performance, and nutrient digestibility by lambs. Translational Animal Science 3(2):761-774. doi: 10.1093/tas/txz011

Honig, H. 1991. Reducing losses during storage and unloading of silage. Landbauforschung Voelkenrode. Sonderheft (Germany, FR)

Honig, H., and M. K. Woolford. 1980. Change in silage onexposure to air British Grassland Society C. Thomas Forage conservation in the 80s(Occasional Symposium No.11):p. 76-87.

Hristov, A. N., and G. A. Broderick. 1996. Synthesis of microbial protein in ruminally cannulated cows fed alfalfa silage, alfalfa hay, or corn silage. J Dairy Sci 79(9):1627-1637. doi: 10.3168/jds.S0022-0302(96)76526-8

Hunt, C., W. Kezar, and R. Vinande. 1989a. Yield, chemical composition and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. Journal of Production Agriculture 2(4):357-361.

Hunt, C. W., W. Kezar, and R. Vinande. 1989b. Yield, Chemical Composition and Ruminal Fermentability of Corn Whole Plant, Ear, and Stover as Affected by Maturity. Journal of Production Agriculture 2(4):357-361. doi: https://doi.org/10.2134/jpa1989.0357

Johnson, L., J. H. Harrison, C. Hunt, K. Shinners, C. G. Doggett, and D. Sapienza. 1999. Nutritive Value of Corn Silage as Affected by Maturity and Mechanical Processing: A Contemporary Review. J Dairy Sci 82(12):2813-2825. doi: https://doi.org/10.3168/jds.S0022-0302(99)75540-2

Johnson, L. M., J. H. Harrison, D. Davidson, J. L. Robutti, M. Swift, W. C. Mahanna, and K. Shinners. 2002. Corn Silage Management I: Effects of Hybrid, Maturity, and Mechanical Processing on Chemical and Physical Characteristics. J Dairy Sci 85(4):833-853. doi: https://doi.org/10.3168/jds.S0022-0302(02)74143-X

Jones, C., A. Heinrichs, G. Roth, and V. Ishler. 2004. From harvest to feed: understanding silage management. Pennsylvania State University. College of Agricultural Sciences:2-11.

Kleinschmit, D., and L. Kung Jr. 2006. The effects of Lactobacillus buchneri 40788 and Pediococcus pentosaceus R1094 on the fermentation of corn silage. J Dairy Sci 89(10):3999-4004.

Koc, F., L. Coskuntuna, M. L. Ozduven, A. Coskuntuna, and H. E. Samli. 2009. The effects of temperature on the silage microbiology and aerobic stability of corn and vetch-grain silages. Acta Agriculturae Scandinavica, Section A — Animal Science 59(4):239-246. doi: 10.1080/09064700903490596

Kononoff, P., A. Heinrichs, and H. Lehman. 2003. The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating dairy cows. J Dairy Sci 86(10):3343-3353.

Kung, L. 2011. Silage temperatures: how hot is too hot. URL https://cdn. canr. udel. edu/wp-content/uploads/2014/02/HowHotisTooHot-2011. pdf

Latham, M., J. Storry, and M. E. Sharpe. 1972. Effect of low-roughage diets on the microflora and lipid metabolism in the rumen. Applied Microbiology 24(6):871-877.

Loerch, S. C., and F. L. Fluharty. 1998. Effects of corn processing, dietary roughage level, and timing of roughage inclusion on performance of feedlot steers. J Anim Sci 76(3):681-685. doi: 10.2527/1998.763681x

Mader, T. L., J. M. Dahlquist, and L. D. Schmidt. 1991. Roughage sources in beef cattle finishing diets. J Anim Sci 69(2):462-471. doi: 10.2527/1991.692462x

Mahanna, B., B. Seglar, F. Owens, S. Dennis, and R. Newell. 2014. Silage zone manual. DuPont Pioneer Global.

McDonald, P., A. Henderson, and S. J. E. Heron. 1991. The biochemistry of silage. Chalcombe publications. Food and agriculture organization of the United Nations.

McGechan, M. B. 1990. A review of losses arising during conservation of grass forage: Part 2, storage losses. Journal of Agricultural Engineering Research 45:1-30. doi: https://doi.org/10.1016/S0021-8634(05)80135-0

Merry, R. J., and D. R. Davies. 1999. Propionibacteria and their role in the biological control of aerobic spoilage in silage. Le Lait 79(1):149-164.

Mertens, D. R. 1997. Creating a System for Meeting the Fiber Requirements of Dairy Cows. J Dairy Sci 80(7):1463-1481. doi: https://doi.org/10.3168/jds.S0022-0302(97)76075-2

Morrison, F. B. 1936. Feeds and feeding. A handbook for the student and stockman. Feeds and feeding. A handbook for the student and stockman. (Edn 20)

Muck, R., and B. J. Holmes. 2019. Muck & Holmes. 2000. Factors Affecting Bunker Silo Density. 2000 Applied Engineering in Agriculture p 613-619.

Muck, R. E., L. E. Moser, and R. E. Pitt. 2003. Postharvest Factors Affecting Ensiling. Pages 251-304 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

NASEM. 2016. Nutrient requirements of beef cattle. 8th rev. ed. Natl. Acad. Press, Washington, DC. doi:10.17226/19014.

Nocek, J. E., and A. L. Grant. 1987. Characterization of in situ nitrogen and fiber digestion and bacterial nitrogen contamination of hay crop forages preserved at different dry matter percentages. J Anim Sci 64(2):552-564. doi: 10.2527/jas1987.642552x

Ovinge, L. A., F. H. Hilscher, C. J. Bittner Bittner, B. M. Boyd, J. N. Anderson, and G. E. Erickson. 2018. Effects of Kernel Processing at Harvest of Brown Midrib Corn Silage on Finishing Performance of Steers. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p.89-91.

Pahlow, G., R. E. Muck, F. Driehuis, S. J. O. Elferink, and S. F. Spoelstra. 2003. Microbiology of ensiling. Pages 31-93 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Parsons, C. H., J. T. Vasconcelos, R. S. Swingle, P. J. Defoor, G. A. Nunnery, G. B. Salyer, and M. L. Galyean. 2007. Effects of wet corn gluten feed and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle. J Anim Sci 85(11):3079-3089. doi: 10.2527/jas.2007-0149

Pitt, R. E. 1990. Silage and Hay Preservation (NRAES 5). Northeast Regional Agricultural Engineering Service (NRAES). doi: https://hdl.handle.net/1813/69422

Pitt, R. E., and R. E. Muck. 1993. A Diffusion Model of Aerobic Deterioration at the Exposed Face of Bunker Silos. Journal of Agricultural Engineering Research 55(1):11-26. doi: https://doi.org/10.1006/jaer.1993.1029

Poore, M. H., J. A. Moore, and R. S. Swingle. 1990. Differential passage rates and digestion of neutral detergent fiber from grain and forages in 30, 60 and 90% concentrate diets fed to steers. J Anim Sci 68(9):2965-2973. doi: 10.2527/1990.6892965x

Preston, R. L. 1975. Net Energy Evaluation of Cattle Finishing Rations Containing Varying Proportions of Corn Grain and Corn Silage. Journal of Animal Science 41(2):622-624. doi: 10.2527/jas1975.412622x

Price, M., S. Jones, G. Mathison, and R. Berg. 1980. The effects of increasing dietary roughage level and slaughter weight on the feedlot performance and carcass characteristics of bulls and steers. Canadian J of Anim Sci 60(2):345-358.

Roberge, M., P. Savoie, and E. R. Norris. 1998. Evaluation of a Crop Processor In a Pull-Type Forage Harvester. Transactions of the ASAE 41(4):967-972. doi: https://doi.org/10.13031/2013.17254

Rojas-Bourrillon, A., J. R. Russell, A. Trenkle, and A. D. McGilliard. 1987. Effects of Rolling on the Composition and Utilization by Growing Steers of Whole-Plant Corn Silage. J Anim Sci 64(1):303-311. doi: 10.2527/jas1987.641303x

Rooke, J. A., and R. D. Hatfield. 2003. Biochemistry of Ensiling. Pages 95-139 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Rusche, W. C., J. A. Walker, and Z. K. Smith. 2020. Effect of inclusion rate of silage with or without alpha-amylase trait on finishing steer growth performance, carcass characteristics, and agronomic efficiency measures. Translational Animal Science 4(2):942-949. doi: 10.1093/tas/txaa056

Samuelson, K. L., M. E. Hubbert, M. L. Galyean, and C. A. Löest. 2016. Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech University survey. J Anim Sci 94(6):2648-2663. doi: 10.2527/jas.2016-0282

Santini, F., A. Hardie, N. Jorgensen, and M. Finner. 1983. Proposed use of adjusted intake based on forage particle length for calculation of roughage indexes. J Dairy Sci 66(4):811-820.

Savoie, P., and J. C. Jofriet. 2003. Silage Storage. Pages 405-467 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Saylor, B., E. Diepersloot, C. Heinzen Jr, C. McCary, and L. Ferraretto. 2021. Effect of kernel breakage on the fermentation profile, nitrogen fractions, and in vitro starch digestibility of whole-plant corn silage and ensiled corn grain. JDS Communications. doi: https://doi.org/10.3168/jdsc.2021-0093

Schmitz, R., K. Schnabel, D. von Soosten, U. Meyer, H. Spiekers, J. Rehage, and S. Dänicke. 2018. The effects of energy concentration in roughage and allowance of concentrates on performance, health and energy efficiency of pluriparous dairy cows during early lactation. Archives of Animal Nutrition 72(2):100-120.

Schukking, S. 1976. The history of silage making. Stikstof Dutch Nitrogen Fertilizer Review. doi: https://agris.fao.org/agris-search/search.do?recordID=NL19770134913

Shain, D., R. Stock, T. J. Klopfenstein, and D. Herold. 1999. The effect of forage source and particle size on finishing yearling steer performance and ruminal metabolism. J Animal Sci 77(5):1082-1092.

Smith, W., C. Lockard, C. Lockard, M. Homolka, K. Karr, B. Holland, A. Word, and J. Jennings. 2021. 251 Effects of Roughage Source on Rumination Time and Ruminal Ph in Steers Fed a Steam-flaked Corn Finishing Diet. J Anim Sci 99(Supplement_1):127-127. doi: 10.1093/jas/skab054.212

Smith, Z. K. 2021. Forages in the feedlot. doi: https://mnnutritionconf.umn.edu/sites/mnnutritionconf.umn.edu/files/2021-09/RN%204%20MAN%20Smith%20Final_Westway.pdf

Spoelstra, S. 1987. Degradation of nitrate by enterobacteria during silage fermentation of grass. Netherlands Journal of Agricultural Science 35(1):43-54.

Stock, R., M. Sindt, J. Parrott, and F. Goedeken. 1990a. Effects of grain type, roughage level and monensin level on finishing cattle performance. J Anim Sci 68(10):3441-3455.

Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990b. Effects of grain type, roughage level and monensin level on finishing cattle performance. J Anim Sci 68(10):3441-3455. doi: 10.2527/1990.68103441x

Sudweeks, E. M., L. O. Ely, D. R. Mertens, and L. R. Sisk. 1981. Assessing Minimum Amounts and Form of Roughages in Ruminant Diets: Roughage Value Index System. J Anim Sci 53(5):1406-1411. doi: 10.2527/jas1981.5351406x

Sun, L., N. Na, X. Li, Z. Li, C. Wang, X. Wu, Y. Xiao, G. Yin, S. Liu, Z. Liu, Y. Xue, and F. Yang. 2021. Impact of Packing Density on the Bacterial Community, Fermentation, and In Vitro Digestibility of Whole-Crop Barley Silage. Agriculture 11(7):672.

USDA. 2019. Crop Production Summary 2019. National Agricultural Statistics Service 12. doi: https://www.nass.usda.gov/Publications/Todays_Reports/reports/cropan20.pdf

Webster, J. 1992. The Biochemistry of Silage (Second Edition). By P. McDonald, A. R. Henderson and S. J. E. Heron. Marlow, Bucks, UK: Chalcombe Publications, (1991), pp. 340, £49.50, ISBN 0-948617-225. Experimental Agriculture 28(1):125-125. doi: 10.1017/S0014479700023115

Weiss, W. P., D. G. Chamberlain, and C. W. Hunt. 2003. Feeding silages. Pages 469-504 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Weiss, W. P., and D. J. Wyatt. 2000. Effect of oil content and kernel processing of corn silage on digestibility and milk production by dairy cows. J Dairy Sci 83(2):351-358. doi: 10.3168/jds.S0022-0302(00)74886-7

Wiersma, D., P. Carter, K. Albrecht, and J. Coors. 1993. Kernel milkline stage and corn forage yield, quality, and dry matter content. Journal of Production Agriculture 6(1):94-99.

Wilkinson, J. 1982. The Biochemistry of Silage. By P. McDonald. Chichester, England: John Wiley (1981), pp. 200,£ 16.00. Experimental Agriculture 18(3):329-329.

Wilkinson, J. M., K. K. Bolsen, and C. J. Lin. 2003. History of Silage. Pages 1-30 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Woolford, M. K. 1984. The silage fermentation. Marcel Dekker, Inc. 2014 Open Journal of Applied Sciences, Vol. 4 No. 5.

Zinn, R., and R. Ware. 2003. Understanding nutritive value: Alternative Forages. In: Proceedings California Alfalfa Symposium. p 1-11.

Zinn, R. A., A. Plascencia, and R. Barajas. 1994. Interaction of forage level and monensin in diets for feedlot cattle on growth performance and digestive function. J Anim Sci 72(9):2209-2215. doi: 10.2527/1994.7292209x

CHAPTER 2

IMPACT OF CORN SILAGE MATURITY AND KERNEL PROCESSING AT HARVEST ON FINISHING STEER GROWTH PERFORMANCE, EFFICIENCY OF DIETARY NET ENERGY UTILIZATION, AND CARCASS TRAITS.

ABSTRACT

Single sourced Red Angus influenced steers (n = 192; initial shrunk BW = 446 ± 28.3 kg) were used in a 112-d finishing experiment. Treatments were arranged in a 2 x 2 factorial (24 pens total; 8 steers/pen) to evaluate corn silage harvest time (1/2 to 2/3 milk line [ML] and black line [BL]) and kernel processing (KP; Yes [KP+] or No [KP-]) at harvest on finishing steer growth performance and carcass traits when silage is fed at a DM inclusion of 20%. Fresh feed was manufactured once daily for each treatment in a single batch using a mixer wagon and bunks were managed using a slick bunk management approach. Steers were blocked by batch fraction (n = 6) and pen served as the experimental unit. The model included the fixed effects of harvest time, processing, and their interaction. Block was included as a random factor. No harvest time x KP interaction was detected ($P \geq 0.16$) for any growth performance parameters. No harvest time × KP interaction was detected ($P \geq 0.26$) for any parameters related to the efficiency of dietary NE utilization. Comparative NEm for harvest time indicates that delayed harvest enhanced corn silage NEm by 6% and KP decreased apparent NEm value of corn silage by 9% compared to current feeding standards. No harvest time × KP interaction (*P*

≥ 0.08) was detected for any carcass traits except the distribution of USDA Prime carcasses ($P = 0.04$). Steers from ML/KP- had fewer ($P = 0.05$) USDA Prime carcasses compared to ML/KP+, BL/KP-, and BL/KP+. Harvest time ($P \geq 0.07$) and KP ($P \geq 0.07$) had no appreciable influence on any carcass trait parameters. These data indicate that corn silage harvest can be delayed without detriment to growth performance and kernel processing does not enhance the apparent feeding value of corn silage when corn silage is fed a at 20% diet DM in a feedlot finishing diet.

INTRODUCTION

Corn silage is a cornerstone feed ingredient in the Northern Plains and throughout the United States as it serves as a high energy forage source that can be used in growing and finishing cattle diets, cow and calf production, heifer development, and lactating dairy cow diets (Allen et al., 2003). Corn silage is typically harvested in early fall once whole plant moisture is near 65% which coincides with one half to two thirds milk line. Once harvested, corn silage is stored in variety of structures such as up-right silos, bunker silos, oxygen exclusion bags, pits, or piles in the absence of oxygen where it is allowed to ferment for a minimum of 3 weeks prior to feeding. A key advantage of using corn silage as a roughage source in finishing cattle diets is that is can be harvested in a single event annually compared to multiple harvests required to generate sufficient inventory for feeding as with other forage sources. Harvest time (HT) dictates total DM tonnage produced. Corn silage differs from other forage crops in that maximal yield and feeding quality occur around the same time. Accurately determining whole plant moisture content for an entire field can be challenging because of weather conditions and field variation. In addition, meteorological challenges and other workload demands at harvest can result in delayed harvest and greater DM content than deemed ideal (i.e. black layer). Harvesting corn silage at a greater DM content can lead to challenges in properly packing the harvested feed and consequently poorer aerobic stability.

The feeding value and quality of silage is largely influenced by DM content which varies with maturity of the corn crop. This has been demonstrated by Hunt et al. (1989a), where it was found that while DM and starch content increased linearly with maturity, concentrations of plant ADF and NDF decreased. Hunt et al. (1989b) also noted that whole plant in *situ* degradation decreased when going from early (60.3% moisture) to late maturity (56.4% moisture). Decreased digestibility as maturity progresses has particularly been identified in the stover (leaves, stalk, cob) portion of the plant as increased ADF and lignification result in decreased in *vitro* dry matter digestibility of stover as illustrated by Russell (1986). This relationship between plant maturity and total digestibility is often offset due to the increased proportion of grain in the silage (Johnson et al., 1999).

Kernel processing (KP) of corn silage is a mechanical processing method used to break the kernel and cob into pieces resulting in increased surface area for rumen microbes to act on the starch. Processing corn silage has been shown to reduce particle size by 15 to 30% (Roberge et al., 1998) and to decrease the number of intact kernels (Ebling and Kung, 2004). Potential for increased starch utilization and animal production is why KP has gained wide acceptance in the last 20 years, especially on dairy operations. Kernel processing effects on diet digestibility and growth performance have yielded inconsistent results in beef cattle. This may be a function of differing DM content of corn silage at harvest and inclusion levels of corn silage in the diet. As illustrated by Johnson et al. (2002) silage maturity plays a significant role in the effectiveness of KP, where black layer silage had less intact kernels than that harvested at one-third, or two-third milk line as a result of KP. Kernel processing has proven beneficial in growing cattle diets when fed at greater than 50% DM (Ovinge, 2019). However, no improvements in growth performance or gain efficiency from KP were noted in finishing cattle diets fed at 40% DM (Ovinge et al., 2018).

Limited research has investigated the interaction of whole corn crop plant moisture and KP in finishing diets. We hypothesize that kernel processing will have no influence on finishing steer growth performance regardless of moisture content at time of harvest when fed to finishing steers at 20% diet DM. The objective of this experiment is to investigate the impact of corn silage moisture content and kernel processing at harvest on growth performance, efficiency of dietary net energy utilization, and carcass traits in finishing steers when fed at 20% DM inclusion in diets containing modified distillers grains plus solubles (MDGS).

MATERIALS AND METHODS

Institutional Animal Care and Use Approval

This study was conducted at the Southeast Research Farm (SERF) in Beresford, SD, USA between September 2020 and February 2021. The animal care and handling procedures used in this study were approved by the South Dakota State University Animal Care and Use Committee (Approval Number: 2101-003E).

Treatments

This study used 6 replicate pens (24 total pens) of 8 steers per pen assigned to one of 4 dietary treatments (arranged as a 2 x 2 factorial). Main factors were HT (1/2 to 2/3 [ML]) or (black layer [BL]) with (KP+) or without (KP-) kernel processing.

Animals, Initial Processing, and Study Initiation

This study used 192 single source, Red Angus influenced steers (initial BW = 446 ± 28.3 kg) in a 112-d finishing experiment at SERF located near Beresford, SD. Steers were procured from a local South Dakota auction facility and received 2 weeks prior to study initiation. Steers were offered a common diet containing 60% concentrate upon arrival and steers were weighed and processed 3 d prior to study initiation. Initial processing included individual BW measurement (scale readability 0.91 kg), application of a unique identification ear tag, vaccination against viral respiratory pathogens (Bovi-Shield Gold 5, Zoetis, Parsippany, NJ) and clostridial species (Ultrabac/Somubac 7, Zoetis) and application of a 200 mg trenbolone acetate and 28 mg estradiol benzoate steroidal implant (Synovex-Plus, Zoetis). An implant retention check was conducted 31 d later, and any steers with missing implants were readministered their steroidal implant. On the day of experiment initiation, all steers were administered pour-on moxidectin (Cydectin, Bayer Animal Health, Shawnee Mission, KS) for control of internal and external parasites. The processing BW (d -3) was used for allotment purposes. Steers were blocked by location (n = 6) and allotted to their study pens on d 1.

Dietary Management

Fresh feed was manufactured once daily for each treatment in a single batch using a mixing feed wagon (5.2 m^3; scale readability 0.91 kg) and bunks were managed using a slick bunk management approach. Steers were transitioned to a 90% concentrate diet over a of 14-d period. Steers were consuming the finishing diet (Table 1) at the initiation of the experiment. Diets were fortified to provide vitamins and minerals to meet or exceed nutrient requirements (NASEM, 2016) and provided monensin sodium (Rumensin 90; Elanco, Indianapolis, IN) at 33.1 g/Mg (DM basis). Steers were fed ractopamine hydrochloride (Optaflexx 45, Elanco, Indianapolis, IN) at a rate of 300 mg/steer·d^{-1} for the final 28-d prior to harvest. Orts were collected, weighed and dried in a forced air oven at 100 °C for 24 h to determine DM content if carryover feed went out of condition, or was present on weigh days. If carryover feed was present on weigh days, the residual feed was removed prior to the collection of BW measurements. Dry matter intake (DMI) of each pen was adjusted to reflect the total DM delivered to each pen after subtracting dry orts for each interim period. Actual diet formulation and composition is based upon weekly DM analyses (drying at 60 °C until no weight change), actual nutrient values, and corresponding feed batching records. Diets presented in Table 1 are actual DM diet composition, actual nutrient concentrations, and tabular energy values (Preston, 2016).

Growth Performance Calculations

Steers were individually weighed on d -3, 1, 28, 56, 84, and 112. Cumulative growth performance was based upon initial BW (average BW from d -3 and 1 with a 4% shrink applied to account for digestive tract fill) and carcass-adjusted final BW (FBW; HCW/0.625). Average daily gain (ADG) was calculated as the difference between FBW and initial shrunk BW, divided by days on feed and feed efficiency was calculated from ADG/DMI. Efficiency of weight gain (G:F) was calculated by dividing the period ADG by the period daily DMI.

Carcass Trait Determination

Steers were harvested after 112-d on feed. Steers were shipped the afternoon following final BW determination and harvested the next day at Tyson Fresh Meats in Dakota City, NE. Steers were comingled at the time of shipping and remained this way until 0700 h the morning after shipping. Hot carcass weight (HCW) was captured immediately following the harvest procedure. Video image data were obtained from the packing plant for rib eye area (REA), rib fat (RF), and USDA marbling scores. A common kidney, pelvic, heart (KPH) fat percentage of 2.5% was applied to all calculations requiring a KPH%. Yield grade was calculated according to the USDA regression equation (USDA, 1997). Dressing percentage (DP) was calculated as HCW/(final BW × 0.96). Estimated empty body fat (EBF) percentage and final BW at 28% EBF (AFBW) were calculated from observed carcass traits (Guiroy et al., 2002), and proportion of closely trimmed boneless retail cuts from carcass round, loin, rib, and chuck (Retail Yield, RY; Murphey et al., 1960). Carcass data were available for all but four steers: ML/KP- (2), BL/KP- (1), BL/KP+ (1).

Dietary NE utilization Calculations

Observed dietary NE was calculated from daily energy gain (EG; Mcal/d): EG = $ADG^{1.097} \times 0.0557W^{0.75}$, where W is the mean equivalent BW [average initial shrunk BW and FBW × (478/AFBW), kg; (NRC, 1996)]. Maintenance energy required (EM; Mcal/d) was calculated by the following equation: EM = $0.077BW^{0.75}$ (Lofgreen and Garrett, 1968) where BW is the mean shrunk BW (average of initial shrunk BW and FBW). Using the estimates required for maintenance and gain the observed dietary NEm and NEg values (Owens and Hicks, 2019) of the diet were generated using the quadratic formula: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$, where x = NEm, Mcal/kg, a = -0.41EM, b = 0.877EM + 0.41DMI + EG, c = -0.877DMI, and NEg was determined from: 0.877NEm – 0.41 (Zinn and Shen, 1998; Zinn et al., 2008). The ratio of observed-to-expected NE ratio was determined from observed dietary NE for maintenance or gain/tabular NE for maintenance or gain.

Calculated Ingredient NE values

Based upon observed NE (determined through observed steer performance), the comparative NEm value for varying harvest time and kernel processing of corn silage were estimated using the replacement technique assuming that corn silage has a NEm value of 1.65 Mcal/kg. Using the replacement technique, the comparative NEm value was determined as follows: corn silage NEm, Mcal/kg = [(test diet NEm – control diet NEm)/0.20] + 1.65, where 0.20 represents the proportion of the replacement and 1.65 is the NEm value of corn silage (Mcal/kg). Ingredient NEg values can be derived from the following equation NEg (Mcal/kg) = 0.877NEm – 0.41 (Zinn, 1987).

Statistical Analysis

Growth performance, carcass traits, and efficiency of dietary NE utilization were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included the fixed effects of harvest time, kernel processing, and their interaction; block (location) was included as a random effect. Least squares means were generated using the LSMEANS statement of SAS and treatment effects were analyzed using the pairwise comparisons PDIFF and LINES option of SAS 9.4. Distribution of USDA Yield and Quality Grade data as well as carcass weight distributions were analyzed as binomial proportions in the GLIMMIX procedure of SAS 9.4 with fixed and random effects in the model as described previously. If a significant harvest time by processing interaction was detected ($P < 0.05$), simple treatment means were separated. An α of 0.05 or less determined significance and tendencies are discussed between 0.05 and 0.10.

RESULTS AND DISCUSSION

No HT × KP interactions were detected ($P \geq 0.16$) for any growth performance measures (Table 2), nor were there any HT x KP interactions detected for net energy efficiency measures ($P \geq 0.26$; Table 2). There also were no HT x KP interactions detected ($P \geq 0.12$) for carcass traits with exception of proportion of USDA Prime carcasses ($P = 0.04$; Table 4).

Feedlot Performance

Harvest Time

Neither final BW (*P* = 0.66) or ADG (*P* = 0.60) were affected by silage HT (Table 2). Dry matter intakes were similar between ML and BL (*P* = 0.23), consequently G:F was unaffected by HT (*P* = 0.93). The effect of harvest time has been shown to have minimal influence on DMI in finishing steers when corn silage is included in the diet at 15 or 45% of diet DM (Hilscher et al., 2019). Previous research studying effects of corn silage maturity in dairy cattle diets found HT had no impact on DMI; however, performance responses were noted when fed at inclusion levels of 33.5% (Bal et al., 1997). In that study, corn silage was harvested at early dent (30.1% DM), quarter milk line (32.4% DM), two-thirds milk line (35.1% DM), and black layer (42.0% DM). Milk production in that study was greatest for silage harvested at two-thirds milk line and least for cows fed the silage harvested at early dent stage. Delaying harvest to black layer maturity did not affect milk production (Bal et al., 1997); however, total tract digestibility of dry matter and starch were lowest for corn harvested at black layer stage of maturity which would agree with work done by Russell (1986). However, reduced starch digestibility of black layer corn silage was offset by greater starch concentration in the silage resulting in similar total starch intake compared to silage harvested at two-third milk line.

Kernel Processing

Final BW ($P = 0.14$) was unaffected by KP in the current experiment. Cumulative ADG was numerically decreased by 3.6% ($P = 0.12$) for KP+ steers while daily DMI was numerically reduced by KP+ ($P = 0.12$) by 1.3%. Ovinge et al. (2018) have reported decreases in DMI in finishing steers as a result of KP+ where DMI was reduced by 0.37 kg/d. The reduction of both ADG and DMI in our work when KP+ was applied could be a consequence of metabolic upset or irritation as a result of increased starch concentrations and utilization while on a relatively low roughage diet containing both DRC (~55% DM basis) and a processed high moisture corn kernel within the silage. These responses are consistent with the hepatic oxidation theory as described by Allen et al. (2009). This theory suggests that intake is controlled by signals from the liver to the brain triggered by high VFA concentrations as a result of starch digestion. Increased fermentability of the diet from processing grain has been shown in previous work to depress DMI (Zinn, 1993). This is particularly important when dealing with grains high in starch as propionate is a primary byproduct of starch fermentation (Allen, 2000) and has been identified as the primary driver of hepatic oxidation and may decrease meal size and frequency (Allen et al., 2009). Work by Ovinge et al. (2018) did not find any significant differences in rumen pH when kernel processed corn silage was fed at 40% diet DM. However, reducing the silage inclusion to 20% DM basis therefore decreasing dietary NDF could magnify the effect that KP has on rumen pH and stability in finishing steers. Additionally, growth efficiency was not impacted by KP+ ($P = 0.22$) in the current experiment. The responses we observed related to growth performance are similar to what was found by Rojas-Bourrillon et al. (1987) when KP was applied to corn silage fed at DM inclusion rates of 60, 65, and 90% to growing steers.

Contrary to the current experiment, KP has been reported to enhance animal performance in other dairy and beef studies, particularly when corn silage is included at greater inclusion of dietary DM. Reviewing this work, it would indicate that kernel processing is more likely to provoke a positive response in performance when fed at inclusions of > 38% diet DM as illustrated by Ovinge et al. (2018) in beef cattle and Cooke and Bernard (2005) in dairy cattle. In beef cattle, positive G:F responses were noted for steers fed KP+ silage and in dairy cattle milk yield, milk fat, and milk protein increased in response to KP. These responses in dairy cattle, could be influenced by the mature size of these high producing animals and their ability to consume greater quantities of feed. It has also been speculated that the importance of having more readily available starch as a result of KP is magnified when feeding dairy cattle that often spend less time masticating their feed and have increased rumen passage rate as a result of increased DMI (Owens et al., 2018).

These results are consistent with other research showing that kernel processing silage increases both starch and fiber digestion in corn silage (Johnson et al., 1999). Processing has also been shown to increase *in situ* rates of DM and starch disappearance in beef cattle (Andrae et al., 2001). Positive effects of KP on the feeding value of silage have also been noted during the silage fermentation process when kernel processing enhanced fermentation of the silage resulting in improved or maintained production of lactating dairy cattle (Ferraretto et al., 2018). The absence of a positive performance response to KP in our research could be a result of relatively low inclusion rates of processed silage (20% DM basis). In addition, Andrae et al. (2001) observed that increased starch digestibility of processed silage was offset by decreased NDF and ADF digestibility ($P < 0.01$). This is supported by work done by Kendall et al. (2009), where decreased NDF digestibility decreased both DMI and production in dairy cattle. Decreased NDF and ADF digestibility could have been a result of increased passage rate related to decreased particle size of the processed corn silage. Reducing particle size of forages has been shown to reduce total digestive tract retention time in dairy cattle (Yang et al., 2002). An increased passage rate could have resulted in minimal exposure to substrates and fibrolytic bacteria necessary for digestion to occur as explained by Andrae et al. (2001). However, reduced NDF and ADF digestibility because of KP are not likely to cause appreciable differences in finishing cattle performance when dietary DM inclusions are low (Andrae et al., 2001).

Efficiency of dietary NE utilization

Harvest Time

Observed dietary NE value for maintenance and gain were not influenced by harvest time ($P = 0.43$), neither were the ratios of observed-to-expected dietary NE for maintenance and gain ($P \geq 0.55$; Table 2). Comparative NE for harvest time indicates that delayed harvest enhanced corn silage NE by 6% (1.74 Mcal/kg NEm) in the current experiment. Delayed harvest likely enhanced NE because of increased grain in the silage (Table 5). A linear relationship between maturity, grain, and starch content was also illustrated by Hunt et al. (1989) and Johnson et al. (1999). Increased starch content, however, does not consistently translate to increased production or digestibility. Bal et al. (1997) found that although physical starch increased as silage matured from two-thirds milk line to black layer, total tract starch digestibility and digestible starch intake were decreased in dairy cattle with no differences in milk production resulting in decreased NE_l (net energy for lactation) for milk production.

Kernel Processing

Observed dietary NE value for maintenance and gain were not affected by KP (*P* ≥ 0.21; Table 2). The ratio of observed-to-expected dietary NE for maintenance and gain also were not influenced by KP (*P* ≥ 0.29). Previous work has illustrated that KP+ can increase the feeding value of silage by 6.5% when silage is fed 40% of diet DM to finishing beef steers (Ovinge et al., 2018). This could indicate that the effects of KP+ relative to NE and feeding values are dependent upon dietary inclusion levels. This difference could also be a result of the effect that KP+ has on particle size of the corn silage. Decreased particle size as a result of KP+ has been reported by Johnson et al. (2002) and could result in greater passage rate and decreased total digestibility of the silage. This was reported to have an effect on available TDN and NE_l in dairy cattle when KP- silage had elevated NE_L compared to cows fed KP+ silage (Johnson et al., 2002).

Carcass Traits

A HT × KP interaction (*P* = 0.04; Table 4) was detected for the distribution of USDA Prime carcasses. Steers from ML/KP- had the fewest (*P* = 0.05) USDA Prime carcasses compared to ML/KP+, BL/KP-, and BL/KP+ (Figure 1). The difference noted in USDA Prime carcass distribution could be correlated to the effect of KP as Browne et al. (2004) concurred with the results of the current experiment that silage maturity had no significant effect on carcass quality or marbling scores. Others have also reported no effect of KP on carcass characteristics or marbling scores (Ovinge et al., 2018).

Harvest Time

Harvest time did not influence ($P \geq 0.17$; Table 3) hot carcass weight, dressing percentage, 12th rib fat thickness, ribeye area, marbling, calculated YG, retail yield, or estimated EBF. However, delayed harvest time tended ($P = 0.07$) to reduce final BW at 28% EBF by 1.6%. Harvest time ($P \geq 0.18$) did not affect the distribution of USDA Yield Grades. Harvest time did not influence ($P \geq 0.14$) the distribution of USDA Select, Low Choice, or Prime carcasses. However, delayed harvest time tended to reduce USDA Average Choice carcasses ($P = 0.09$) and increase USDA High Choice carcasses ($P = 0.06$). Delayed harvest resulted in fewer carcasses less than 408 kg ($P = 0.01$) and a greater number of carcasses between 408 and 476 kg ($P = 0.02$); however, HT did not influence carcass weighing greater than 476 kg ($P = 0.42$). This agrees with previous work by Brennan et al. (1987) where adding corn grain to a silage based diet had no impacts on carcass characteristics. In the current experiment, we did not add grain into the diet directly, but increased grain and starch content of the silage was observed with delaying harvest to black layer. Despite the numerical tendencies noted for USDA Quality Grade distribution, HT did not affect marbling score in the current experiment.

Kernel Processing

Kernel processing had no effect on distribution of USDA Yield Grades or the distribution of USDA Quality Grades ($P \geq 0.14$, Table 4). Kernel Processing did not affect the proportion of carcasses weighing less than 408 kg, 408 to 476 kg or greater than 476 kg ($P \geq 0.28$). These results are similar to those observed by Ovinge et al. (2018), where no differences were observed in HCW, marbling score, or rib fat thickness when KP was applied to silage fed to finishing steers over a 104-d period. Increasing starch availability by KP likely has little impact on carcass traits as it has been demonstrated that feeding beef cattle high, medium, or low starch diets had no effect on carcass characteristics (Krehbiel et al., 2012). These results would indicate that increased grain and starch content have no significant impact on marbling score, or other carcass traits measured.

CONCLUSION

Harvest time and kernel processing of corn silage had minimal effects on animal growth performance and only moderately affect carcass traits in finishing steers when corn silage comprised 20% diet DM. Delayed harvest enhanced the comparative NE value of corn silage by 6% above current feed standards and kernel processing decreased comparative NE value of corn silage by 9% compared to current feeding standards. These data indicate that corn silage harvest can be delayed without detriment to growth performance and kernel processing does not enhance the apparent feeding value of corn silage when corn silage is fed at 20% diet DM in a feedlot finishing diet.

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LITERATURE CITED

Allen, M., B. Bradford, and M. Oba. 2009. Board-invited review: The hepatic oxidation theory of the control of feed intake and its application to ruminants. J Anim Sci 87(10):3317-3334.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J Dairy Sci 83(7):1598-1624. doi: 10.3168/jds.S0022-0302(00)75030-2

Allen, M. S., J. G. Coors, and G. W. Roth. 2003. Corn Silage. Pages 547-608 in Silage Science and Technology. Pages 547–608 in Silage Science and Technology. D.R Buxton, R. Muck, and J. Harrison, ed. ASA, CSSA, and SSSA, Madison, WI.

Andrae, J. G., C. W. Hunt, G. T. Pritchard, L. R. Kennington, J. H. Harrison, W. Kezar, and W. Mahanna. 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J Anim Sci 79(9):2268-2275. doi: 10.2527/2001.7992268x

Bal, M. A., J. G. Coors, and R. D. Shaver. 1997. Impact of the Maturity of Corn for Use as Silage in the Diets of Dairy Cows on Intake, Digestion, and Milk Production. J Dairy Sci 80(10):2497-2503. doi: https://doi.org/10.3168/jds.S0022-0302(97)76202-7

Brennan, R. W., M. P. Hoffman, F. C. Parrish, F. Epplin, S. Bhide, and E. O. Heady. 1987. Effects of Differing Ratios of Corn Silage and Corn Grain on Feedlot

Performance, Carcass Characteristics and Projected Economic Returns. J Anim Sci 64(1):23-31. doi: 10.2527/jas1987.64123x

Browne, E. M., D. T. Juniper, M. J. Bryant, D. E. Beever, and A. V. Fisher. 2004. Intake, live-weight gain and carcass characteristics of beef cattle given diets based on forage maize silage harvested at different stages of maturity. J Anim Sc 79(3):405-413. doi: 10.1017/S1357729800090275

Cooke, K. M., and J. K. Bernard. 2005. Effect of Length of Cut and Kernel Processing on Use of Corn Silage by Lactating Dairy Cows. J Dairy Sci 88(1):310-316. doi: https://doi.org/10.3168/jds.S0022-0302(05)72689-8

Ebling, T. L., and L. Kung, Jr. 2004. A comparison of processed conventional corn silage to unprocessed and processed brown midrib corn silage on intake, digestion, and milk production by dairy cows. J Dairy Sci 87(8):2519-2526. doi: 10.3168/jds.S0022-0302(04)73376-7

Ferraretto, L. F., R. D. Shaver, and B. D. Luck. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J Dairy Sci 101(5):3937-3951. doi: https://doi.org/10.3168/jds.2017-13728

Guiroy, P., L. Tedeschi, D. Fox, and J. Hutcheson. 2002. The effects of implant strategy on finished body weight of beef cattle. J Anim Sci 80(7):1791-1800.

Hilscher, F. H., D. B. Burken, C. J. Bittner, J. L. Gramkow, R. G. Bondurant, M. L. Jolly-Breithaupt, A. K. Watson, J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2019. Impact of corn silage moisture at harvest on performance of growing steers with supplemental rumen undegradable protein, finishing steer performance, and nutrient digestibility by lambs1. Translational Animal Science 3(2):761-774. doi: 10.1093/tas/txz011

Hunt, C. W., W. Kezar, and R. Vinande. 1989. Yield, Chemical Composition and Ruminal Fermentability of Corn Whole Plant, Ear, and Stover as Affected by Maturity. J of Prod Agr 2(4):357-361. doi: https://doi.org/10.2134/jpa1989.0357

Johnson, L., J. H. Harrison, C. Hunt, K. Shinners, C. G. Doggett, and D. Sapienza. 1999. Nutritive Value of Corn Silage as Affected by Maturity and Mechanical Processing: A Contemporary Review. J Dairy Sci 82(12):2813-2825. doi: https://doi.org/10.3168/jds.S0022-0302(99)75540-2

Johnson, L. M., J. H. Harrison, D. Davidson, J. L. Robutti, M. Swift, W. C. Mahanna, and K. Shinners. 2002. Corn Silage Management I: Effects of Hybrid, Maturity, and Mechanical Processing on Chemical and Physical Characteristics. J Dairy Sci 85(4):833-853. doi: https://doi.org/10.3168/jds.S0022-0302(02)74143-X

Kendall, C., C. Leonardi, P. C. Hoffman, and D. K. Combs. 2009. Intake and milk production of cows fed diets that differed in dietary neutral detergent fiber and neutral detergent fiber digestibility. J Dairy Sci 92(1):313-323. doi: https://doi.org/10.3168/jds.2008-1482

Krehbiel, C. R., P. A. Lancaster, E. D. Sharman, G. W. Horn, and D. L. VanOverbeke. 2012. Effects of Nutrition and Management during the Stocker Phase on Marbling Score and Quality Grade. In: 65th Reciprocal Meats Conference. p 1-7.

Lofgreen, G. P., and W. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J Anim Sci 27(3):793-806.

Murphey, C., D. Hallett, W. Tyler, and J. Pierce Jr. 1960. Estimating yields of retail cuts from beef carcasses. J Anim. Sci 19(Suppl 1):1240.

NASEM. 2016. Nutrient requirements of beef cattle. 8th rev. ed. Natl. Acad. Press, Washington, DC. doi:10.17226/19014.

Ovinge, L. A., F. H. Hilscher, C. J. Bittner Bittner, B. M. Boyd, J. N. Anderson, and G. E. Erickson. 2018. Effects of Kernel Processing at Harvest of Brown Midrib Corn Silage on Finishing Performance of Steers. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p.89-91.

Ovinge, L. A., M. L. Jolly-Breithaupt, H. C. Hamilton Hamilton, J. N. Anderson, and G. E. Erickson. 2019. Effects of Brown Midrib Corn Silage Hybrids with or without Kernel Processing at Harvest on Nutrient Metabolism in Beef Steers. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p 72-75.

Owens, F., A. DiCostanzo, and T. Johnson. 2018. Efficiency of various corn cropping and feeding systems. In: Proceedings of the 2018 Plains Nutrition Council Spring Conference, San Antonio, TX. Amarillo, TX: Texas AgriLife Res. and Ext. Ctr. p 38-82.

Owens, F. N., and R. B. Hicks. 2019. Can net energy values be determined from animal performance measurements? A review of factors affecting application of the California Net Energy System. Translational Animal Science 3(3):929-944.

Preston, R. 2016. 2016 feed composition table. Beef Magazine 2016 March p 16-34.

Roberge, M., P. Savoie, and E. R. Norris. 1998. Evaluation of a Crop Processor in a Pull-Type Forage Harvester. Transactions of the ASAE 41(4):967-972. doi: https://doi.org/10.13031/2013.17254

Rojas-Bourrillon, A., J. R. Russell, A. Trenkle, and A. D. McGilliard. 1987. Effects of Rolling on the Composition and Utilization by Growing Steers of Whole-Plant Corn Silage. J Anim Sci 64(1):303-311. doi: 10.2527/jas1987.641303x

Russell, J. R. 1986. Influence of harvest date on the nutritive value and ensiling characteristics of maize stover. Animal Feed Science and Technology Pages 11-27.

USDA. 1997. Official United States Standard for Grades of Beef Carcasses. Agric. Marketing, USDA Washington (DC).

Yang, W. Z., K. A. Beauchemin, and L. M. Rode. 2002. Effects of Particle Size of Alfalfa-Based Dairy Cow Diets on Site and Extent of Digestion1. J Dairy Sci 85(8):1958-1968. doi: https://doi.org/10.3168/jds.S0022-0302(02)74272-0

Zinn, R., A. Barreras, F. Owens, and A. Plascencia. 2008. Performance by feedlot steers and heifers: daily gain, mature body weight, dry matter intake, and dietary energetics. J Anim Sci 86(10):2680-2689.

Zinn, R., M. Monta o, and Y. Shen. 1997. Ruminal undigestible intake protein value and post ruminal digestibility of menhaden fish meal versus two high-bypass animal protein blends in an 88% concentrate finishing diet for feedlot cattle. In: Proceedings-American society of animal science western section. p 153-156.

Zinn, R., and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J Anim Sci 76(5):1280-1289.

Zinn, R. A. 1993. Influence of processing on the comparative feeding value of barley for feedlot cattle. J Anim Sci 71(1):3-10. doi: 10.2527/1993.7113

Table 1. Actual Diet Formulation and Composition.[1]

Item	1 to 7				8 to 56				57 to 84				85 to 112			
	ML		BL		ML		BL		ML		BL		ML		BL	
	KP-	KP+	KP-	KP+	KP-	KP+	KP-	KP+	KP-	KP+	KP-	KP+	KP-	KP+	KP-	KP+
DRC, %	54.9	53.7	53.5	53.9	55.7	55.3	55.3	55.7	55.5	55.3	56.4	55.8	54.6	54.5	55.1	55.1
LS[2], %	4.2	4.1	4.1	4.1	4.0	3.9	3.9	4.0	3.9	3.9	4.0	3.9	4.0	4.0	4.0	4.0
DDGS[3], %	20.9	20.4	20.4	20.5	4.9	4.9	4.9	4.9	--	--	--	--	--	--	--	--
RH[4], %	--	--	--	--	--	--	--	--	--	--	--	--	1.8	1.8	1.8	1.8
MDGS[5], %	--	--	--	--	15.6	15.5	15.5	15.6	20.5	20.5	20.9	20.7	19.9	19.9	20.1	20.1
Corn Silage, %	20.1	21.7	22.0	21.4	19.9	20.4	20.4	19.9	20.1	20.3	18.7	19.6	19.7	19.9	18.9	19.0
DM, %	70.07	71.55	74.99	74.47	67.23	68.26	71.44	70.25	65.64	66.70	68.38	67.96	64.45	65.39	67.64	66.52
CP, %	13.42	13.24	13.24	13.27	13.29	13.24	13.24	13.29	13.26	13.26	13.40	13.32	13.00	13.01	13.05	13.06
NDF, %	22.11	22.58	22.70	22.49	18.85	19.03	19.03	18.85	17.95	18.03	17.43	17.77	17.58	17.66	17.28	17.33
ADF, %	11.49	11.88	11.97	11.81	9.77	9.91	9.91	9.77	9.32	9.38	8.93	9.18	9.13	9.19	8.90	8.94
Ash, %	5.56	5.53	5.54	5.52	10.22	10.14	10.14	10.22	11.68	11.68	11.83	11.73	11.48	11.49	11.52	11.53
EE, %	3.65	3.63	3.63	3.63	3.55	3.55	3.55	3.55	3.52	3.52	3.53	3.53	3.45	3.45	3.45	3.45
Mcal/kg, NEg	2.05	2.04	2.04	2.04	2.05	2.05	2.05	2.05	2.05	2.05	2.06	2.05	2.05	2.05	2.06	2.06
Mcal/kg, NEm	1.39	1.38	1.38	1.38	1.39	1.39	1.39	1.39	1.39	1.40	1.39	1.39	1.39	1.39	1.40	1.40

[1]All values except DM on a DM basis. ML = silage harvested at ½ to 2/3 milk line, BL = silage harvested at black line, KP- = No kernel processing, and KP+ = kernel processing.

[2]LS, Liquid Supplement

[3]DDGS, Dried Distillers Grains Plus Solubles

[4]RH, Ractopamine hydrochloride

[5]MDGS, Modifies Distillers Grains Plus Solubles

Table 2. Cumulative Growth Performance Responses[1]

	Harvest Time		Kernel Processing			*P* - value		
Item	ML	BL	KP+	KP-	SEM[2]	HT	KP	Interaction
Initial body weight (BW)[3], kg	445	445	445	445	1.7	0.53	0.95	0.35
Final BW[4], kg	713	711	708	717	18.4	0.66	0.14	0.63
Average daily gain (ADG), kg	2.40	2.37	2.34	2.42	0.159	0.60	0.12	0.55
Dry matter intake (DMI), kg	14.34	14.15	14.15	14.34	0.447	0.23	0.22	0.28
ADG/DMI (G:F)	0.167	0.168	0.166	0.169	0.0039	0.93	0.21	0.16
F:G[5]	5.99	5.97	6.04	5.92	-	-	-	-
Observed dietary net energy (NE), Mcal/kg[6]								
Maintenance	2.08	2.10	2.08	2.11	0.036	0.43	0.21	0.26
Gain	1.41	1.43	1.41	1.44	0.031	0.43	0.21	0.26
Observed-to-expected NE[7]								
Maintenance	1.01	1.02	1.01	1.02	0.017	0.55	0.29	0.35
Gain	1.01	1.02	1.01	1.03	0.022	0.57	0.30	0.37

[1]HT = harvest time, ML = silage harvested at ½ to 2/3 milk line, BL = silage harvested at black line, KP- = No kernel processing, and KP+ = kernel processing.
[2]Pooled SEM
[3]Average of d -3 and d 1 BW; a 4% pencil shrink was applied to account for gastrointestinal tract fill.
[4]Final BW = HCW/0.625.
[5]F:G = 1/G:F
[6]Performance adjusted (Owens and Hicks, 2019)
[7]Observed dietary NE : Tabular NE

Table 3. Carcass Trait Responses.[1]

	Harvest Time		Kernel Processing			*P* - value		
Item	ML	BL	KP+	KP-	SEM[2]	HT	KP	Interaction
Hot carcass weight, kg	446	444	442	448	11.5	0.66	0.14	0.63
Dressing, %[3]	62.16	62.24	62.25	62.15	0.497	0.84	0.78	0.40
Rib fat, cm	1.56	1.62	1.56	1.62	0.031	0.22	0.25	0.43
Ribeye area, cm^2	95.45	95.48	96.00	94.94	0.22	0.99	0.30	0.18
Marbling score[4]	541	564	551	554	23	0.17	0.84	0.98
Calculated yield grade (YG)	3.53	3.58	3.47	3.63	0.125	0.55	0.08	0.28
Retail Yield[5], %	48.97	48.87	49.09	48.75	0.257	0.57	0.07	0.28
Estimated empty body fatness (EBF), %	32.5	32.98	32.48	33.00	0.53	0.21	0.18	0.48
Final BW at 28% EBF, kg	622	612	617	617	16.7	0.07	0.99	0.20

[1]HT = harvest time, ML = silage harvested at ½ to 2/3 milk line, BL = silage harvested at black line, KP- = No kernel processing, and KP+ = kernel processing.
[2]Pooled SEM
[3]HCW/final BW shrunk 3%
[4]USDA marbling score
[5]As a percent of HCW

Table 4. Carcass Trait Distributions.[1]

Item	Treatment				SEM	*P* - value		
	ML/KP-	ML/KP+	BL/KP-	BL/KP+		HT	KP	Interaction
<u>USDA YG distribution</u>								
YG 1, %	0.0	0.0	0.0	0.0	-	-	-	-
YG 2, %	25.0	22.9	16.7	27.1	6.15	0.74	0.51	0.32
YG 3, %	58.3	68.8	58.3	56.3	7.37	0.41	0.58	0.41
YG 4, %	16.7	8.3	22.9	16.7	5.21	0.18	0.18	0.84
YG 5, %	0.0	0.0	2.1	0.0	1.04	0.33	0.33	0.33
<u>USDA Quality Grade distribution</u>								
Select, %	2.1	0.0	0.0	4.5	1.76	0.51	0.51	0.08
Low Choice, %	26.2	41.1	29.8	23.5	6.47	0.29	0.51	0.12
Average Choice, %	48.2	35.7	28.0	33.9	6.27	0.09	0.61	0.16
High Choice, %	23.5	10.4	29.5	27.7	5.77	0.06	0.21	0.34
Prime, %	0.0^{b}	12.8^{a}	12.7^{a}	10.4^{a}	3.40	0.14	0.14	0.04
<u>HCW distribution, %</u>								
< 408 kg, %	14.6	20.8	6.3	8.3	3.78	0.01	0.28	0.59
408 to 476 kg, %	66.7	64.6	79.2	79.2	5.21	0.02	0.84	0.84
> 476 kg, %	18.7	14.6	14.5	12.5	3.81	0.42	0.42	0.79

[1]HT = harvest time, ML = silage harvested at ½ to 2/3 milk line, BL = silage harvested at black line, KP- = No kernel processing, and KP+ = kernel processing.

$^{a, b}$ Columns lacking a common superscript differ ($P \leq 0.05$).

Table 5. Silage Composition[1,2,3]

Item	ML	BL	SEM	*P* - value
Harvest Date	August 28, 2020	September 9, 2020	---	---
DM, %	43.1	49.2		
Yield AF, kg/ha	38,983	37,727	---	---
Yield DM, kg/ha	16,790	18,561	---	---
Grain Content, %	45.7	52.1	1.63	0.01
Starch, %	32.9	37.5	1.19	0.01
Crude Protein, %	6.5	6.6	---	---
NDF, %	46.0	49.8	---	---

[1]ML = silage harvested at 1/2 to 2/3 milk line, BL = silage harvested at black line
[2]All values are on a DM basis except for DM and Yield AF, kg/ha
[3]AF = feed as normally fed to animals prior to drying

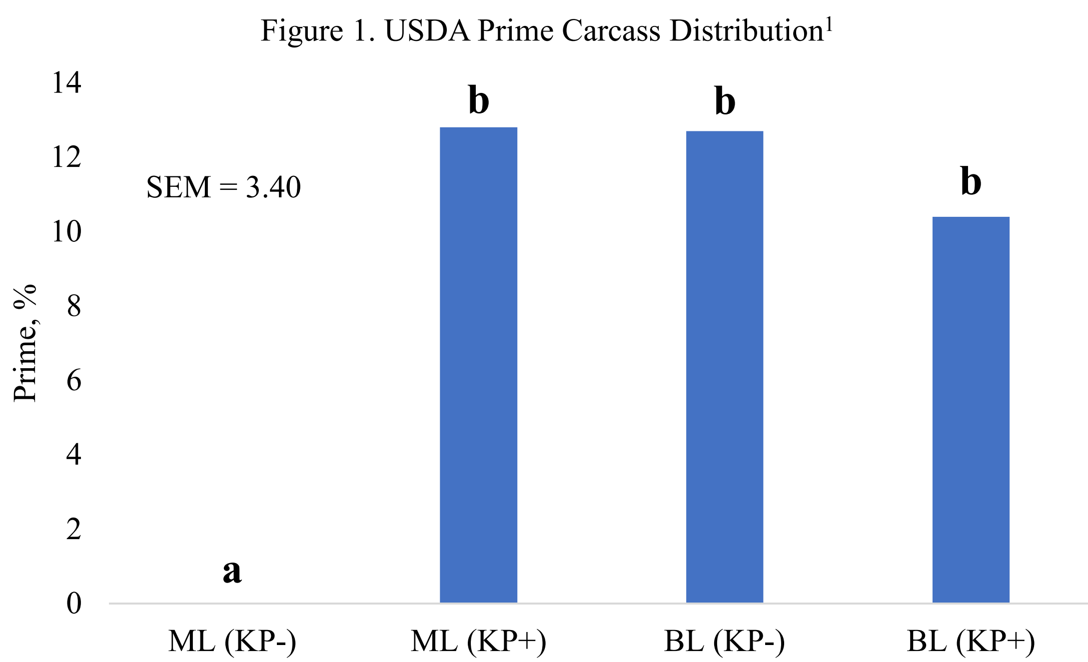


Figure 1. USDA Prime Carcass Distribution.
[a, b] Columns lacking a common superscript differ ($P \leq 0.05$).
[1]HT = harvest time, ML = silage harvested at ½ to 2/3 milk line, BL = silage harvested at black line, KP- = No kernel processing, and KP+ = kernel processing

CHAPTER 3

EVALUATION OF DIETARY ROUGHAGE INCLUSION IN A SINGLE OR TWO-DIET SYSTEM FOR BACKGROUDNING AND FINISHING STEERS.

ABSTRACT

The objective of this experiment was to determine the influence that equal cumulative roughage inclusion in a single or two-diet system during a 210-d growing-finishing period has on growth performance responses, efficiency of dietary net energy (NE) utilization, and carcass traits in beef steers. Pre-conditioned beef steers (n = 46; initial shrunk [4%] BW = 281 ± 40.4 kg) were fed once daily, and bunks were managed according to a slick bunk management system at the Ruminant Nutrition Center in Brookings, SD. Treatments included: 1) A single diet program (targeted a 1.30 Mcal/kg NEg diet fed for 210-d; 1D) or 2) Two diet program (targeted a 1.21 Mcal/kg NEg diet fed for 98-d, a 1.30 Mcal/kg NEg diet fed for 14-d, and a 1.39 Mcal/kg NEg diet fed for 98-d; 2D). All steers were implanted on d 1 with a 100 mg trenbolone acetate (TBA) and 14 mg estradiol benzoate (EB) implant and re-implanted with a 200 mg TBA and 28 mg EB implant on d 112. Average daily gain tended (P = 0.06) to be 9.5% greater for 1D compared to 2D during the backgrounding portion and ADG was increased 11.3% (P = 0.01) for 2D compared to 1D during the finishing phase of the experiment. Cumulative ADG did not differ between treatments (1.61 vs. 1.62 ± 0.046 kg) for 1D and 2D, respectively. Cumulative observed dietary NEm and NEg did not differ ($P \geq 0.96$)

between treatments. There were no differences ($P \geq 0.18$) detected between treatments for HCW, DP, REA, RF, USDA marbling score, KPH, yield grade, retail yield, EBF, or body weight at 28% estimated EBF. Northern Plains feedlot producers can feed a single growing-finishing diet to preconditioned beef steers with minimal effects on overall growth performance or carcass traits. Feeding a single diet during both the growing and finishing phases could be used as a strategy to simplify management by reducing number of diets fed, or as a way to utilize ensiled roughage more rapidly to reduce feedout losses during summer months.

INTRODUCTION

Cattle feeders in the Northern Plains routinely feed pre-conditioned feeder cattle two distinct diets with one (primarily forage based) fed during the backgrounding phase and a second diet fed during the finishing phase (primarily concentrate based). Backgrounding cattle is often done to market a low-cash value feed resource through cattle to prepare them for the finishing phase of production. Overall goals of backgrounding programs include: 1) managing disease and health, 2) achieving economical gains, 3) enhancing finishing phase feed conversion, 4) achieving maximal total carcass weight gain, and 5) managing feeder cattle supply into the feedlot phase or production.

Roughages can be defined as feeds high in fiber and therefore low in total digestible nutrients (Morrison, 1936). Feeds such as hay, straw, fodder, pasture, and silage would fall into the roughage classification. Adequate amounts of roughage are necessary in ruminant diets to ensure rumen health, promote microbial protein synthesis, and support milk fat production in dairy cattle; however, roughages are generally limited in finishing cattle diets because of cost per unit of energy. Smith (2021) explained that purchased forage is considerably more expensive per unit of energy when compared to cereal grains often resulting in removal of forages from the diet when the diet is formulated on a least-cost formulation basis. Because of this forage is often forced into the diet as a “functional” ingredient depending on management capabilities of the operation (Zinn and Ware, 2003).

Roughage source has been found to have an effect in finishing cattle performance as explained by Mader et al. (1991). The ideal roughage source in a finishing diet may depend on energy source of the diet. Roughages such as silages that are high in moisture were shown to complement high moisture corn while hay or dry roughage complements dry corn. The feeding value of roughages in feedlot diets depends on the nutrient content of the roughage, characteristics of the fiber, palatability, and potential associative effects it may have on other ingredients in the diet (Zinn and Ware, 2003).

Impacts of roughage type and inclusion level on beef cattle performance, behavior, and ruminal characteristics have been thoroughly investigated. The objective of this experiment was to determine the influence of equal cumulative roughage inclusion in a single or two-diet system during a 210-d backgrounding - finishing period in pre-conditioned beef steers on growth performance responses, efficiency of dietary net energy (NE) utilization, and carcass traits.

MATERIAL AND METHODS

Institutional Animal Care and Use Approval

This study was conducted at the Ruminant Nutrition Center (RNC) in Brookings, SD, USA. The animal care and handling procedures used in this study were approved by the South Dakota State University Animal Care and Use Committee (Approval Number: 2012-056E).

Treatments

This study used 5 replicate 7.6 x 7.6-m concrete pens (10 total pens) with 4 or 5 steers assigned to one of two dietary treatments. The targeted cumulative roughage inclusion for both treatments was 16% for the 210-d background-finish period. Treatments included: 1) Single Diet (1D), one diet throughout the feeding period, (16% Roughage) 1.34 Mcal/kg NEg 210-d, 2) Two Diet (2D), initial growing diet, (25% Roughage) 1.25 Mcal/kg NEg for 98-d, transition diet, (16% Roughage) 1.34 Mcal/kg NEg for 14-d, finishing diet, (7% Roughage) 1.43 Mcal/kg NEg for 98-d.

Animals, Initial Processing, and Study Initiation

This study used 46 single source, crossbred beef steers (initial BW = 281 ± 40.4 kg) in the 210-d background-finish experiment at the RNC in Brookings, SD. Steers were procured from a ranch in central South Dakota and were allotted by initial body weight prior to the initiation of the experiment. All steers were implanted initially (d 1) with a 100 mg trenbolone acetate (TBA) and 14 mg estradiol benzoate (EB) implant (Synovex Choice, Zoetis, NJ) and re-implanted with a 200 mg TBA and 28 mg EB implant (Synovex-Plus, Zoetis, NJ) on d 112.

Dietary Management

Fresh feed was manufactured twice daily in a stationary mixer (2.35 m^3; readability 0.454 kg) and bunks were managed using a slick bunk management approach. A combination of oat hay and corn silage (d 1 to 77) and sorghum silage (d 78 to 210) were used as the primary roughage sources. Diets were fortified to provide vitamins and minerals to meet or exceed nutrient requirements (NASEM, 2016) and provided monensin sodium (Rumensin 90; Elanco, Indianapolis, IN) at 30 g/Mg (DM basis). Steers were fed ractopamine hydrochloride (Optaflexx 45, Elanco, Indianapolis, IN) at a rate of 300 mg/steer·d^{-1} for the final 28 d prior to harvest. Orts were collected, weighed and dried in a forced air oven at 100°C for 24 h in order to determine DM content if carryover feed spoiled, or was present on weigh days. If carryover feed was present on weigh days, the residual feed was removed prior to the collection of BW measurements. The DMI of each pen was adjusted to reflect the total DM delivered to each pen after subtracting the quantity of dry orts for each interim period. Weekly ingredient samples were stored in a freezer at -20° C until nutrient analyses were completed. After weekly DM determination (method no. 935.29), weekly samples from each ingredient were composited by month and analyzed for N (method no. 968.06; Rapid Max N Exceed; Elementar; Mt. Laurel, NJ), and ash (method no. 942.05) content (AOAC, 2012, 2016). Dried distillers grains plus solubles samples were analyzed for ether extract content using an Ankom Fat Extractor (XT10; Ankom Technology, Macedon, NY). Percentages of ADF and NDF were assumed to be 3 and 9 percent for corn (Preston, 2016). Diets presented in Table 6 are actual DM diet composition, actual nutrient concentrations, and tabular energy values (Preston, 2016).

Growth Performance Calculations

All steers were weighed individually on d -1, 1, 35, 70, 98, 112, 140, 168, 182, and 210, growth performance data is based upon live weight reduced 4% to account for digestive tract fill. Cumulative growth performance was based upon initial BW (average BW of d -1 and 1 with a 4% shrink applied to account for digestive tract fill) and FBW (shrunk 4%). Average daily gain (ADG) was calculated as the difference between FBW and initial shrunk BW, divided by days on feed; feed efficiency (G:F) was calculated from ADG/DMI.

Carcass Trait Determination

Steers were harvested after 210-d on feed; steers were shipped the afternoon following final BW determination and harvested the next day at Tyson Fresh Meats in Dakota City, NE. Steers were comingled at the time of shipping and remained this way until 0700 h the morning after shipping. Liver abscess prevalence and severity was determined following evisceration according to the Elanco Scoring System as: Normal (no abscesses), A- (1 or 2 small abscesses or abscess scars), A (2 to 4 well organized small abscesses), or A+ (1 or more large active abscesses with inflammation of surrounding tissue). Hot carcass weight (HCW) was captured immediately following the harvest procedure. Video image data were obtained from the packing plant for rib eye area, rib fat, and USDA marbling scores. A common kidney, pelvic, heart (KPH) fat percentage of 2.5% was applied to all calculations requiring a KPH%. Yield grade was calculated according to the USDA regression equation (USDA, 1997). Dressing percentage was calculated as HCW/(final BW × 0.96). Estimated empty body fat (EBF) percentage and final BW at 28% EBF (AFBW) were calculated from observed carcass traits (Guiroy et al., 2002), and proportion of closely trimmed boneless retail cuts from carcass round, loin, rib, and chuck (Retail Yield, RY; Murphey et al., 1960).

Dietary NE utilization Calculations

Observed dietary NE was calculated from daily energy gain (EG; Mcal/d): EG = $ADG^{1.097} \times 0.0557W^{0.75}$, where W is the mean equivalent BW [average initial shrunk BW and FBW × (478/AFBW), kg; (NRC, 1996)]. Maintenance energy required (EM; Mcal/d) was calculated by the following equation: EM = $0.077BW^{0.75}$ (Lofgreen and Garrett, 1968) where BW is the mean shrunk BW (average of initial shrunk BW and FBW). Using the estimates required for maintenance and gain the observed dietary NEm and NEg values (Owens and Hicks, 2019) of the diet were generated using the quadratic formula: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$, where x = NEm, Mcal/kg, a = -0.41EM, b = 0.877EM + 0.41DMI + EG, c = -0.877DMI, and NEg was determined from: 0.877NEm – 0.41 (Zinn and Shen, 1998; Zinn et al., 2008). The ratio of observed-to-expected NE ratio was determined from observed dietary NE for maintenance or gain/tabular NE for maintenance or gain.

Statistical Analysis

Growth performance, carcass traits, and efficiency of dietary NE utilization were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included the fixed effect of dietary treatment; block (weight grouping) was included as a random variable. Least squares means were generated using the LSMEANS statement of SAS and treatment effects were analyzed using the pairwise comparisons PDIFF and LINES option of SAS 9.4. Distribution of USDA Yield and Quality grade data as well as liver abscess prevalence and severity were analyzed as binomial proportions in the GLIMMIX procedure of SAS 9.4 with fixed and random effects in the model as described previously. An α of 0.05 or less determined significance and tendencies are discussed between 0.05 and 0.10.

RESULTS AND DISCUSSION

Growth Performance

Backgrounding (initial to d 112), finishing (d 113 to 210), and cumulative (initial to d 210) growth performance responses are presented in Table 8. Steers from 1D tended to be 3.6% (P = 0.06) heavier than steers from 2D at the conclusion of the backgrounding phase. Average daily gain tended (P = 0.06) to be 9.5% greater for 1D compared to 2D during this phase with no differences in DMI (P =0.91) resulting in steers from 1D having improved (P = 0.05) G:F by 9.4% compared to 2D (0.174 and 0.159, respectively). During the finishing phase, ADG was increased (P = 0.01) for 2D steers compared to 1D by 11.3%. Finishing phase DMI did not differ between treatments (*P* = 0.97) hence, steers from 2D had improved feed conversion by 11.4% (*P* = 0.01).

The growth performance responses observed during both the backgrounding and finishing phases aligns with previous research that demonstrates increased ADG and feed conversion when roughage is limited in the diet (Zinn et al., 1994; Gentry et al., 2016; Rusche et al., 2020). However, decreasing roughage in the diet could only improve performance to a certain extent as roughage serves as a "functional" ingredient that promotes ruminal health and microbial protein synthesis (Smith, 2021). It has been demonstrated that the benefit of roughage in high energy diets on growth performance and ruminal health will be greatest when dietary peNDF is between 7 and 15% (Mertens, 1997; Fox and Tedeschi, 2002). These recommendations derived from equations developed by Pitt et al. (1996) that calculated roughage needed to maintain a rumen pH greater than 5.7; the minimum pH before feed intake is significantly impacted and microbial protein production is depressed (Britton et al., 1989; Pitt et al., 1996). In lower energy diets, it is recommended that the diet contains at least 20% DM peNDF in effort to maximizing cell wall digestibility and forage utilization (Fox and Tedeschi, 2002).

During the backgrounding phase, the steers from 1D had greater growth performance and were closest to these recommendations as they were fed a 16% roughage diet during this period compared to the 2D at 25%. Increasing dietary roughage inclusion in the current study diluted net energy available for gain, since the silage and hay used as roughage had less (Mcal/kg) than the grain source used to replace it. Owens et al. (2018) found similar results while investigating the efficiency of various corn cropping and feeding systems as it relates to roughage inclusion level.

The benefit of adequate roughage in the diet has been illustrated in previous work where a linear increase in DMI and ADG was observed when alfalfa hay was used as the primary roughage source and increased in the diet from 0, 4.5, and 9% of the dietary dry matter (Parsons et al., 2007). Within the current study, the DMI observed coincide with findings reported previously in which varying roughage inclusion levels did not influence intake (Zinn et al., 1994; Rusche et al., 2020). Although greater dietary NDF concentrations have been shown to increase DMI in cattle (Stock et al., 1990; Shain et al., 1999; Benton et al., 2015), the variation in NDF between our treatments did not appear to be sufficiently large enough to induce a response in DMI in either the backgrounding or finishing phases of the study.

Final BW at the conclusion of the finishing period were similar ($P \geq 0.87$) between treatments and cumulative ADG did not differ between 1D and 2D ($P = 0.87$; 1.61 and 1.62, respectively). Neither cumulative DMI ($P = 0.93$) or G:F differed between treatments ($P = 0.76$; 0.161 and 0.162, respectively). Differences between treatments observed in the backgrounding and finishing phase were not apparent when evaluating growth performance measures for the entire experiment (Figure 2). These findings may differ from previous results that have investigated a fixed roughage inclusion level over equal days on feed as this study fed equal cumulative dietary roughage, NEm, and NEg (Table 7; 1D: 16.7% roughage, 1.34 Mcal/kg NEg; 2D: 16.5% roughage, 1.34 Mcal/kg NEg) over the 210-d period.

Efficiency of dietary NE utilization

Energetics measures (dietary NEm and NEg from observed growth performance, and ratio of observed-to-expected dietary NEm and NEg) are presented in Table 8.

During the backgrounding phase, steers from 1D had greater ($P \leq 0.01$) observed dietary NEm and NEg compared to steers from 2D by 6.9% and 9.4%, respectively. The ratio of observed-to-expected dietary NEm tended ($P = 0.09$) to be 3.4% greater for steers from 1D compared to 2D during the backgrounding phase. During the finishing phase, steers from 2D tended ($P \leq 0.09$) to have greater observed dietary NEm and NEg compared to steers from 1D (5.1% and 6.6%, respectively). Thus, cumulative observed dietary NEm and NEg did not differ ($P \geq 0.96$) between treatments. Cumulative observed dietary NEm and NEg did not differ ($P \geq 0.96$) between treatments and no other appreciable responses ($P \geq 0.14$) were noted between treatments for any other applied energetics measures.

During both phases, the treatment consuming less roughage at the given time had or tended to have greater energetic efficiency. Similar to what was observed in growth performance responses, this could be expected as a lower energy roughage source is replaced with a high energy grain source as dietary roughage is limited (Owens et al., 2018). This could also be explained by findings from Hales et al. (2014) that illustrated a decrease in digestible and retained energy as roughage level increased in the diet. Fecal energy loss, methane, and heat production were also shown to increase with elevated roughage inclusion (Hales et al., 2014). Roughage inclusions effect on fecal organic matter output has been thoroughly investigated with similar results indicating that increased roughage levels depress organic matter digestibility in the rumen (Crawford et al., 2008; Zinn et al., 2008).

However, a similarly designed research project reported that dairy cows fed a diet with increased roughage inclusion had increased energy efficiency contradicting the work previously mentioned (Schmitz et al., 2018). This contradicting evidence was explained as a result of decreased fiber digestion as the rumen microbial population transitioned to an amylolytic population (Fernando et al., 2010) and increased passage rate as a result of lower dietary peNDF (Poore et al., 1990). Thus, limiting roughage in the diet can improve efficiency of dietary net energy utilization as long as adequate peNDF is provided to limit passage rate and maintain a stable rumen microbial population. With cumulative roughage being fed over the 210-d period we were not surprised to see the differences observed in both the backgrounding and finishing phases dissipate when energy efficiency is looked at on a cumulative basis.

Carcass Traits

Carcass trait responses are located in Table 9. There were no differences ($P \geq 0.18$) detected between treatments for HCW, DP, REA, RF, USDA marbling score, KPH, yield grade, retail yield, EBF, or AFBW. The distribution of USDA Yield Grades were not influenced ($P \geq 0.18$) by treatment. The distribution of USDA Select, Low Choice, Average Choice, and Prime was not influenced ($P \geq 0.37$) by dietary treatment, however, steers from 2D treatment tended ($P = 0.09$) to have an increase in the proportion of carcasses that qualified for USDA High Choice compared to 1D. No differences ($P \geq 0.14$) were noted between dietary treatments for liver abscess prevalence or severity.

The similarity observed in the current experiment align with previous work where carcass characteristics and final BW were not influenced by corn silage and subsequent roughage inclusion level (Kreikemeier et al., 1990; Burken et al., 2014). Similar dressing percentage as a result of varying roughage inclusion has also been demonstrated by Gill et al. (1976). Reduced FBW, HCW, and YG have been noted in previous work investigating roughage inclusion in finishing cattle diets when dietary roughage was increased (Burken et al., 2017; Hilscher et al., 2019), however, these trends were not noted in the current experiment. Gill et al. (1976) also noted that marbling scores were similar for cattle fed either 7 or 15% roughage; however, decreased when cattle were fed a 37.5% roughage diet with corn silage as the primary roughage source. Differences have been previously observed in carcass characteristics when cattle are fed different roughage levels with equal days on feed. Feeding a cumulative roughage and only varying timing of roughage inclusion within the feeding period could have prevented significant differences from arising in the current experiment. The authors believe the tendency for 2D to have an increase in the proportion of USDA High Choice carcasses to have little biological significance and was not necessarily a result of feeding management strategy as marbling scores were similar between treatments.

CONCLUSION

Northern Plains feedlot producers can feed a single growing-finishing diet to preconditioned beef steers with minimal effects on overall growth performance or carcass traits. Observed responses for growth performance were as anticipated for varying levels of roughage fed during backgrounding vs. finishing production phases. Feeding a single diet during both the backgrounding and finishing phases could be used as a strategy to simplify management by reducing number of diets fed, or as a way to utilize ensiled roughage more rapidly to reduce feedout losses during summer months.

LITERATURE CITED

Benton, J. R., A. K. Watson, G. E. Erickson, T. J. Klopfenstein, K. J. Pol, N. F. Meyer, and M. A. Greenquist. 2015. Effects of roughage source and inclusion in beef finishing diets containing corn wet distillers' grains plus solubles. J Anim Sci 93(9):4358-4367. doi: 10.2527/jas.2015-9211

Britton, R., R. Stock, and U. Cornell. 1989. Acidosis: A continual problem in cattle fed high grain diets. In: Proceedings of Cornell Nutrition Conference for Feed Manufactures. Ithaca (NY): Cornell University. p 8.

Burken, D., B. Nuttelman, J. Gramkow, A. McGee, K. Sudbeck, S. Gardine, T. Hoegemeyer, T. Klopfenstein, and G. Erickson. 2017. Effects of agronomic factors on yield and quality of whole corn plants and the impact of feeding high concentrations of corn silage in diets containing distillers grains to finishing cattle. Translational Animal Science 1(3):367-381.

Burken, D., B. Nuttelman, T. Klopfenstein, and G. Erickson. 2014. Feeding Elevated Levels of Corn Silage and MDGS in Finishing Diets. Neb. Beef Rep. Univ. Nebraska Lincoln, NE. p. 66-67.

Crawford, G. I., C. D. Keeler, J. J. Wagner, C. R. Krehbiel, G. E. Erickson, M. B. Crombie, and G. A. Nunnery. 2008. Effects of calcium magnesium carbonate and roughage level on feedlot performance, ruminal metabolism, and site and extent of digestion in steers fed high-grain diets. J Anim Sci 86(11):2998-3013. doi: 10.2527/jas.2007-0070

Fernando, S. C., H. Purvis, F. Najar, L. Sukharnikov, C. Krehbiel, T. Nagaraja, B. Roe, and U. Desilva. 2010. Rumen microbial population dynamics during adaptation to a high-grain diet. Applied and Environmental Microbiology 76(22):7482-7490.

Fox, D., and L. Tedeschi. 2002. Application of physically effective fiber in diets for feedlot cattle. In: Proceedings of the Plains Nutrition Conference, San Antonio, TX. p 67.

Gentry, W. W., C. P. Weiss, C. M. Meredith, F. T. McCollum, N. A. Cole, and J. S. Jennings. 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. J Anim Sci 94(11):4759-4770. doi: 10.2527/jas.2016-0734

Gill, D. R., J. R. Martin, and R. Lake. 1976. High, medium and low corn silage diets with and without monensin for feedlot steers. J Anim Sci 43(2):363-368.

Guiroy, P., L. Tedeschi, D. Fox, and J. Hutcheson. 2002. The effects of implant strategy on finished body weight of beef cattle. J Anim Sci 80(7):1791-1800.

Hales, K., T. Brown-Brandl, and H. Freetly. 2014. Effects of decreased dietary roughage concentration on energy metabolism and nutrient balance in finishing beef cattle. J Anim Sci 92(1):264-271.

Hilscher, F. H., D. B. Burken, C. J. Bittner, J. L. Gramkow, R. G. Bondurant, M. L. Jolly-Breithaupt, A. K. Watson, J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2019. Impact of corn silage moisture at harvest on performance of growing steers with supplemental rumen undegradable protein, finishing steer performance, and nutrient digestibility by lambs. Translational Animal Science 3(2):761-774. doi: 10.1093/tas/txz011

Kreikemeier, K., D. Harmon, R. Brandt Jr, T. Nagaraja, and R. Cochran. 1990. Steam-rolled wheat diets for finishing cattle: Effects of dietary roughage and feed intake on finishing steer performance and ruminal metabolism. J Anim Sci 68(7):2130-2141.

Lofgreen, G. P., and W. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J Anim Sci 27(3):793-806.

Mader, T. L., J. M. Dahlquist, and L. D. Schmidt. 1991. Roughage sources in beef cattle finishing diets. J Anim Sci 69(2):462-471. doi: 10.2527/1991.692462x

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J Dairy Sci 80(7):1463-1481. doi: https://doi.org/10.3168/jds.S0022-0302(97)76075-2

Morrison, F. B. 1936. Feeds and feeding. A handbook for the student and stockman. Feeds and feeding. A handbook for the student and stockman. Morrison Publishing Co.

Murphey, C., D. Hallett, W. Tyler, and J. Pierce Jr. 1960. Estimating yields of retail cuts from beef carcasses. J Anim. Sci 19(Suppl 1):1240.

NASEM. 2016. Nutrient requirements of beef cattle. 8th rev. ed. Natl. Acad. Press, Washington, DC. doi:10.17226/19014.

NRC. 1996. Nutrient Requirements of Beef Cattle. Nat. Acad. Press, Washington, DC. 7th ed.

Owens, F., A. DiCostanzo, and T. Johnson. 2018. Efficiency of various corn cropping and feeding systems. In: Proceedings of the 2018 Plains Nutrition Council Spring

Conference, San Antonio, TX. Amarillo, TX: Texas AgriLife Res. and Ext. Ctr. p 38-82.

Owens, F. N., and R. B. Hicks. 2019. Can net energy values be determined from animal performance measurements? A review of factors affecting application of the California Net Energy System. Translational Animal Science 3(3):929-944.

Parsons, C. H., J. T. Vasconcelos, R. S. Swingle, P. J. Defoor, G. A. Nunnery, G. B. Salyer, and M. L. Galyean. 2007. Effects of wet corn gluten feed and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle. J Anim Sci 85(11):3079-3089. doi: 10.2527/jas.2007-0149

Pitt, R., J. Van Kessel, D. Fox, A. Pell, M. Barry, and P. Van Soest. 1996. Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. J Anim Sci 74(1):226-244.

Poore, M. H., J. A. Moore, and R. S. Swingle. 1990. Differential passage rates and digestion of neutral detergent fiber from grain and forages in 30, 60 and 90% concentrate diets fed to steers. J Anim Sci 68(9):2965-2973. doi: 10.2527/1990.6892965x

Preston, R. 2016. 2016 feed composition table. Beef Magazine 2016 March p 16-34.

Rusche, W. C., J. A. Walker, and Z. K. Smith. 2020. Effect of inclusion rate of silage with or without alpha-amylase trait on finishing steer growth performance, carcass characteristics, and agronomic efficiency measures. Translational Animal Science 4(2):942-949. doi: 10.1093/tas/txaa056

Schmitz, R., K. Schnabel, D. von Soosten, U. Meyer, H. Spiekers, J. Rehage, and S. Dänicke. 2018. The effects of energy concentration in roughage and allowance of concentrates on performance, health and energy efficiency of pluriparous dairy cows during early lactation. Archives of Animal Nutrition 72(2):100-120.

Shain, D., R. Stock, T. J. Klopfenstein, and D. Herold. 1999. The effect of forage source and particle size on finishing yearling steer performance and ruminal metabolism. J Anim Sci 77(5):1082-1092.

Smith, Z. K. 2021. Forages in the feedlot. doi: https://mnnutritionconf.umn.edu/sites/mnnutritionconf.umn.edu/files/2021-09/RN%204%20MAN%20Smith%20Final_Westway.pdf

Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance. J Anim Sci 68(10):3441-3455. doi: 10.2527/1990.68103441x

USDA. 1997. Official United States Standard for Grades of Beef Carcasses. Agric. Marketing, USDA Washington (DC).

Zinn, R., A. Barreras, F. Owens, and A. Plascencia. 2008. Performance by feedlot steers and heifers: daily gain, mature body weight, dry matter intake, and dietary energetics. J Anim Sci 86(10):2680-2689. doi: 10.2527/jas.2007-0561

Zinn, R., and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J Anim Sci 76(5):1280-1289. doi: 10.2527/1998.7651280x

Zinn, R., and R. Ware. 2003. Understanding nutritive value: Alternative Forages. In: Proceedings California Alfalfa Symposium. p 1-11.

Zinn, R. A., A. Plascencia, and R. Barajas. 1994. Interaction of forage level and monensin in diets for feedlot cattle on growth performance and digestive function. J Anim Sci 72(9):2209-2215. doi: 10.2527/1994.7292209x

Table 6. Actual Diet Formulation and Composition[1,2]

	1 to 77		78 to 98		99 to 112		113 to 196		197 to 210	
	1D	2D	1D	2D	1D	2D	1D	2D	1D	2D
Ingredient Composition, %										
DRC[3], %	56.07	47.16	31.97	27.22	31.61	31.61	32.09	36.97	64.63	73.20
HMC[4], %	-	-	30.82	26.24	30.45	30.45	30.52	35.17	-	-
DDGS[5], %	14.95	14.99	14.84	14.70	14.73	14.73	14.95	15.10	15.22	15.10
Corn Silage, %	14.16	14.19	-	-	-	-	-	-	-	-
Oat Hay, %	8.88	17.63	-	-	-	-	-	-	-	-
Sorghum Silage, %	-	-	17.36	26.87	18.27	18.27	17.42	7.70	14.88	6.46
Liquid Supplement, %	6.01	6.02	5.01	4.96	4.94	4.94	5.02	5.07	5.27	5.23
Nutrient Composition[6], %										
Roughage, %	15.88	24.73	17.36	26.87	18.27	18.27	17.42	7.70	14.88	6.46
DM, %	71.62	71.46	63.19	56.91	64.04	64.04	63.06	71.00	68.21	77.88
CP, %	13.16	13.23	13.34	13.30	13.19	13.19	12.92	13.02	13.04	13.02
NDF, %	21.98	26.67	19.73	26.09	20.69	20.69	21.08	16.55	19.90	15.83
ADF, %	10.90	14.08	12.51	15.64	17.15	17.15	12.23	8.84	10.93	8.01
Ash, %	6.34	6.97	6.03	6.13	5.71	5.71	5.73	5.18	5.79	5.24
EE, %	2.78	2.77	3.49	3.30	3.05	3.05	3.29	3.33	3.43	3.46
NEg, Mcal/kg	1.31	1.23	1.36	1.28	1.35	1.35	1.36	1.44	1.35	1.42
NEm, Mcal/kg	1.98	1.90	2.02	1.93	2.01	2.01	2.02	2.11	2.01	2.10

[1]All Values except for DM on a DM basis.
[2]1D = Single diet and 2D = Two diet treatment
[3]DRC = dry-rolled corn
[4]HMC = high moisture corn
[5]DDGS = dried distillers grains plus solubles
[6]Tabular NE from Preston (2016) and actual nutrient composition from weekly assays of ingredients

Table 7. Actual Cumulative Dietary Roughage and Net Energy.[1,2]

Item	1D	2D
NEm, Mcal/kg	2.00	2.00
NEg, Mcal/kg	1.34	1.34
Roughage Inclusion, %	16.7	16.5

[1]1D = Single diet and 2D = Two diet treatment

[2]Based on actual nutrient composition from weekly assays of ingredients

Table 8. Backgrounding (d 1-112), Finishing (d 113-210), and Cumulative (d 1-210) Growth Performance Responses.[1]

	Treatment[2]			
Item	1D	2D	SEM[3]	P – value
Steers, n	23	23	-	-
Pens, n	5	5	-	-
Live weight, kg				
Initial	279	279	3.1	0.93
112-d	461	445	13.7	0.06
210-d	618	620	21.2	0.87
Average daily gain (ADG), kg				
1-112 d	1.62	1.48	0.117	0.06
113-210 d	1.61	1.79	0.093	0.01
1-210 d	1.61	1.62	0.101	0.86
Dry matter intake (DMI), kg				
1-112 d	9.35	9.33	0.334	0.91
113-210 d	10.79	10.78	0.606	0.97
1-210 d	10.02	10.01	0.342	0.93
G:F				
1-112 d	0.174	0.159	0.0054	0.05
113-210 d	0.149	0.166	0.0020	0.01
1-210 d	0.161	0.162	0.0027	0.76
F:G				
1-112 d	5.75	6.29	-	-
113-210 d	6.71	6.02	-	-
1-210 d	6.21	6.17	-	-
Dietary NEm, Mcal/kg[4]				
1-112 d	1.81	1.69	1.246	0.01
113-210 d	2.02	2.12	2.389	0.09
1-210 d	1.92	1.92	1.156	0.96
Dietary NEg, Mcal/kg				
1-112 d	1.18	1.07	1.093	0.01
113-210 d	1.36	1.45	2.095	0.09
1-210 d	1.27	1.27	1.013	0.96
Observed-to-expected NEm[5]				
1-112 d	0.91	0.88	0.014	0.09
113-210 d	1.00	1.00	0.025	0.88
1-210 d	0.96	0.96	0.012	1.00
Observed-to-expected NEg[5]				
1-112 d	0.89	0.86	0.020	0.14
113-210 d	1.00	1.01	0.034	0.82
1-210 d	0.95	0.95	0.017	0.91

[1]All BW were reduced 4% to account for digestive tract fill
[2]1D = Single diet and 2D = Two diet treatment
[3]Pooled SEM
[4]Performance adjusted (Owens and Hicks, 2019)

[5]Performance adjusted NE : Tabular NE value

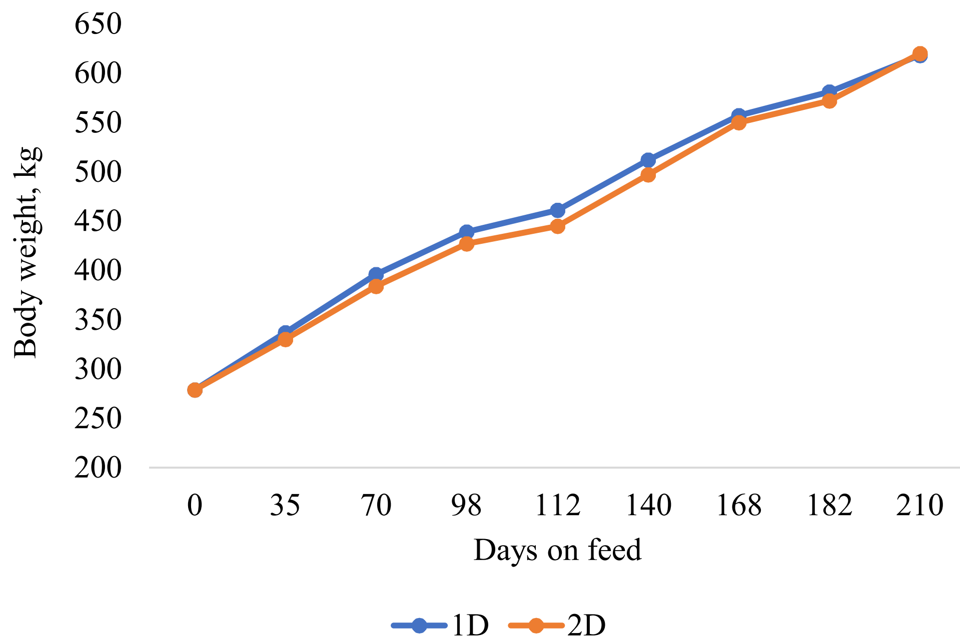
Table 9. Carcass Trait Responses

	Treatment[1]			
Item	1D	2D	SEM[2]	*P* - value
Pens, n	5	5	---	---
Steers, n	22	22	---	---
Carcass Traits				
HCW[3], kg	400	401	12.9	0.82
Dressing[4], %	64.55	64.70	0.487	0.77
Rib fat, cm	1.22	1.19	0.030	0.85
REA[5], cm^2	93.16	96.26	0.448	0.34
Marbling Score[7]	526	529	33.7	0.95
KPH[6], %	1.87	1.90	0.064	0.39
Yield Grade[8]	2.79	2.64	0.092	0.18
Retail Yield, %[9]	50.92	51.19	0.225	0.29
EBF, %[10]	30.06	29.82	0.517	0.67
AFBW, kg[11]	594	600	31.4	0.70
USDA Yield Grade (YG) distribution, %				
YG 1	10.0	9.0	8.09	0.91
YG 2	56.0	50.0	12.37	0.46
YG 3	25.0	41.0	12.77	0.22
YG 4	9.0	-	3.93	0.18
YG 5	-	-	-	-
USDA Quality Grade distribution, %				
Select	13.0	17.0	8.00	0.50
Low Choice	34.0	30.0	7.86	0.71
Average Choice	37.0	28.0	9.30	0.44
High Choice	4.0	21.0	5.33	0.09
Prime	12.0	4.0	8.94	0.37
Liver Scores, %[12]				
Normal	77.0	92.0	5.72	0.14
A-	9.0	0.0	3.94	0.18
A	5.0	0.0	3.94	0.18
A+	9.0	8.0	5.24	0.90

[1]1D = Single diet and 2D = Two diet treatment
[2]Pooled SEM
[3]HCW = hot carcass weight
[4]HCW/ final BW shrunk 4%
[5]REA = Ribeye area
[6]KPH = Kidney, pelvic, heart fat
[7]400 = small^{00}
[8]According to the regression equation described by USDA (1997).

[9]As a percentage of HCW according to Murphey et al. (1960).
[10]EBF = Empty body fat, calculated according to the equations described by Guiroy et al. (2002).
[11]AFBW = Adjusted final bodyweight, calculated according to the equations described by Guiroy et al. (2002).
[12]According to the Elanco Liver Scoring System: Normal (no abscesses), A- (1 or 2 small abscesses or abscess scars), A (2 to 4 well organized small abscesses), or A+ (1 or more large active abscesses with inflammation of surrounding tissue).

Figure 2. Body Weights[1,2]



[1]A 4% pencil shrink was applied to all BW measure.
[2]1D = Single diet and 2D = Two diet treatment