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REPLACEMENT OF GRAZED FORAGE WITH WDGS AND POOR QUALITY HAY
AND STRAW MIXTURES

By

Sandra Villasanti

A THESIS

Presented to the Faculty of
The Graduate College at the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professors L. Aaron Stalker and Terry J. Klopfenstein

Lincoln, Nebraska

December, 2010

REPLACEMENT OF GRAZED FORAGE WITH WDGS AND POOR QUALITY HAY
AND STRAW MIXTURES

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University of Nebraska, 2010

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A grazing study was conducted at the University of Nebraska Gudmundsen Sandhills Laboratory from mid-June to late-August across two years (2009 and 2010) to evaluate the effects of supplementation with mixtures of wet distillers grains (WDGS) and straw or hay on grazed forage intake. Twenty 1 ha paddocks replicated over two blocks were randomly assigned to one of four treatments: Control (CON) at the recommended stocking rate (1.68 AUM/ha in 2009 and 1.64 AUM/ha in 2010), and three double stocked treatments supplemented with 60% straw and 40% WDGS (STRAW), 60% hay and 40% WDGS (LOW), and 70% hay and 30% WDGS (HIGH). Forty yearling steers were stratified by BW and assigned randomly to treatment paddocks, giving a total of five steers per treatment. Five paddocks on each block were rotationally grazed for each treatment once during the experimental period. Post-grazing standing crop was determined by clipping five 0.25 m² quadrats from each paddock at the end of the grazing period. Pre-graze forage allowance was calculated by adding an estimated amount of forage intake to the amount of forage remaining in the paddocks at the end of the grazing period. Forage intake was estimated by the difference between pre-graze and post-grazing forage availability. During the first year of the study, there was no difference in

ADG between CON and HIGH; steers supplemented with 60:40 blends of straw or hay with WDGS presented higher ADG than the other two treatments. During the second year, steers in the STRAW treatment achieved significantly lower ADG than steers in the other treatments. Forage intake was significantly higher for the CON steers and intake of range forage was reduced by 18% to 22% when the animals were supplemented with the mixes. Mixing WDGS with low quality harvested forage to cattle grazing rangeland may be an alternative to increase or maintain stocking rates without hurting animal performance.

Key words: Forage intake, Hay, Supplementation, Wet Distillers grains, Wheat Straw

Acknowledgments

I would like to thank my advisors, Dr. Terry Klopfenstein and Dr. Aaron Stalker for all their time and patience and for providing invaluable help over the course of the last 2 years. I would also like to thank my committee members, Dr. Walter Schacht and Dr. Karla Jenkins, and also Dr. Jerry Volesky for their support and advice that throughout this project.

I also appreciate all the help provided by the people at the ranch, Jacki, Ancy, CR, John, and Jay, as well as Angie Peterson and Kelly Brink and their clipping crew, without their help this project would not have been possible. I would also like to thank Judy Huff for her kindness and willingness to help.

Finally, I would like to thank my family and friends for their encouragement and support that helped me reach my goals.

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Introduction

The beef industry is the largest single industry in Nebraska. According to the 2007 census of agriculture there are approximately 6.5 million head of cattle and calves and nearly 5 million head are finished and marketed each year. About 40% of the total cattle are on feed and the remaining 60% are grazed on the 24 million acres of rangeland and pastures throughout the state (USDA, 2007). The Nebraska Sandhills encompasses about 12.75 million acres that are used primarily for the grazing of cattle (Adams et al. 1998). The variety of plant species including warm and cool season grasses, allows higher quality forage to be available for a longer period of time in the grazing season.

Cost of rangelands has increased in the last years in many areas throughout the United States including Nebraska. In order to maintain profitability of livestock production it is important for producers to find alternatives that allow them to increase stocking rates and expand current production without needing to add additional land. On the other hand, fuel ethanol production has been increasing in the last decade and as a consequence the availability of corn by products resulting from the fermentation of cereal grains has also increased. Distillers grains, one of the by products from the ethanol industry, has been used as a feedstuff for many years; the first study in the United States that focused on feeding distillers grains as a feedstuff to cattle was published in 1907. The supply of distillers grains has been increasing due to the growth of fuel ethanol production, resulting in an increased interest in feeding them. The production of distillers grains was about 1 million tons in 1998. It increased to about 10 million tons in 2006, and is estimated to reach 16 million tons by 2010 (Weiss et al., 2007).

Van Soest (1965) stated that intake is limited by the amount of fiber in the diet when cell-wall content lies between 50 and 60% of forage dry matter. Voluntary intake is expected to be inversely related to the fiber content of the forage because further intake is limited as the slower digesting fraction becomes large in relation to the volume of the digestive tract. Campling et al. (1961) reported retention time in the rumen increases with the amount of fiber in the ration and therefore voluntary intake decreases with time of retention in the whole gut. In the same way, particle passage is expected to decrease with increasing NDF intake, particle size, coarseness of forage and decreasing forage digestibility. Based on these statements it can be said that intake in grazing situations is limited by fill, and therefore replacement of grazed forage using low quality forages mixed with wet distillers grains seems to be a good way to increase carrying capacity or provide additional forage in years affected by drought. Mixing low quality forage such as hay and wheat straw with wet distillers grains increases palatability of the forage as well as adding nutritional value since it contains higher levels of protein, energy and phosphorus.

Previous research has shown mixing wet distillers grains with wheat straw decreased grazed forage intake and improved animal performance (Nuttelman et al., 2010; Gustad et al., 2008). It was hypothesized that mixing WDGS with low quality hay and wheat straw would decrease forage intake since it was expected the NDF content in the hay and straw would provide a filling effect while the WDGS would add palatability making it more acceptable to the animals. Therefore an experiment was conducted in the Nebraska Sandhills with the objective of determining the effect of supplementing WDGS

mixed with low quality hay and wheat straw on forage replacement and animal performance.

Review of literature

Forage

The soil in the sandhills is characterized by valentine fine sands (mixed, mesic, ustpamments) while the dominant grass species are composed mainly by little bluestem [*Schizachrium scoparium* (michx.) Nash], prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.], sand bluestem (*Andropogon gerardii* var *paucipilus* Hack.), switchgrass (*Panicum virgatum* L.), sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood], indiangrass [*Sorghastrum nutans* (L.) Nash], sedge (*Carex* spp), Needleandthread (*Stipa comata*), prairie junegrass (*Koeleria macrantha*), sand dropseed (*Sporobolus cryptandrus*), hairy gramma (*Bouteloua hirsute*), and blue grama [*Bauteloua gracilis* (H.B.K.) Lag. Ex Griffiths]. Common forbs and shrubs found in the area are western ragweed (*Ambrosia psilostachya* DC.), Stiff sunflower (*Helianthus pauciflorus*) and leadplant [*Amorpha canescens* (Nutt.) Pursh] (Lardy et al. 1999; Gustad 2008).

According to Cogswell and Kamstra (1976) the nutritive value of range forages is greatly affected by plant maturity and seasonal climatic conditions. When native range is grazed year round there is variation in diet quality throughout the year and with level of grazing pressure (Geisert et al., 2008). Lardy et al. (1999) also affirmed quality of warm-season grasses declines in late summer. Stubbendieck and Reece (1992) explained quality varies with plant growth with nutrients being more digestible in the vegetative stage and then declining as the plant matures and enters dormancy. Geisert (2007) stated

leaf:stem ratios, digestibility and crude protein decrease while lignin, NDF, and ADF increase leading to a decline in forage quality.

A trial conducted by Geisert et al. (2008) in Sandhills range using fistulated cattle showed high crude protein values between May and July, averaging 11.56%, while the lowest values were found during the winter (6.9%). Similarly Haugen et al. (2006) showed summer CP values to range from 12% in May to 9.4% in September. Lardy et al. (1997) reported a similar trend during the year, observing an increase in CP values in April that remained between 10 and 12% for the duration of the summer and started to decline in September reaching values close to 5% during the winter. Patterson et al. (2003), found similar results when analyzing diets from fistulated cows in the Sandhills. They found a decline in CP from October to February with average values of 8.7 and 5.9% respectively, while Lardy et al. (1999) reported fall CP values ranging between 9.2 to 5.9%. When Patterson et al. (1999) evaluated the effect of summer grazing on fall CP values on Sandhills upland range, they found CP average values of 7.2% when the pastures were deferred in the summer and 7.5 and 7.1% when the pastures were grazed in June and July respectively.

In the same way, several authors have found a decline in forage digestibility as the growing season advances. In a study conducted in the Sandhills by Haugen et al. (2006), IVDMD averaged 67.7% at the beginning of the growing season and decreased to 52.5% by the end of September. Lardy et al. (1999) reported decreasing digestibility percentages from 59.5 to 48.3% from September to November. This agrees with the results found by Geisert et al. (2008) using fistulated cows over a period of three years,

observing average values for IVOMD of 60% for the summer and 54.2% for the winter. Similar values were obtained by Creighton et al. (2003) who reported average values of 63.1% for the summer season in diets obtained in the Sandhills native range.

Neutral detergent fiber (NDF) is an estimation of the cell wall content of grasses which is composed of cellulose, hemicelluloses, pectin, silica, and lignin. The proportions of these components change as the plant matures increasing the amount of lignin and reducing the digestibility of the material, reducing the feeding value of the plants as they get more mature (Kellems and Church, 2009). According to Lardy et al. (1997) Sandhills upland range is composed mainly of warm season grass species that reach the highest quality during the summer months. Hollingsworth-Jenkins et al. (1996) reported average NDF values for the Sandhills range of 66.9% in November, 72.3 in December/January and 77.1 in February. Lardy et al. (1999) found higher average values for September (74.5%) and late October (82.25%), but they still noticed the increase in NDF percentage as the season advanced from fall to winter. These results are close to the ones obtained by Lardy et al. (2004) who evaluated Sandhills range diets for two years and observed the lowest NDF percentages for the summer season with an average of 76.7% and the highest values for the winter reporting an average of 84.6%.

Forage yield and quality have also been reported to be affected by precipitation. Geisert (2007) indicated that below average moisture has a negative effect on forage yield, however digestibility appears to increase with moderate drought due to the decrease rate of plant maturation. According to Hailim et al. (1989) perennial forage plants grown under water stress have higher nutritive quality than those grown under well

watered conditions. Smoliak, (1956), determined the influence of climatic factors upon range forage production estimating the correlation coefficients for numerous variables. His study showed May and June precipitation were significantly correlated with forage production ($r = 0.845$). Similar results were obtained by Rauzi (1964) who found a high correlation between April through August precipitation and annual forage yield ($r = 0.745$). When Dahl (1963) studied the factors that influence yield of a Sandhill range in eastern Colorado, he concluded that stored spring soil moisture was a major factor contributing to maximum potential yield of grass.

Hart et al. (1983) determined the effect of weather in forage quality on the Wyoming high plains. They found an increase in crude protein content of species such as blue gamma and western wheat grass after heavy rains. Holechek and Vavra (1983) compared diet quality during a drought year and a year with average precipitation finding lower crude protein and digestibility percentages in the drought year. Hailim et al. (1989) evaluated the response to water stress of alfalfa and observed that plant maturity linearly decreased with increasing water stress, while digestibility in stems and CP concentration increased by 9 and 11% respectively. These results agree with those found by Peterson et al. (1992) who also reported decreasing concentrations of NDF and ADF and decrease rate of plant maturation in legumes when drought was initiated early the growth season of the herbage.

Nutritive value of native range plants also depends on the nutrient content of the available species. Rodgers and Box (1967) conducted a study to evaluate the seasonal protein content of four southern mixed prairie grasses (buffalograss, *Hierochloe ordata*; blue gamma, *Bouteloua gracilis*; sideoats grama, *Bouteloua curtipendata*; and black

gamma, *Bouteloua eriopoda*). Their results showed Blue gamma contained the highest average per cent protein followed by black gamma and buffalograss whereas sideoats gamma presented the lower CP content. When Wallace et al. (1972) evaluated chemical composition and dry matter digestibility of different species they found marked differences in chemical composition among species (blue gamma, needleandthread, and prairie sandreed) in early summer but the difference was minimal during the winter. Higher digestibility was also reported for cool season grasses when compared to warm season grasses. Forbs presented higher digestibility and CP than all the evaluated grasses.

The diet consumed by cattle is generally higher in quality than total herbage available since cattle have the ability to select green material over dry material, young growth over old growth, and leave tissue over stem tissue (Wallace et al. 1972). According to Bredon et al. (1967) the potential for selection increases in tropical and subtropical areas because of the much wider variation in herbage than in temperate areas. Reppert (1960) conducted a study to determine preference for native forage by yearling heifers using a pasture observation method. His results indicated a preference for certain species that varied at different times of the year and with the availability of the preferred species. He also observed heifers had a tendency to select green forage and leaves in preference to old forage and stems. According to Vavra et al. (1973) diet selectivity is affected by grazing intensity since the opportunity for selective grazing is reduced with increasing grazing pressures.

The chemical and botanical composition of the grazing animal's diet is difficult to determine due to their selective behavior. Diet collection using hand-clipped samples do not reliably represent the composition of the animal's forage intake (Cable and Shumway, 1966). Lardy et al. (1997) indicated the use of esophageally-fistulated cattle is the most reliable method to obtain estimates of the animal's diet since the collecting is made by the animal itself. When Bredon et al. (1967) compared the differences in chemical composition of esophageal-fistula samples and hand-plucked grass samples he found that the fistula samples contained 66.4% more crude protein and 7.71% less crude fiber than the average values for the available pasture forage, which reflects the inaccuracy of the clipping method to assess the value of grazed diets. These results agree with those found by Kiesling et al. (1969) who observed a higher content of protein and ashes and a lower content of fiber in samples obtained from esophageal fistulated animals. He attributed the higher content of ash to saliva contamination and the differences in protein and fiber to the selectivity capacity of the grazing animals. Jefferies and Rice (1969) compared digestibility and protein values of clipped grasses and sedges to samples obtained using esophageal fistulated steers. The study was conducted over two years, limited summer rainfall was observed in the first year in opposite to the second year characterized by a humid summer. During the dry year protein and digestibility values were comparable in both sample methods but during the year with good rainfall the fistula samples presented higher protein and dry matter digestibility than the clipped samples due to the presence of forbs with higher nutrient value grazed by the animals.

Grazing systems

Livestock production from rangelands is affected by the stocking rate since lower animal gain per unit area and wasted forage results from under-stocking; while lower gain per animal from excessive utilization of forage and deterioration of range conditions are the consequences of over-stocking (Ralphs et al. 1990). According to these authors, as frequency and intensity of defoliation increase, production and vigor of plants decrease, palatable plants decrease as well as the carrying capacity of the pastures. Thurow et al. (1988) affirmed the intensity of grazing defines the impact grazing livestock have on a plant community. Lemus (2008) also stated the importance of balancing livestock demand with forage availability in order to promote rapid pasture re-growth and increase the opportunity for long-term pasture persistence.

Grazing strategies have been developed due to the need to sustain efficient use of the forage resource by livestock over long periods of time (Manley et al. 1997). Mckown et al. (1991) stated grazing management strategies are employed to manipulate factors affecting nutrient intake to improve individual animal production and/or production per area. The main types of grazing systems are continuous and rotational grazing; the success of either system depends on factors such as land configuration, type of livestock, capital resources, and the producer's goals, attitude, and ability to adapt to the daily challenges of each system (Lemus, 2008). According to Gammon (1978) pasture deterioration can be expected under continuous grazing even when moderate stocking rates are applied while stability can be facilitated by a variety of rotational systems.

Continuous grazing consists on keeping a set of animals out on a pasture season long or year-round. The problems related to this system are the overgrazing of specific areas due to livestock selectivity causing the pasture to become less productive with time and the loss of desirable species and low animal gain per acre (Lemus, 2008). According to Manley et al. (1997) the rotational grazing system is based on the division of a pasture into a number of paddocks and rotating cattle among paddocks relatively quickly, which results in higher stocking densities for short periods of time. These authors also affirmed that under this system, a given plant or tiller is expected to be grazed only once during a particular rotation period and the major objectives of this grazing system are the increase in forage production and even utilization of forage by grazing cattle. Short duration rotational grazing can be used as a management strategy to increase livestock number while maintaining range condition (Gillen et al. 1998). Taylor et al. (1980) mentioned even though this kind of system is an effective scheme for range improvement it might reduce nutrient intake due to the decreased selectivity of the most nutritive plants.

In a study conducted by Heitschmidt et al. (1982) to evaluate cow-calf response to continuous grazing using heavy (5.1 ha/cow/yr) and moderate (7.6 ha/cow/yr) stocking rates and a deferred rotation system (7.2 ha/cow/yr) they found higher weight gains for cows and calves and higher conception rate for the deferred rotation treatment followed by the moderately and heavily stocked continuous system. These authors also concluded as rate of stocking increases, production/animal unit slowly declines and production /unit area of land increases until rate of stocking exceeds carrying capacity leading to a further decline in production/unit area. Likewise Willms et al. (1986) found decreasing individual animal weights and increasing cattle gains per unit area with increased

stocking rates when evaluating cattle weight gains under continuous grazing at four stocking rates (1.2, 1.6, 2.4, and 4.8 AUM/ha).

Manley et al. (1997) evaluated the effects of stocking rate and grazing method on performance of yearling beef cattle allocated to continuous, rotationally deferred, or time controlled rotation methods at stocking rates varying from 0.16 to 0.23 steers/ha (light), 0.42 steers/ha (moderate), and 0.56 steers/ha (heavy). Their data showed a linear decrease in average daily gain with increasing grazing pressure with no effect of grazing strategy. These results agree with those found by Hart and Ashby (1998) who reported a linear decline in weight gain of heifers with increasing grazing pressure. Likewise, McCollum et al. (1999) found lower gain per head and higher gain per hectare as grazing pressure increased. In this trial continuous grazing also provided higher total live weight gain per head and per hectare as a consequence of the gain per head relationship. Sims and Gillen (1999) observed similar responses to stocking rates reporting a decrease in total live weight gain per head and an increase in live weight gain per hectare with increasing stocking rate.

Herbage availability and species composition have also been reported to be affected by different grazing methods and stocking rates. Thurow et al. (1988) conducted a trial to compare vegetation cover under continuous grazing moderately and heavily stocked (8.1 ha/AU and 4.6 ha/AU respectively), high intensity, low-frequency moderately stocked (8.1 ha/AU), short duration grazing heavily stocked (4.6 ha/AU) and livestock exclusion. Midgrass species declined in the continuous heavily stocked and short duration grazing while they were maintained under high intensity low-frequency

system, increased slightly in the continuous system under moderate stocking rate and increased significantly in the animal excluded area. Gillen et al. (1998) evaluated the vegetation response to continuous and rotational grazing systems at several stocking rates ranging from 51.5 to 89.8 AUD/ha. Standing crop was similarly affected by both grazing methods but they observed a decline in standing crop of all major species with higher grazing pressures. Manley et al. (1997) observed similar response of peak standing crop to different grazing systems and reported shifts in the botanical composition of the pastures under heavy stocking rates.

When Willms et al. (1986) examined the effects of stocking rates on cattle production they observed a decline in forage availability from higher stocking rates. In this trial, when forage production was related with precipitation and previous stocking rate, the equation suggested a decrease in forage of about 258 kg/ha for each additional AUM increase in stocking rate. Heitschmidt et al. (1982) observed a change in species composition of the vegetation from midgrasses to shortgrasses which reduced forage production at heavier stocking rates. Likewise when Ralphs et al. (1990) measured standing crop from four stocking rates under short duration grazing ranging from the recommended rate to 2.5 times the recommended rate, a decline in all major forage classes and in midgrass frequency and composition occurred as stocking rate increased.

Forage quality under different grazing systems and stocking rates has also been documented. The effects of 3 grazing strategies: high intensity low-frequency system where livestock grazed 7 pastures for 21 days followed by an 18-week deferment, short duration grazing where the same pastures were grazed for 7 days, and Merrill system

were pastures were grazed for 12 months followed by 4 months of rest were evaluated by Taylor et al. (1980). Diets from the short duration grazing system presented higher values of CP and digestibility than the high intensity low-frequency system and were comparable to those obtained from the Merrill system. Mckown et al. (1991) compared nutrient intake of cattle under continuous and rotational grazing system. The continuous treatment was stocked at a moderate rate of 6.2 ha/cow per year and the rotational system at a heavy rate of 3.7 ha/cow per year. Higher nutrient intake was obtained from the continuous system with higher OM intake, forage CP intake, and forage ME intake. These findings supported the idea that as forage availability declines, nutrient intake and therefore livestock performance also decline regardless of grazing strategy.

Distillers grains supplementation in forage based diets

Distillers grains are a byproduct of ethanol industry obtained from the dry milling process. During this process the corn is mixed with yeast to convert the starch into ethanol and carbon dioxide. The ethanol is distilled off and the remaining liquid is centrifuged to remove some water; the residue of this process is called wet distillers grains (WDG) and usually is made up of 30 to 35% dry matter and most of the fiber, fat, protein, and minerals found in the original grain and yeast are found on this portion. The remaining liquid after centrifuging is partially dried and is called condensed distillers solubles, they are usually added back to the wet distillers grains to obtain wet distillers grains with solubles (WDGS). When the WDGS are heat dried, dried distillers grains plus soluble are obtained (Weiss et al., 2007).

During the fermentative process, only the starch is removed from the grain, since corn grain is about two-thirds starch, the nutrient composition of distillers grains in terms of protein, fat, fiber, and P concentrations are increased 3-fold. Because oil and the gluten fraction are not removed during processing distillers grains contain high levels of fat and escape protein (52% undegradable intake protein; Stock et al., 2000). The percentage levels of crude protein, fat, NDF, phosphorous in distillers grains average 30%, 10%, 43%, and 0.8% respectively (NRC, 1996).

Availability of distillers grains is increasing due to the expansion of the ethanol industry. The number of ethanol plants in Nebraska increased from a single plant in 1985 to 24 ethanol plants in 2010 that produce more than 4 million tons of distillers grains. Prices of distillers grains are expected to decrease due to the increasing supply which makes this byproduct a good alternative to be used as a supplement in grazing situations (Nebraska Corn Board).

According to Klopfenstein et al. (2008) distillers grains have been used primarily as a protein source because of the increased concentration in distillers grains compared with corn. Tjardes & Wright (2002) affirmed that distillers grains with or without solubles, can be fed as a replacement for other protein sources such as urea, soybean meal, etc. The protein in distillers grains is approximately 50% undegraded intake protein (UIP) and 50% degraded intake protein (DIP). Rumen microbes require a certain level of DIP to digest starch and fiber and synthesize microbial protein which is the primary source of protein for beef cattle; however microbial protein production may be deficient in forage based diets. They also stated mature cattle can be supplemented with

a source of DIP to meet the nutrient requirements, but heifers and young cows that have greater nutrient requirements may also require UIP supplementation to meet their demands for growth, gestation and lactation. DIP and UIP requirements can be met using supplements formulated from a variety of feeds while distillers grains can be used as a sole protein source for cattle.

MacDonald et al. (2007) evaluated the contributions of UIP contained in DDG on performance of growing cattle grazing high quality forage. They observed average daily gain was linearly increased with increasing levels of DDG (750, 1,500, or 2,250 g/d). The rate of increase in ADG of heifers supplemented with corn gluten meal in amounts that provided the same amount of UIP as DDG was 39% of that for DDG which the authors concluded represented the proportion of the response of DDG that is due to meeting a metabolizable protein deficiency. Ham et al. (1994) compared the protein value of dry and wet distillers by products, supplementing crossbred calves with wet distillers grains and 3 levels of dry distillers grains plus soluble. Their results did not show differences in rate of gain or protein efficiency among calves fed wet or dry distillers byproducts. They concluded that distillers by products are a good source of bypass protein and that drying seems to have little effect on the value of the protein for growing calves.

Although distillers grains are low in starch, they represent a viable source of supplemental energy because this corn by product is high in digestible fiber and contains 11 to 12% fat, resulting in a similar to slightly higher energy value than corn (Loy et al., 2007). When energy is provided from highly digestible fiber, the negative associative

effects (reduced forage intake and digestibility) associated with feeding high starch feeds can be avoided as well as digestion disturbances in feedlot cattle (Tjardes and Wright, 2002). According to Stock et al. (2000) wet distillers by products have about 97 to 147% the net energy value of corn, this value can be affected by the type of grain and the amount of solubles added to the distillers grains. They also stated that drying distillers by products reduces their net energy value.

Loy et al. (2003) conducted research to supplement heifers with dry distillers grains (DDG), dry rolled corn (DRC) and DRC with corn gluten meal (DRC+CGM) with the objective of determining the value of DDG in high forage based diets. Their results indicated that DDG has a higher energy value than DRC based on the fact that even when intake did not differ between DDG and DRC, average daily gain was improved by DDG. They calculated net energy value of DDG to be 27% higher than that of DRC.

MacDonald et al. (2007) compared the ADG of heifers supplemented with either DDG or corn oil adjusting the amount of each supplement in order to provide the same amount of ether extract. They observed supplementation with corn oil tended to result in ADG less than that of DDG. The higher gains from DDG supplementation was attributed to be the effect of providing a combination of protein and energy from UIP and fat respectively.

A study conducted by Nuttelman et al. (2009) evaluated the energy value of wet distillers grains in high forage diets. For this study 160 crossbred steers were allocated to one of two treatments: wet distillers grains (WDGS) or dry-rolled corn (DRC). Their results showed a TDN value of 108% for WDGS, which was estimated to be 130% that of corn. They concluded that distillers grains have a high energy value relative to corn, which was

attributed to the low level of starch and energy density of fat, undegraded protein and corn fiber.

Forage replacement using distillers grains

In the last ten years an increase of about 20 to 25% in the cost of grazed forages in Nebraska has been observed, while corn prices have remained relatively constant within a cyclical price pattern (MacDonald and Klopfenstein, 2004). Cereal grains have been used as a traditional source of supplement to cattle on forage based diets, but because of the high amount of starch in the grains, a negative associative effect has been observed between starch and forage digestibility leading to a depression in forage utilization (Morris et al. 2005).

According to Corrigan et al. (2007) supplementation with dried distillers grains (DDG) in forage based diets decreases forage DM intake and increases ADG. This decrease in voluntary forage intake is beneficial since producers can increase carrying capacity of their pastures, and expand production without needing to add extra land devoted to grazing. Morris et al. (2005) evaluated the effects of five levels of dry distillers grains (0, 1.5, 3, 4.5, and 6 lb DM DDGS) using heifers on forage intake. The forage diets consisted of smooth brome grass hay or alfalfa hay and sorghum silage mix selected to simulate the differences in nutritive values between dormant and growing range. They found a significant difference in forage intake between different forage sources. Even though in both cases forage intake linearly decreased as level of DDGS increased, they found the level of replacement was greater for heifers fed the alfalfa hay and sorghum silage mix than those fed brome hay (0.53 v 0.33 lb of forage per lb of

DDGS). In this trial average daily gain also increased with the inclusion of DDGS. These results agree with those found by McDonald and Klopfenstein (2004) who supplemented heifers grazing smooth bromegrass pastures with 0, 1, 2.1, 3.1 or 4.2 lb per head per day (DM) dry distillers grains (DDG) for 84 days. Their results showed forage intake was decreased by 1.72 lb for every pound of DDG added to the supplement and ADG was increased by 0.06 lb for every lb of DDG supplemented showing the decrease in forage intake did not hurt animal performance.

On the other hand, Gustad et al. (2008) did not find a significant reduction in forage intake when they supplemented yearling heifers with 2.27 kg dry matter/head of DDGS. Their results indicated that at that rate of supplementation only 1.14 kg/head per day was replaced which was less than the replacement rates found by other authors. However they did find higher ADG for the supplemented heifers and attributed this difference to a response to the undegradable protein contained in the distillers grains.

According to Klopfenstein et al. (2008) the moisture and physical characteristics of wet distillers grains (stickiness) helps to improve palatability and reduce separation and sorting of less palatable ingredients. These characteristics could be used to utilize less expensive and lower digestibility forages as a complement to grazed forage. Nuttelman et al. (2008) stated the storage time of WDGS can be increased by mixing it with forage such as hay and then storing the mixture in a silo bunker or plastic silage bag. Since NDF has been reported to be the factor that has a strongest influence in limiting dry matter intake, these authors hypothesized this mixture could be utilized to provide the filling effect and therefore reduce forage intake in grazing situations. They compared

forage intake and ADG when steers were supplemented with wet distillers grains, dry distillers grains, and a mix of 66% wet distillers grains and 33% wheat straw. Their results indicated similar DMI for cattle supplemented with DDGS and WDGS, and lower DMI for cattle supplemented with the mix compared to DDGS and WDGS. These authors calculated from their results each pound of DDGS replaced 0.5 lb of forage and each pound of WDGS replaced 0.8 lb of forage, while each pound of the mix replaced 0.9 lb of forage. They also observed higher final body weight for the wet and dry distiller grains treatments compared to the mix. ADG increased linearly with increasing levels of distillers grains and the lowest level of forage intake was obtained with the daily inclusion of 6 lbs of distillers grains. Nuttelman et al. (2010) fed a mixture of 45% WDGS and 55% grass hay to lactating beef cows with spring born calves at side and compared it to a control group stocked at the recommended stocking rate and to a double stocked group with no supplementation. Their results showed a small reduction in forage intake using the mix, every pound of the mix replaced 0.22 lb of forage; however ADG for the animals in the supplemented treatment was higher, outgaining animals in the control and double stocked groups by 1.54 lb and 1.70 lb per day. In another trial they compared different mixtures of wheat straw and WDGS. In this study they fed three blends of 50:50, 60:40, and 70:30 of the mix and again compared forage intake and animal performance to a control group. They found forage intake for the supplemented groups was significantly lower than that of the control group. Replacement rates increased as the fiber content of the supplement increased, therefore the highest replacement rate occurred in the group fed with the 70:30 blend, which nearly replaced grazed forage intake on a 1:1 basis.

Forage intake

According to Forbes (1988), the quantity and quality of forage produced, the animal's capacity to harvest and utilize the forage efficiently and the livestock producer's ability to manage the available resources are key elements determining profitability of livestock production. Forbes (1995) defined voluntary intake as "the weight eaten by an animal or group of animals during a given period of time during which they have free access to food". Intake is controlled in ruminants by three major processes which are chemostatic regulation, thermostatic regulation and physical capacity regulation. In farming practice it is often difficult to get animals to eat the necessary amounts of low priced roughages, for this reason it is important to understand the factors that control the voluntary intake of roughages (Allison, 1985). The total amount of forage consumed varies among animals and pastures (Fontenot and Blaser, 1965). Crampton (1957) stated in grazing situations, the value of forages depends more on the amount consumed than on its chemical composition. If a grazing animal could consume enough forage to meet its energy needs, it would be able to get all the nutrients it needs from low quality forages. In grazing situations economic returns are often limited because the voluntary intake of the animal restricts the amount of inexpensive food that can be utilized (Campling, 1964). According to Caton and Dhyuvetter (1997), intake of grazed forage has been reported to range from .91 to 4.3% of BW in cattle grazing native range throughout the year.

Mertens (1987) mentioned short-term intake regulation is associated to within-day events that affect the frequency, size and pattern of meals while long term regulation of intake is dependent on dietary and animal characteristics. Forbes (1988) affirmed short-

term intake is influenced by plant structural factors that influence rate of ingestion, the effect of masticated forage on gut fill and social behavior, and environmental factors that affect the appetite-satiety complex. According to Allison (1985), forage based diets are characterized by being bulky and fibrous and for having a relatively low content of digestible energy. For this reason, the physical effect of gut distention plays an important role in limiting voluntary intake. Decruyenaere et al. (2009) stated voluntary intake is regulated by fill gut capacity and by the maximal volume the digestive tract can reach. These authors also affirmed that intake decreases more when the ruminal ballast is more bulky in volume or in weight with or without digestibility modification. Welch (1967) also stated in forage based diets, physical capacity has been pointed to be the main regulating factor.

Forages are high in fiber and low in energy. When this type of diet is fed to the animal; intake is limited by physical capacity of the animal and becomes a function primarily of dietary characteristics (Mertens, 1987). Kruger and Mullen (1955), cited by Campling et al (1961), stated the filling effect of a meal in the reticulo-rumen rises a feeling of satiety that determines the amount of roughage cows will voluntarily consumed. According to Campling et al. (1961) when roughages are offered ad libitum, voluntary intake ceases when the amount of digesta in the reticulum-rumen reaches some critical level. These authors conducted an experiment feeding cows ad libitum with hay and straw to determine whether the critical level is determined by the capacity of the reticulo-rumen or whether it is fixed in relation to the amount of digesta in the reticulo-rumen at some time of the day other than during a meal. Their results showed after feeding the amount of digesta in the reticulo-rumen at the end of a meal was not the same for the hay

and straw treatments, all cows offered hay always presented higher amounts before and after feeding than cows in the straw treatments. These results suggested voluntary intake was regulated in relation to their respective rates of disappearance from the alimentary tract in such a way that a constant amount of food residues could be maintained in the reticulo-rumen immediately before feeding.

According to Campton (1957) quality of the forage also has an influence in voluntary intake since greater amounts are consumed when better quality forages are fed. This author also expressed that rate of digestion of cellulose and hemicellulose are major factors limiting voluntary consumption of forage. Carr and Jacobson (1966) affirmed that voluntary intake increases with increasing digestibility in the ration. Digestibility, rate of passage of the indigestible residues, and body weight could also account for much of the variation in feed intake on rations with low digestibility (Conrad et al., 1964).

Allison (1985) affirmed the capacity of the reticulo-rumen and the rate of disappearance of digesta from this organ are the main factors limiting voluntary intake in roughage based diets. Balch (1950) suggested voluntary intake is influenced by changes in the rate of passage of foods and the degree of their digestion, an increase in the rate of passage is accompanied by an increased voluntary intake of food and a lowered digestibility. Campling and Balch (1961) determined the effects of removing swallowed hay or altering the amount of digesta before, during or after a meal. Time spent eating and total intake were increased after the removal of the feed, showing hay accumulation in the rumen exerted an immediate effect on termination of eating by cows and therefore intake was influenced by the accumulation of food in the reticulo-rumen. Anil et al.

(1993) found a decrease of 70 g DM for every additional liter of water put in balloons inserted in the rumen of lactating cows consuming grass silage. Welch (1967), demonstrated the effects of rumen fill on intake introducing into the rumen 150 g of polypropylene fibers of 30 cm in length. Intake was depressed to 33% of control values and remained low. They also observed voluntary intake was reduced with the addition of water-filled bladders but it was not affected when large quantities of water were added to the reticulo-rumen, implying forage moisture content does not have an important effect on intake because of the rapid removal. However Murdoch (1964) stated voluntary intake of roughage is determined by its dry matter content based on evidence that dry matter intake of silage increases with increasing dry matter content.

Dado and Allen (1995) affirmed voluntary intake may be limited by rumen capacity for diets containing at least 28.5% NDF. In a trial using rumen cannulated cows fed with diets containing 25 or 35% NDF with or without added rumen inert bulk as water filled plastic containers, they found higher DM intakes for cows fed the 25% NDF diets and a decrease in DM of 2 kg caused by the addition of inert bulk to the higher NDF diet, while they saw no effect on the lower NDF diet. Time spent eating or ruminating per unit of DM or NDF intake also increased with added dietary NDF or inert bulk. Llamas-Lamas and Combs (1991), found similar results when diets containing low, medium, and high percentage of NDF (56, 71, and 86% respectively) were fed to lactating cows. Their data showed higher DM intake for cows fed the low NDF diet supporting the theory that intake is limited by physical constraints. These results also agree with those found by Aitchison et al. (1986), who fed sheep with early and late cut grass hay and clover hay and found higher voluntary intake in the sheep fed the clover

hay and lower intake in the ones fed the late-cut grass hay, which also contained the highest amount of NDF, supporting the hypothesis that degree of rumen fill is involved in the control of voluntary intake.

According to Holloway et al. (1979) in grasses with low digestibility, intake is controlled by physical factors therefore voluntary intake is expected to increase as DM digestibility increases. Conrad et al. (1964) determined voluntary dry feed intake and dry matter digestibility feeding dairy cows with rations with digestibility ranging between 52 and 82%. When feeding a ration with 52.1 and 66.7% dry matter digestibility, their regression analysis showed digestibility of the feed, body weight (reflecting roughage capacity) and undigested residue per unit body weight per day (reflecting rate of passage) accounted for essentially all the variation in dry matter intake supporting the theory that appetite is determined by physical factors when the roughage fed falls between this range of digestibility. Jones et al. (1988) examined the changes in intake by beef cows and growing steers when grain was included in low levels in warm (Bermuda grass) and cool-season (Orchard grass) grass hay diets. In this trial, intake of hay dry matter declined with corn supplementation (0.3 % BW) and was greater for Bermuda than for Orchard grass. The greater consumption of Bermuda grass was explained by the higher concentration of NDF and lignin in Orchard grass caused by the higher maturity of these species at the time of consumption. In a study made by Holloway et al. (1979) they evaluated differences in intake in dairy cows fed with good and low quality tall fescue. They found cows in the high quality treatment (60.9% digestible) consumed on average 10.5 kg DM per day in comparison with the ones in the low quality treatment (58.35 % digestible) that consumed 8.8 kg DM per day. However, when the herbage is very young and highly

digestible, regulation of voluntary intake seems to be similar to that which occurs on highly digestible concentrate diets (Campling, 1964)

Plants produce compounds such as lignin, tannins, cutin, and silica that provide a degree of protection against microbial invasion. According to Hoover (1986) the concentrations and form of these compounds in forages, grains, and grain by-products, are partially responsible for differences in fiber digestion among various feedstuffs. Van Soest (1965) stated the amount of lignin and fiber content is negatively associated with digestibility, and at the same time, intake is positively related to digestibility. In the same way Aitchison et al. (1986) implied that high content of structural carbohydrates in forages will lead to a higher degree of rumen fill since they are fermented more slowly than other substrates. Fibrous and bulky materials are digested slower than the non-fibrous parts of forages, when the volume occupied by the slower-digesting fraction becomes large relative to the volume of the digestive tract, it starts to limit intake. This author also affirms cell wall constituents limit intake when they represent more than 55 to 60% of the dry matter, therefore when the proportion of total fibrous components increases, intake becomes increasingly restricted by the volume the fibrous mass occupies in the rumen. According to Dado and Allen (1995) rumen NDF is considered to be the component most associated with space occupying properties of rumen digesta since it represents the structural cell wall. Regression results of a study made by these authors showed that every Kg of rumen NDF is equivalent to 7.5 l of rumen digesta volume. Brake et al. (1989) also stated voluntary intake of tropical and temperate grasses without supplementation is generally influenced by NDF concentration. In a study made by Deswysen and Ellis (1988) the relationship between site and extent of NDF digestion and

voluntary intake were analyzed using fistulated heifers with ad libitum access to corn silage with or without monensin. The results of this study indicated a negative relationship between voluntary intake and unitary fluxes of NDF through the reticulo-omasal orifice and extent of digestion of potentially digestible NDF in the forestomachs. However, with increasing intake, the reduction in potentially digestible NDF in the forestomachs was compensated for by more extensive digestion in the cecum-colon, which was seen as a compensatory strategy by cattle with higher voluntary intake. Fontenot and Blaser (1965), considered if rumen fill is an important factor determining feed intake then it should be also related to liveweight of animals since organ size is usually related to body size.

In another study Carr and Jacobson (1966) added inert mass to the rumen of dairy breeding animals at levels of 1.6, 4.9, and 8.2% of metabolic size. Their results did not show a significant reduction in forage intake. In an additional trial, these authors removed ingesta from the rumen at levels of 1.6 and 4.9% of metabolic size prior to feeding and 8.2% of metabolic size three hours after feeding. They found a significant increase in dry matter intake of 0.4 kg per day in the last treatment, when 8.2% of metabolic size was removed from the rumen. They came to the conclusion that the increase in intake appeared to be the result of a chemical change, either a nutrient loss or the resultant alteration in metabolic products available to the animal and not a consequence of the decreased volume or bulk of the rumen content. Similar results were obtained by Johnson and Combs (1992), they did not find an effect of water-filled bladders on intake when 19.6 L of rumen content was replaced using rumen-cannulated cows in a 53:47 forage to concentrate diet. In another trial they fed dairy cows with

74:26 and 50:50 forage to concentrate diet with or without 23 L rumen bladders. They found that intake increased with greater proportion of concentrate in the diet but the bladders had no significant effect on intake. In these trials they observed cows compensated for the replacement of the digesta with bladders with an increase in total organ volume. The results of an experiment conducted by Brake et al. (1989) showed voluntary intake appeared to be more related to nutrient status of the animal than being limited by physical constraints. They fed the steers with bermudagrass and orchardgrass and found NDF and DM intake were higher for the animals fed Bermuda grass. The Bermuda grass was of a lower quality than the Orchardgrass.

Thornton and Minston (1972) stated voluntary intake in ruminants is dependent on the quantity of dry matter in the reticulo-rumen and the time that feed is retained in the reticulo-rumen. Campling et al. (1961) suggested the fill in the rumen is relatively constant; therefore voluntary dry matter intake of food should be inversely related to retention time. These authors found when cows were fed different amounts of hay, voluntary intake was inversely related to the time of retention of undigested residues in the whole gut. Particle passage rate is expected to decrease with increasing NDF intake, particle size, and coarseness of forage and decreasing forage digestibility (Chabot et al., 2008). Allen and Martens (1988) also affirmed increases in intake are associated with an increased rate of passage of feedstuff from the rumen and by the rate residues are broken down while they are retained in the rumen. Feeds that pass more quickly through the rumen are considered to be less filling because they occupy space within the rumen for a shorter time (Dado and Allen, 1995). The volume of digesta in the gastrointestinal tract is regulated by the proportional rates of influx and removal of digesta by net absorption and

passage. Rate of removal of indigestible residues from the reticulo-rumen is associated with observed differences in voluntary intake and fill levels of animals on different diets and therefore increased passage rate may allow greater voluntary intake in cases where intake is limited by physical fill (Johnson and Cobs, 1991). Campling (1964) affirmed rate of disappearance can be affected by a number of factors like the small size of the reticulo-omasal orifice that only allows the passage of reduced size of roughage particles. He also stated the time of retention in the reticulo-rumen of feed residues is indirectly linked with voluntary intake of roughages since intake is regulated by the amounts of digesta in this part of the tract.

Crampton (1957) reported that factors that interfere with the number or activity of rumen microflora, such as excessive lignification, starvation of flora from nitrogen or mineral deficiency, leads to an inhibition of the rate of digestion of forages and that it can be increased by providing rumen microorganisms with adequate nitrogen and mineral elements. Rate of digestion is related to voluntary intake because the more quickly the ingesta moves out of the reticulo-rumen, the sooner the animal gets hungry and therefore more food is eaten over a given period of time.

Voluntary intake of roughages can also be influenced by the amount and type of concentrates added to the diet. It has been reported voluntary intake of low quality roughages increases when concentrates containing nitrogen are added to the ration (Campling et al. 1962). The increase in intake appears to be the consequence of an accelerated rate of disappearance of digesta from the reticulo-rumen (Campling, 1964). Energy supplementation has often produced reduction in intake of grazed forage (Garces-

Yepez et al. 1997), when supplementing growing steers with different types of carbohydrates (corn-soybean meal, wheat middlings, and soybean hulls) at low and high levels (25 and 50% of total TDN intake) they observed forage intake as a percentage of BW decreased with supplementation and the change was more negative at the high than at the low level of supplementation (-0.01 to -0.40). Matejovsky and Sanson (1995) also observed linear decreases in forage intake with increasing levels of corn supplementation when lambs were fed low, medium and high quality grass hay. When restricted amounts of concentrates are given, the extent of depression in voluntary intake varies inversely with the quality of the roughage, greater depression in voluntary intake has been found with more digestible roughages. This depression in digestible forage intake has been attributed to a depression in the rate of disappearance from the rumen since the addition of starch to the diet depresses the digestibility of the cellulose of hay (Campling, 1964). According to Conrad et al. (1964) in diets containing forages with high digestibilities, intake appeared to be regulated by metabolic size, production and digestibility. They observed when feeding dairy cows with high roughage rations between 67 and 80% dry matter digestibility, intake decreased with increasing digestibility after adjusting for body weight and productive energy.

Campling (1964), suggested other factors that can affect voluntary intake are the kind of animal since adult animals that get fatter usually reduced their intake, and environmental factors such as ambient temperature also have an influence on voluntary intake; in general a rise in temperature leads to a decrease in intake that may be due to a decreased rate of passage of digesta through the rumen. Other characteristics such as

flavor, appearance, texture as well as the post-ingestive feedback occurring after intake can condition level of intake (Decruyenaere et al. 2009).

Estimation of forage intake

According to Van dyne and Meyer (1964a) range forage is the major source of nutrient for millions of livestock therefore knowing the quantitative forage intake of grazing animals is a valuable tool for range management. Quantifying the amount of forage consumed in grazing situations is necessary to estimate nutrient consumption by ruminant animals, but it is difficult to estimate forage intake in grazing systems (Macon et al. 2003). A good method for determining forage intake by grazing animals should be accurate and precise, applicable to individual animals and to all types of forages, and based on chemical components easy to estimate (Van dyne and Meyer, 1964a).

Decruyenaere et al. (2009) mentioned two categories under which methods to estimate intake under grazing situations can be classified: direct or indirect methods. All these methods have unique advantages and disadvantages and provide estimations of forage intake with an associated error that varies in magnitude (Macon et al. 2003). Direct methods are based on herbage mass measurement, therefore herbage mass from a defined area is cut and weighed before and after grazing and the difference between these two herbage masses and a correction factor for the regrowth are used to calculate the amount of herbage consumed in the area. This method is easy to apply and gives reliable data when grazing period is short and stocking rate is high; on the other hand Smith et al. (1988) mentioned the large variation associated with this method as the main disadvantage and it is more suitable to measure herbage intake for groups of animals.

Van dyne and Meyer (1964a) stated this method overestimates forage consumption by livestock because of herbage losses such as those due to weathering and trampling, and forage consumption by wildlife.

The other type of measurement referred as indirect techniques, consists of methods such as calculation of intake from fecal collection, ratio techniques and index procedures. Cordoba et al. (1978) stated the fecal collection is the oldest method for determining forage intake and digestibility; intake is estimated by combining determinations of digestibility of pastures grazed by animals with measurements of fecal output. They mentioned this method provides reliable estimates of forage intake but it has the disadvantage of being expensive, time consuming, and impractical under some situations. According to the same authors, the ratio techniques involve the calculation of digestibility and fecal output data through their ratio to an indigestible indicator or marker while the index procedures relate level of intake or digestibility to some component in the feces through a regression equation. Decruyenare et al. (2009) affirmed the use of markers implies the determination of natural indigestible plant components such as lignin, alkanes, or insoluble ashes which are excreted in the feces.

Van dyne and Meyer (1964a) affirmed the lignin ratio technique has been widely used in the United States although they mentioned some disadvantages such as lignin not being a distinct chemical entity, the possibility of impurities to become attached to lignin during chemical analysis, the introduction of high errors in sampling of forage actually consumed due to selective grazing, the tediousness and expensive of the method, the possibility of a partial digestion of lignin and the occurrence of changes in chemical

composition of lignin in the digestive tract. According to the same authors, chromogen and silica has also been used as naturally occurring indicators in range forage. Silica was reported to be a good marker for digestibility trials that could be used to estimate intake if an accurate estimate can be made of dietary silica content while the use of chromogen was reported to be unsatisfactory when used in winter range forage because of variable levels in the plants.

Van Dyne and Meyer (1964b) compared lignin and silica ratio techniques using cattle and sheep and found the method using silica gave more reliable and significantly higher estimates of forage intake (about 10% higher) than did the lignin ratio technique. Cook and Harris (1951) determined forage intake by sheep using the lignin ratio technique and chromogen method. Higher intakes were obtained using the lignin technique and the amounts agreed closely with average intakes observed for sheep. Lower values obtained using the chromogen method were attributed to the lower chromogen recovered in the feces than was actually consumed. In another study Macoon et al. (2003) estimated forage intake comparing the pulse-dose marker method using chromium-mordanted fiber as the external marker, the animal performance method, and the herbage disappearance method. Their results showed similar estimates of forage intake and a positive correlation between the animal performance and herbage disappearance methods, while the pulse-dose marker method overestimated intake comparing with the other two methods. These authors mentioned when using the marker method close attention should be paid to the procedure and precision in preparing the mordanted fiber, in dosing, in obtaining samples, in chemical analysis, and in quantifying supplement intake.

Decruyenare et al. (2009) described the n-alkanes method as the best one to estimate intake under grazing. This method is based on long-chain hydrocarbons (C_{25} to C_{35}) present in the cuticular wax of plants. Since odd-numbered chain length alkanes are present in greater amounts in grassland species, animals are dosed with a synthetic even-numbered alkan and then herbage intake can be calculated from the alkane dose, the alkane content in the herbage, and the ratio of the dosed and natural alkanes in the feces (Smith et al. 1988). According to Decruyenare et al. (2009), the fact that the plant organs and species present different n-alkanes profiles constitutes the major source of error in the estimation of intake from this method. When Smith et al. (1988) compared the sward cutting technique with the n-alkanes method using dairy cows for two years they found a weak relationship between both methods. In the first year dry matter intake was significantly higher for the n-alkane method but during the second year it was not significantly different from the sward cutting method. They concluded that the n-alkane method was a better technique to use in grazing animals since the cutting method provided results with high variation across years.

Index procedures use regression equations to relate level of intake or digestibility to some component in the feces. Studies of this type usually have dual objectives of estimating both intake and digestibility since some measurement of digestibility is necessary to calculate intake by grazing animals (Cordova et al. 1978). The most common technique is the fecal nitrogen index that requires herbage to be cut and fed to animals in dry-lot digestion trials to develop equations that relate fecal nitrogen content to organic matter digestibility of the forage or to the ratio of organic matter in the forage to that in feces. The main disadvantage of this procedure is the difficulty in obtaining

enough representative herbage with which to conduct the dry-lot digestibility trials, and that accurate estimates are given for groups of animals rather than for individual animals (Van dyne and Meyer 1964a).

Forage intake may also be predicted from performance of grazing animals; in order to apply this method it is necessary to know the energy concentration in the pasture grazed and the energy required to meet the observed performance of the grazing animal (Minson and Mc Donald, 1987). These authors estimated forage intake from animal growth using a multiple regression equation with liveweight and growth rate as explanatory variables and found that the differences between predicted and observed intake using this equation was 0.7%. Forage intake based on animal performance can also be predicted using an energetic model based on the NE equations in the beef NRC model (1996) This method is based on back-calculations of forage intake from individual animal average daily gain, known amounts of supplement intake in the case of supplementation, and known digestible energy densities for the forage and supplement. The NE adjusters have to be calculated for each animal in the model development data set until their ADG is accurately predicted by their TDN intake, obtaining in this way the amount of forage necessary to reach the observed performance (McDonald et al. 2007). Patterson et al. (2000) evaluated the accuracy of the NRC model equations in predicting intake and gain of growing calves. They found the model accurately predicted intake when the animals were fed diets containing moderate energy levels (0.58-0.60 Mcal/lb NEm), but when diets contained low and high energy levels, intake was over-predicted and under-predicted respectively.

Literature cited

- Adams , D. C., R. T. Clark, P. E. Reece, and J. D. Volesky. 1998. Research and education for managing resources with the Nebraska Sandhills: The Gudmundsen Sandhills Laboratory. *Rangelands* 20(5):4-8.
- Aitchison, E. M., M. Gill, M. S. Dhanoa, D. F. Osbourn. 1986. The effect of digestibility and forage species on the removal of digesta from the rumen and the voluntary intake of hay by sheep. *Brit. J. Nutr.* 56:463-476.
- Allison, D. 1985. Factors affecting forage intake by range ruminants: A review. *J. Range Manage.* 38 (4): 305-311.
- Allen, M. S., D. R. Mertens. 1988. Evaluating constraints on fiber digestion by rumen microbes. *The J. Nutr.* 118 :261-270.
- Anill, M. H., J. N. Mbanya, H. W. Symonds, J. M. Forbes. 1993. Responses in the voluntary intake of hay or silage by lactating cows to intraruminal infusions of sodium acetate, sodium propionate or rumen distention. *Brit. J. Nutr.* 69:699-712.
- Balch, C. C. 1950. Factors affecting the utilization of food by dairy cows. *Brit. J. Nutr.* 4:361- 388.
- Brake, A. C., A. L. Goetsch., L. A. Forster Jr., K. M. Landis. 1989. Feed intake, Digestion and Digesta characteristics of cattle fed bermudagrass or Orchardgrass alone or with ground barley or corn. *J. Anim. Sci.* 67:3425-3436.
- Bredon, R.M., D.T. Torell, and B. Marshall. 1967. Measurement of selective grazing of tropical pastures using esophageal fistulated steers. *J. Range Manage.* 20:317-320.
- Cable, D.R., and P.R. Shumway. 1966. Crude protein in rumen contents and in forage. *J. Range Manage.* 19:124-128.
- Caton, J. S., D. V. Dhuyvetter. 1997. Influence of energy supplementation on grazing ruminants: requirements and responses. *J. Anim. Sci.* 75:533-542.
- Campling, R. C., Freer, M., Balch, C. C. 1961. Factors affecting voluntary intake of food by cows. *Brit. J. Nutr.* 15:531-540.
- Campling, R. C., C. C. Balch. 1961. Factors affecting the voluntary intake of food by cows. 1. Preliminary observations on the effect, on the voluntary intake of hay, of changes in the amount of the reticulo-ruminal contents. *Brit. J. Nutr.* 15:523-530.
- Campling, R. C. 1964. Factors affecting voluntary intake of grass. *Proceedings of nutrition society.* 23:80-88.

- Campling, R. C., M. Freer., C. C. Balch. 1962. Factors affecting the voluntary intake of foods by cows. *Brit. J. Nutr.* 16: 115-124.
- Carr, S. B., D.R. Jacobson. 1966. Intraruminal addition of mass or removal of rumen contents on voluntary intake of the bovine. *J. Dairy Sci.* 50:1814-1818.
- Cogswell, C. and L.D. Kamstra. 1976. The stage of maturity and its effect upon the chemical composition of four native range species. *J. Range Manage.* 29(6):460-463.
- Conrad, H. R., A. D. Pratt., J. W. Hibbs. 1964. Regulation of feed intake in Dairy cows. I. Change in the importance of physical and physiological factors with increasing digestibility. *J. Dairy Sci.* 47:54-62.
- Chabot, D. A., C. D. Chabot., L. D. Conway., S. A. Soto-Navarro. 2008. Effect of fat supplementation and wheat pasture maturity on forage intake and digestion characteristics of steers grazing wheat pasture. *J. Anim. Sci.* 86:1263-1270.
- Crampton, E. W. 1957. Interrelations between digestible nutrient and energy content, voluntary dry matter intake, and the overall feeding value of forages. *J. Anim. Sci.* 16:546-552.
- Corrigan, E., G. Erickson, T. J. Klopfenstain, K. Vander Pol, M. Greenquist, M. Luebbe, K. Karges, M. Gibson. 2007. Effect of distillers grains composition and level on steers consuming high-quality forage. *Beef Cattle Rep.* MP 90:17-18.
- Conrad, H. R., A. D. Pratt, J. W Hibbs. 1964. Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. *J. Dairy Sci.* 47:54-62.
- Cook, C. W., L. E. Harris. 1951. A comparison of the lignin ratio technique and the chromogen method of determining digestibility and forage consumption of desert range plants by sheep. *J. Anim. Sci.* 10:565-573.
- Cordova, F. J., J. D. Wallace, R. D. Pieper. 1978. Forage intake by grazing livestock: a review. *Journal Range Manage.* 31:430-438.
- Dado, R. G., M. S. Allen. 1995. Intake limitations, feeding behavior, and rumen function of cows challenged with rumen fill from dietary fiber or inert bulk. *J. Dairy Sci.* 75:118-133.
- Dahl, B.E. 1963. Soil moisture as a predictive index to forage yield for the Sandhills range type. *J. Range Manage.* 16:128-132.
- Decruyenaere, V., A. Buldgen, D. Stilmant. 2009. Factors affecting intake by grazing ruminants and related quantification methods: a review. *Biotechnol. Agron. Soc. Environ.* 13:559-573.

- Deswysen, A. G., W. C. Ellis. 1988. Site and extent of neutral detergent fiber digestion, efficiency of ruminal digesta flux and fecal output as related to variations in voluntary intake and chewing behavior in heifers. *J. Anim. Sci.* 66:2678-2686.
- Forbes, T. D. 1988. Researching the plant-animal interface: the investigation of ingestive behavior in grazing animals. *J. Anim. Sci.* 66:2369-2379.
- Forbes, J. M. 1995. Voluntary food intake and diet selection in farm animals. Edit Cab international. Wallingford, UK. 532 p.
- Fontenot, J. P., R. E. Blaser. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: selection and intake by grazing animals. *J. Anim. Sci.* 24:1202-1208.
- Gammon, D. M. 1978. A review of experiments comparing systems of grazing management on natural pastures. *Proc. Grass. Soc. S. Afr.* 13:75-82.
- Garces-Yepez, P., W. E. Kunkle, D. B. Bates, J. E. Moore, W. W. Thatcher, L. E. Sollenberger. 1997. Effects of supplemental energy sources and amount on forage intake and performance by steers and intake and digestibility by sheep. *J. Anim. Sci.* 75:1918:1925.
- Geisert, B. G. 2007. Development of a set of forage standard to estimate in vivo digestibility of forages and prediction of forage quality of diets consumed by cattle grazing Nebraska Sandhills range pastures. PhD. Diss., Univ. Nebraska, Lincoln.
- Geisert, B. G., T. J. Klopfenstein, D.C. Adams, J. A. Musgrave and W. H. Schacht. 2008. Determination of diet protein and digestibility of native Sandhills upland range. *Nebraska Beef rep.* MP 91:20-22.
- Gillen, R. L., F. T. McCollum III, K. W. Tate, M. E. Hodges. 1998. Tallgrass prairie response to grazing system and stocking rate. *J. Range Manage.* 51:139-146.
- Gustad, K., L. Stalker, T. Klopfenstein, W. Schacht, D. Adams, J. Musgrave, J. Volesky. 2008. Use of dried distiller's grains to extend range capacity. *Beef Cattle Rep.* M91P :25-27.
- Hailim, R.A., D.R. Buxton, M.J. Hattendorf, and R.E. Carlson. 1989. Water stress effects on alfalfa forage quality after adjustment for maturity difference. *Agron. J.* 81:189-194.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, R. P. Huffman. 1994. Wet corn distillers by products compared with dried corn distillers grains with soluble as a source of protein and energy for ruminants. *J. Anim. Sci.* 72:3246-3257.
- Hart, R. H., M. M. Ashby. 1998. Grazing intensities, vegetation, and heifer gains: 55 years on shortgrass. *J. Range Manage.* 51:392-398.

- Hart, R.H., O.M. Abdalla, D.H. Clark, M.B. Marshall, M.H. Hamid, J.A. Hager, and J.W. Waggoner Jr. 1983. Quality of forage and cattle diets on the Wyoming High Plains. *J. Range Manage.* 36(1):46-49.
- Haugen, H. L., M. J. Lamothe, T. J. Klopfenstein, D. C. Adams and M. D. Ullerich. 2006. Estimation of undegradable intake protein in forages using neutral detergent insoluble nitrogen at a single in situ incubation time point. *J. Anim. Sci.* 84:651-659.
- Heitshmidt, R. K., M. M. Kothmann, W. J. Rawlins. 1982. Cow-calf response to stocking rates, grazing systems, and winter supplementation at the Texas Experimental Ranch. *J. Range Manage.* 35:204-210.
- Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. *J. Dairy Sci.* 69:2755-2766.
- Holecheck, J. L., and M. Vavra. 1983. Drought effects on diet and weight gains of yearling heifers in Northeastern Oregon. *J. Range Manage.* 38: 227-231.
- Holloway, J. W., W. T. Butts, Jr., J. D. Beaty., J. T. Hopper., N. S. Hall. 1979. Forage intake and performance of lactating beef cows grazing high or low quality pastures. *J. Anim. Sci.* 48:692-700.
- Hollingsworth-Jenkins, K. J., T. J. Klopfenstein, D. C. Adams, J. B. Lamb. 1996. Ruminally degradable protein requirement of gestating beef cows grazing native winter Sandhills range. *J. Anim. Sci.* 74:1343-1348.
- Jefferies, N.W. and R.W. Rice. 1969. Nutritive value of clipped and grazed range forage samples. *J. Range. Manage.* 22:192-195.
- Johnson, T. R., D. K. Combs. 1991. Effects of prepartum diet, inert rumen bulk, and dietary polyethylene glycol on dry matter intake of lactating dairy cows. *J. Dairy Sci.* 74:933-944.
- Johnson, T. R., D. K. Combs. 1992. Effects of inert rumen bulk on dry matter intake in early and midlactation cows fed diets differing in forage content. *J. Dairy Sci.* 75:508-519.
- Jones, A. L., A. L. Goetsch, S. R. Stokes, M. Colberg. 1988. Intake and digestion in cattle fed warm or cool-season grass hay with or without supplemental grain. *J. Anim. Sci.* 66:194-203.
- Kellems, R. O., D. C. Church. 2009. *Livestock feed and feedings*. 6th ed. Pearson.
- Kiesling, H.E., A.B. Nelson, and C.H. Herbel. 1969. Chemical composition of Tobosa Grass collected by hand-plucking and esophageal-fistulated steers. *J. Range Manage.* 22:154-159.

- Klopfenstein, T. J., G. E. Erickson, V. R. Bremer. 2008. Board-invited review: Use of distillers by products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231.
- Lardy, G. P., D. C. Adams, T. J. Klopfenstein, R. T. Clark. 1999. First limiting nutrient for summer calving cows grazing autumn-winter range. *J. Range Manage.* 52:317-326.
- Lardy, G.P., D. C. Adams, T. J. Klopfenstein, D. Clark, J. Lamb. 1997. Seasonal changes in protein degradabilities of Sandhills native range and subirrigated meadow diets and application of a metabolizable protein system. *Nebraska Beef Rep.* MP 67-A:3-5.
- G. P. Lardy, D. C. Adams, T. J. Klopfenstein, and H. H. Patterson. 2004. Building beef cow nutritional programs with the 1996 NRC beef cattle requirements model. *J Anim Sci.* 82: 83-92.
- Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, R. P. Huffman. 1993. Feeding value of wet distillers by products for finishing ruminants. *J. Anim. Sci.* 71:2228-2236.
- Llamas-Lamas, G., D. K. Combs. 1991. Effect of forage to concentrate ratio and intake level on utilization of early vegetative alfalfa silage by dairy cows. *J. Anim. Sci.* 74:526-536.
- Lemus, R. 2008. Developing a grazing system. Cooperative Extension Service. Mississippi State University. Available at <http://msucares.com/crops/forages/newsletters/08/6.pdf>. Accessed Aug. 14, 2010.
- Loy, T., T. J. Klopfenstein, G. E. Erickson, C. Macken. 2003. Value of dry distillers grains in high forage diets and effect of supplementation frequency. *Beef Cattle Rep.* MP 86:8-10.
- Loy, T. W., J. C. Mac Donald, T. J. Klopfenstein, G. E. Erickson. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. *J. Anim. Sci.* 85:2625-2630.
- MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth bromegrass pastures. *J. Anim. Sci.* 85:2614-2624.
- MacDonald, J. C., T. J. Klopfenstein. 2004. Dried distillers grains as a grazed forage supplement. *Nebraska Beef Rep.* MP 87:25-27.

- Macon, B., L. E. Sollenberger, J. E. Moore, C. R. Staples, J. H. Fike, K. M. Portier. 2003. Comparison of three techniques for estimating the forage intake of lactating dairy cows on pasture. *J. Anim. Sci.* 81:2357-2366.
- Manley, W. A., R. H. Hart., M. J. Samuel., M. A. Smith., J. W. Waggoner, JR., J. T. Manley. 1997. Vegetation, cattle, and economic responses to grazing strategies and pressures. *J. Range Manage.* 50:638-646.
- Matejovsky, K. M., D. W. Sanson. 1995. Intake and digestion of low, medium, and high-quality grass hay by lambs receiving increasing levels of corn supplementation. *J. Anim. Sci.* 73:2156-2163.
- McCollum, F. T., R. L. Gillen, B. R. Karges, M. E. Hodges. 1999. Stocker cattle response to grazing management in tallgrass prairie. *J. Range Manage.* 52:120-126.
- Mckown, C. D., J. W. Walker., J. W. Stuth, R. K. Heitschmidt. 1991. Nutrient intake of cattle on rotational and continuous grazing treatments. *J. Range Manage.* 44:596-601.
- Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. *J. Anim. Sci.* 64:1548-1558.
- Minson, D. J., C. K. Mc Donald. 1987. Estimating forage intake from the growth of beef cattle. *Tropical Grasslands.* 21:116-122.
- Morris, S., T. J. Klopfenstein, D. Adams, G. E. Erickson, K. Vander Pol. 2005. The effects of dried distillers grains on heifers consuming low or high quality forage. *Nebraska Beef Rep.* MP 88: 18-20.
- Murdoch, J. C. 1964. Some factors affecting the efficient utilization of conserved grass. *Proceedings of the nutrition society.* 23:99-107.
- Nebraska Corn Board. Uses of Corn. Available at: <http://www.nebraskacorn.org/main-navigation/corn-production-uses/uses-of-corn>. Accessed Sep. 19, 2010.
- NRC. 1996. Nutrient requirement of beef cattle. 7th ed. Nat. Acad. Press, Washington D. C.
- Nuttelman, B., T. J. Klopfenstein, G. E. Erickson, W. Griffin, M. Luebbe. 2008. The effects of supplementing wet distillers grains mixed with wheat straw to growing steers. *Nebraska Beef Rep.* MP 91:33-34.
- Nuttelman, B., M. Luebbe, J. Benton, T. J. Klopfenstein, L. A. Stalker, G. E. Erickson. 2009. Energy value of wet distillers grains in high forage diets. *Nebraska Beef Rep.* MP 92:28-29.

- Nuttelman, B., W. A. Griffin, T. J. Klopfenstein, W. H. Schacht, L.A. Stalker, J. A. Musgrave, J. D. Volesky. 2010. Supplementing wet distillers grains mixed with low quality forage to grazing cow/calf pairs. *Nebraska Beef Rep.* MP 93: 19-21.
- Peterson, P.R., C.C. Sheaffer, and M.H. Hall. 1992. Drought effects on perennial forage legume yield and quality. *Agron. J.* 84:774-779.
- Patterson, T., Klopfenstein, T., Adams, D., Schacht, W., Reece, P., Musgrave, J., Johnson, A. 1999. Summer grazing date and fall grazing intensity effects on protein content and digestibility of fall diets in the Nebraska Sandhills. *Nebraska Beef Rep.* MP 71-A:5-6.
- Patterson, H. H., T. J. Klopfenstein, D. C. Adams, and J. A. Musgrave. 2003. Supplementation to meet metabolizable protein requirements of primiparous beef heifers: I. Performance, forage intake, and nutrient balance. *J. Anim. Sci.* 81:800-811.
- Patterson, T., T. Klopfenstein, T. Milton, D. Brink. 2000. Evaluation of the 1996 beef cattle NRC model predictions of intake and gain for calves fed low or medium energy density diets. *Nebraska Beef Rep.* MP 73-A: 26-29.
- Ralphs, M. H., Kothmann, M. M., Taylor, C. A. 1990. Vegetation response to increased stocking rates in short duration grazing. *J. Range Manage.* 43:104-109.
- Rauzi, F. 1964. Late-spring herbage production on shortgrass rangeland. *J. Range Manage.* 17:210-212.
- Reppert, Jack N. 1960. Forage preference and grazing habits of cattle at the Eastern Colorado Range Station. *J. Range Manage.* 13:58-65.
- Rogers, J.D. and T.W. Box. 1967. Seasonal protein content of four southern mixed prairie grasses. *J. Range Manage.* 20:177-178.
- Sims, P. L., R. L. Gillen. 1999. Rangeland and steer responses to grazing in the southern plains. *J. Range Manage.* 52:651-660.
- Smith, H. J., H. Z. Taweel, B. M. Tas, S. Tamminga, A. Elgersma. 2005. Comparison of techniques for estimating herbage intake of grazing dairy cows. *J. Dairy Sci.* 88:1827-1836.
- Smoliak, S. 1956. Influence of climatic conditions on forage production of shortgrass rangeland. *J. Range Manage.* 9:89-91.
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 77:1-12.

- Stubbenieck, J. and P. E. Reece. 1992. Nebraska hand book of range management. EC-92-124-E.
- Taylor, C. A., M. M. Kothmann, L. B. Merrill, D. Elledge. 1980. Diet selection by cattle under high-intensity low frequency, short duration, and Merrill grazing systems. *J. Range Manage.* 33:428-434.
- Tjardes, K., C. Wright. 2002. Feeding corn distiller's co-products to beef cattle. *Extension Extra*. South Dakota State University. Available at <http://agbiopubs.sdstate.edu/articles/ExEx2036.pdf>. Accessed April 25, 2010.
- Thurrow, T. L., W. H. Blackburn, C. A. Taylor. 1988. Some vegetation responses to selected livestock grazing strategies, Edwards Plateau, Texas. *J. Range Manage.* 41:108-114.
- USDA National Statistics Service. 2007. Agriculture Censuses. Available at http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Nebraska. Accessed Aug. 20, 2010.
- Vander Pol, K. J., M. K. Luebke, G. I. Crawford, G. E. Erickson, T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. *J. Anim. Sci.* 87:639-652.
- Van Dyne, G. M., J. H. Meyer. 1964a. A method for measurement forage intake of grazing livestock using microdigestion techniques. *Journal Range manage.* 17:204-208.
- Van Dyne, G. M., J. H. Meyer. 1964b. Forage intake by cattle and sheep on dry annual range. *J. Anim. Sci.* 23:1108-1115.
- Van Soest, P. J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. *J. Anim. Sci.* 24:831-843.
- Vavra, M., R.W. Rice, R.E. Bement. 1973. Chemical composition of the diet, intake and gain of yearling cattle on different grazing intensities. *J. Range Manage.* 36(2):411-414.
- Wallace, J.D., J.C. Free, and A.H. Denham. 1972. Seasonal changes in herbage and cattle diets on Sandhills Grassland. *J. Range Manage.* 25:100-104.
- Weiss, B., M. Eastridge, D. Shoemaker, N. St-Pierre. 2007. Distillers grains. Fact Sheet. Ohio State University. Available at <http://ohioline.osu.edu/as-fact/pdf/distillers.pdf>. Accessed April 25, 2010.
- Welch, J. G. 1967. Appetite control in sheep by indigestible fibers. *J. Anim. Sci.* 26:849-854.

Willms, W. D., S. Smoliak., G. B. Schaalje. 1986. Cattle weight gains in relation to stocking rate on rough fescue grassland. *J. Range Manage.* 39:182-187.

Materials and Methods

The experiment was conducted during the summer of 2009 and 2010 at the university of Nebraska Gudmundsen Sandhills Laboratory (GSL) located near Whitman, NE (elevation 1,703 m, lat 42° 05'N, long 101° 26'W). Average precipitation during the months in which the study was conducted is presented in Table 1. Treatments were randomly assigned to forty 1 ha paddocks and consisted of: 1) Control (CON) at the recommended stocking rate (1.68 AUM/ha in 2009 and 1.64 AUM/ha in 2010), 2) double stocked (3.18 AUM/ha in 2009 and 3.26 AUM/ha in 2010) supplemented with a mixture consisting of 60% straw and 40% wet distillers grains (WDGS) (STRAW), 3) double stocked (3.30 AUM/ha in 2009 and 3.28 AUM/ha in 2010) supplemented with 60% hay and 40% WDGS (LOW), and 4) double stocked (3.26 AUM/ha in 2009 and 3.25 AUM/ha in 2010) consuming a supplement made of 70% hay and 30% WDGS (HIGH).

The experiment was replicated over two blocks based on location (east and west) due to variation in species composition and topography among the forty paddocks. Experimental unit was a set of 5 paddocks that were assigned to a treatment. The 5 paddocks were rotationally grazed once during the experimental period of 68 d from June 18th to August 26th in 2009 and from June 17th to August 25th in 2010, with days of grazing per paddock adjusted to account for stage of plant growth. The first assigned paddock was grazed for 12 days and the other 4 paddocks were grazed for 14 days because as the growing season advanced forage availability was expected to increase. In both years, the same pastures were grazed by the same treatment but the rotation order was changed to maximize recovery and to graze the pastures at different times in the

growing season. The paddocks grazed at double stocking rates were divided in half on a diagonal with a temporary electric fence to decrease area of grazing, allowing the cattle to graze 0.5 ha per grazing period.

Forty summer born yearling steers (323 ± 15 kg initial weight in 2009 and 327 ± 15 kg in 2010) were stratified by BW and assigned randomly to treatment paddocks, using five steers per treatment on each block. Steers were limit fed a mixture of 60% hay and 40% WDGS at 2% of BW daily for 5 days to eliminate variation due to gut fill and individually weighed for 3 consecutive days at the beginning and end of the trial. The averages of the 3-d weights were used as the initial and final body weight. When Gustad (2006) conducted a trial in the Sandhills and compared the weight gains of calves from pastures stocked at the recommended and double the recommended stoking rates, she found no difference in ADG between the two groups and attributed this response to a metabolizable protein (MP) deficiency since a later analysis using the NRC (1996) model showed a MP deficiency of 147 g/d. For this reason, cattle in the control treatment received $0.36 \text{ kg} \cdot \text{d}^{-1}$ of a protein supplement to meet the MP requirements. The supplement was composed of 50% soy pass, 45% corn gluten meal, and 5% molasses. WDGS in the mixes were expected to provide the MP to the supplemented steers. Cattle in the double stock treatments were supplemented daily with their mixes at a targeted rate of 1.15% BW on a DM basis. This percentage was chosen because it represents 50% of their daily intake (Meyer, 2010). A vertical mixer was used to mix the supplements for the double stocked treatments, and the mixtures were stored in silage bags 30 d prior to the initiation of the trial. Water was added to the mixes until percent moisture was equal to 50% for all mixes. Every morning the supplements were fed in feed bunks located

next to the paddocks to measure any feed refusals. Orts were weighed to accurately estimate total consumption of the mixes. All animal procedures were approved by the University of Nebraska Animal Care and Use Committee.

Forage quality (IVOMD, CP, NDF) were analyzed from extrusa samples collected from each paddock at mid-point of each grazing period using esophageally fistulated cows. Two cows were used per paddock; they were held off feed over night and allowed to graze each paddock for 15 to 30 minutes. Screen bottom bags were used to collect the diets and the samples were compressed to remove the saliva and freeze dried for further analysis. Diets were collected at mid-point of grazing period to obtain diet samples representing the average diet quality for the whole grazing period.

Diet samples, grass hay and wheat straw were ground through a Wiley mill (Thomas Scientific, Swedesboro, NJ) fitted with a 1-mm screen for all laboratory analysis. Two ruminally fistulated steers housed in individual pens and fed a basal diet of Smooth brome (*Bromus inermis*) hay were utilized as donors to provide inoculant for IVOMD. In vitro organic matter disappearance was determined using the Tilley and Terry method (1963) modified by the addition of 1g/L of urea to the McDougall's buffer (Weiss, 1994). Two separate in vitro runs were conducted and five forage standards of different qualities and known in vivo OM digestibilities were included in all of the IVOMD runs. To correct the IVOMD to in vivo values, regression equations were generated for each run, by regressing the IVOMD values of the standards on their known digestibilities. This method was described by Geisert et al. (2006). The NDF content of the diets was determined by the method of Goering and Van Soest (1970). Nitrogen

concentration was determined by the combustion method (AOAC, 1996) using a combustion N analyzer (Leco FP-523, St Joseph, MI) with CP calculated as $N \times 6.25$.

Post-grazing standing crop was determined from each paddock by clipping five randomly selected locations per paddock using 0.25 m² quadrats. Pastures were clipped at the end of the grazing period in late June, mid-July, late July, mid-August, and late August. Plants in the quadrats were clipped at ground level and samples were sorted by live grass, standing dead grass, forbs, shrubs, and litter. Samples were dried in a forced air oven for 48 hours at 60°C and weighed. Pre-graze forage availability was calculated by adding an estimated amount of forage intake to the amount of forage remaining in the paddocks at the end of the grazing period. The control paddocks were used as a reference for the remaining forage, whereas forage consumption was obtained based on the estimated intake of 2.30% BW of forage DM (Meyer, 2010). DM disappearance from each paddock was calculated by subtracting the amount of post-graze remaining forage from pre-graze forage availability. Percent utilization was determined by dividing DM disappearance by the amount of pre-graze forage availability. Forage DM disappearance was used to estimate daily forage intake by dividing forage disappearance by the number of animals grazing the paddock and the number of days in the grazing period. NDF intake was determined based on the range forage and supplement intakes and their respective NDF content.

All data were analyzed using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). Animal performance was analyzed as a randomized complete block design with treatment, year, and block analyzed as fixed effects. Standing crop data were

analyzed with year, treatment, order grazed, and block as fixed variables, and pasture as random effect. IVOMD, crude protein and NDF were analyzed with year, treatment, and order grazed as fixed variables; they were also analyzed using the REG procedure of SAS. Least square means were separated using the Least Significant Difference method when an overall significant treatment ($P \leq 0.05$) F-test was detected. Paddock was the experimental unit. Differences were considered significant when $P \leq 0.05$. Significance of interactions was determined at the 1% significance level.

Results and Discussion

During both years of the trial, there were no differences between treatments for initial BW ($P = 0.92$). Final BW was significantly lower ($P = 0.02$) for the steers in the STRAW compared with the CON, HIGH, and LOW treatments (318, 362, 359, and 370 kg respectively (Table 2). A significant year by treatment interaction ($P < 0.01$) occurred for average daily gain; therefore data are presented by year. In 2009, similar ADG was observed for the CON and HIGH treatments ($P = 0.48$); however steers in the LOW and STRAW treatments showed significantly higher ADG than CON ($P < 0.05$) and tended ($P = 0.08$) to be greater than HIGH. LOW steers outgained CON and HIGH steers by 0.16 and 0.12 kg per day respectively, whereas steers in the STRAW treatment outgained CON and HIGH steers by 0.15 and 0.12 kg per day, respectively. There was no significant difference between the LOW and STRAW treatments ($P = 0.89$). In 2010, steers in the CON, HIGH, and LOW treatments achieved significantly higher daily gains than steers in the STRAW treatment ($P < 0.01$). Steers supplemented with the mix

containing 60% straw and 40% WDGS gained 0.21, 0.14, and 0.23 kg/d less than the CON, HIGH, and LOW steers respectively.

During the first year of the experiment, steers in the supplemented treatments achieved similar or higher gains than the CON steers even when the stocking rate was doubled for the supplemented pastures. The satisfactory gains observed in the supplemented treatments could be attributed mainly to the energy value of distillers grains. The energy value of wet distillers byproducts has been calculated to be about 97 to 147% the net energy value of corn (Stock et al. 2000). In addition to this high energetic content, the fact that starch has been removed from WDGS and that energy comes from highly digestible fiber which offset the negative associative effect related to high starch feeds makes WDGS more favorable to improve performance of grazing cattle. Even though distillers grains are a good source of CP (30%) and UIP (52%), the increase in gain observed for the supplemented steers was not a response to the protein content of the mixes because steers in the CON were offered a protein supplement in quantities sufficient to meet their metabolizable protein requirements. Lower gains observed for the HIGH treatment in comparison to the other two supplemented treatments could be due to the lower content of WDGS and the higher proportion of low quality hay in the mix.

During the second year the lower gains observed in all treatments with respect to the previous year could be related to the lower quality of the range forage in 2010; however, the lack of response to supplementation for the supplemented treatments was unexpected. The lower gain observed in the STRAW treatment was anticipated since the

consumption of the supplement was lower than in the previous year. The energy content of the supplements was on average 19% higher than the range forage; therefore a performance at least similar to the CON was expected for the steers supplemented with the different mixes. A possible cause for this result could be the low number of replications used in the trial since only 5 animals were used in each block making a total of 10 animals per treatment. If a higher number of animals could be used, the low performance that might be observed in a few animals would be offset by the rest of the animals in the same treatment.

When analyzing previous studies, a favorable response was observed to wet distillers grains supplementation in grazing situations. Nuttelman et al. (2010) supplemented cow-calf pairs with 6.64 kg/pair daily of a mix consisting of 55% grass hay and 45% WDGS. Cow-calf pairs were managed in a rotationally grazed system stocked at double the recommended stocking rate (2.96 AUM/ha). Average daily gain for the cows and calves receiving the supplement was 0.70 and 0.25 kg respectively, higher than the control group (no supplement, and stocked at the recommended stocking rate of 1.48 AUM/ha) and 0.77 and 0.32 kg, respectively, higher than the 2X group (no supplement and double stocked). In another study the same authors supplemented cow-calf pairs grazing at double the recommended stocking rate (2.96 AUM/ha) with mixes consisting of 50:50, 40:60, or 30:70 WDGS and wheat straw, and compared them with a control group stocked at the recommended stocking rate (1.48 AUM/ha). Again in this trial they found higher ADG for the supplemented groups and the highest gains were obtained in the 50:50 WDGS:wheat straw treatment.

Gustad et al. (2008) supplemented calves grazing native summer Sandhills range at double the recommended stocking rate (1.2 AUM/ha) with $2.27 \text{ kg hd}^{-1} \text{ d}^{-1}$ of DDGS, and compared the performance with calves in a control group (1.48 AUM/ha) and a double stocked treatment with no supplementation. Their results also showed higher ADG for the supplemented calves that gained 148% more than the non-supplemented groups. Loy et al. (2003) studied the effects of supplementing DDGS to heifers fed chopped native grass hay. Heifers were offered supplements based on DDGS, dry rolled corn, or dry rolled corn with corn gluten meal at 0.21 or 0.81% of BW. Heifers fed at 0.21% of BW achieved higher weight gains when consuming the DDGS supplement while similar gains were observed for heifers fed DDGS or dry rolled corn with corn gluten meal when supplemented at 0.81% of BW. McDonald et al. (2007) also observed higher daily gains when heifers grazing smooth bromegrass were supplemented with DDGS (150, 1,500, or 2,250 g/d) compared with heifers supplemented with corn oil or corn gluten meal (375, 750, or 1,125 g/d).

Pre-graze available forage was assumed to be the same for all treatments (Table 3). During the second year of the trial pre-graze forage was on average 93.13 kg/ha greater than the first year but this difference was not significant ($P = 0.14$). Pre-graze forage averaged across years and treatments varied significantly throughout the experimental period ($P = 0.02$). The amount of pre-graze forage available in the first paddock of the rotation sequence was significantly lower than the amount available in subsequent paddocks; there was not a significant difference among the next three paddocks but the amount of pre-graze forage in the last paddock was numerically higher ($P > 0.05$; Table 4). No year by treatment interaction ($P = 0.83$) was observed for

standing forage after the paddocks were grazed. There was a significant effect of block ($P < 0.01$) with the amount of standing forage in the east block being 13% greater than in the west block during the whole experimental period (Figure 1). This effect indicates the amount of pre-graze forage was higher in block 2 probably because of variations in topography. The amount of standing forage at the end of grazing was significantly higher for the CON than for the other three treatments ($P < 0.01$), however there was not a significant difference between the mix treatments ($P > 0.05$; Table 3). Since the stocking rates were doubled in the supplemented groups, less standing forage was expected for these groups. Given the amount of standing forage for each treatment, it is possible some replacement of forage occurred as a result of the consumption of the different types of supplements. If the mixes did not replace any forage, then the standing forage for this group should have been at least 50% less than the control groups. Standing forage for the supplemented double stocked treatments was on average 26% less than the CON in the HIGH and LOW treatments and 30% less in the STRAW treatment. Standing crop increased significantly ($P < 0.01$) from 693 kg/ha from the first paddock to 1117 kg/ha for the fifth paddock (Table 4). Even though the occupation period was 2 days shorter in the first paddock, a significantly higher amount of forage was left after grazing the second paddock and significant increases were continuously observed throughout the rest of the grazing period.

The variation in the amount of pre-graze and post-graze standing forage during the growing season agrees with the results found by Gustad (2008) and Nuttelman (2010) who also reported increasing forage availability throughout the summer in the Sandhills. As the growing season advanced, an increase in the amount of available forage is

expected since the pasture is composed mostly of warm season grasses, and the peak production for these grasses occurs between July and August (Stubbendiek and Reece, 1992). The pastures utilized in the last rotations of the trial (mid July through late August) had additional time to grow and even though the occupation time was shorter in the first rotation, the amount of forage remaining after grazing was lower compared with the last rotations.

No year by treatment ($P = 0.82$) or year by rotation ($P = 0.74$) interaction occurred for forage dry matter disappearance. The CON treatment presented significantly lower forage dry matter disappearance (DIS) ($P < 0.01$) than all the supplemented treatments and it was similar among supplemented treatments ($P > 0.05$) which suggests that forage consumption was similar for all supplemented steers (Table 2). As was the case for post-graze forage availability; this result was expected since the stocking rate was doubled in the supplemented treatments. The amount of forage dry matter DIS was significantly lower for the first paddock compared with the other four paddocks ($P < 0.05$), this difference is expected since the occupation time in the first paddock was 2 days shorter than in the following paddocks (Table 4). There was not a significant year by treatment interaction for forage utilization ($P = 0.78$). Similar to forage dry matter DIS, percent utilization was significantly lower for the CON ($P < 0.01$) but it was not different among the supplemented treatments ($P > 0.05$; Table 3). Utilization was affected by rotation ($P = 0.04$), the first two paddocks presented higher forage utilization than the last paddocks, which was a consequence of lower forage availability at the beginning of the trial (Table 4).

Daily supplement intakes, range forage, and total DM intake are presented in Table 3. Consumption of the supplement was not different among treatments ($P = 0.17$), over the whole experimental period, steers consumed on average 0.93% BW of the mixes. However, the amount of the 60% straw and 40% WDGS consumed over the whole experimental period tended to be lower than the intake of the 60 hay:40 WDGS and 70 hay:30 WDGS supplements ($P = 0.06$ and 0.07 respectively). The year by treatment interaction was not significant for supplement intake, forage intake, and total DM intake ($P > 0.05$). The amount of range forage consumed by the CON steers was significantly higher compared with the amount consumed by the supplemented steers ($P < 0.05$). On average steers in the CON consumed 1.41, 1.71, and 1.76 kg/day more range forage than steers in the STRAW, LOW, and HIGH treatments, respectively; therefore, supplementation with a low-quality harvested-forage and WDGS reduced intake of range forage by 17.8, 21.6, and 22.2% for the STRAW, LOW, and HIGH treatments respectively, compared with the CON. The amount of range forage intake was not significantly different among the supplemented treatments ($P > 0.05$). Total DM intake was numerically lower for the CON than for the HIGH and LOW treatments, on average CON steers consumed 1.38, 1.58, and 1.64 kg less total DM than the STRAW, LOW, and HIGH respectively; however, this difference was not significant ($P = 0.10$). Considering the amount of range forage replaced and the amount of supplement consumed by the supplemented treatments, 1 kg of the LOW, HIGH, and STRAW treatments replaced 0.52, 0.51, and 0.52 kg of range forage, respectively.

Total NDF consumed was examined to see if it had an effect on dry matter intake (Table 3). Diets composed of low quality forages are thought to be limited by physical

distention in the gastrointestinal tract. When NDF from total DMI was considered, NDF intake by steers in the CON treatment (5.66 kg) tended to be significantly lower than the amount of NDF consumed by the steers in the HIGH, STRAW and LOW treatments (6.60, 6.45, and 6.20 kg respectively; $P = 0.08$). Steers in the supplemented treatments had similar total DMI as the CON steers, and the total amount of NDF consumed also tended to be similar. These results suggest gut fill plays an important role in limiting forage intake. NDF is considered to be associated with space occupying properties of rumen digesta since it represents the structural cell wall (Dado and Allen, 1995).

However in the supplemented treatments 40 and 30% of the NDF consumed from the mixes is coming from the WDGS that contain on average 40% NDF, but lignin accounts for only 10% of the total NDF (NRC, 1996). The digestion of forages is considered to be primarily limited by lignin. (Van Soest, 1965; Aitchison et al., 1986; Forbes, 1995).

Lignin is the indigestible fraction of NDF; therefore, it reduces the potentially digestible fiber fraction in forages (Traxler et al., 1998). Van Soest (1965) stated intake is positively related with digestibility, for this reason, a high amount of lignin will have a detrimental effect on forage intake. Therefore, the filling effect of the NDF from WDGS can be considered minimal. The filling effect that would regulate intake is coming from the NDF contained in the straw and hay portion of the mixes which contain a high percentage of lignin. If only the amount of NDF supplied by the range forage and the hay or straw portion of the mixes is considered a total NDF intake of 5.66, 6.20, 6.02, and 5.83 kg results for CON, HIGH, STRAW, and LOW respectively, which are not significantly different ($P = 0.30$).

Nuttelman et al. (2010) supplemented cow-calf pairs with a mix containing 52% grass hay and 45% WDGS at a rate of 50% of the estimated DMI. They found supplemented pairs consumed 13.5% less range forage than animals receiving no supplementation and calculated 1 kg of the mix replaced 0.22 kg of range forage. In another trial the same authors supplemented grazing cows with mixes containing 70:30 WDGS and wheat straw, 60:40 WDGS and wheat straw, and 50:50 WDGS and wheat straw. Using these mixes they found replacement rates of 47, 35, and 36% for the 70:30, 60:40, and 50:50 mixes respectively. These replacement rates are higher than the ones found in this study. Comparing the 60:40 mixes containing straw from both trials, the replacement rate in this study was 13% lower than the rate reported by Nuttelman et al. (2010). However, diets in this trial contained more NDF than in the previous trial (73 vs. 57%). This high amount of NDF probably limited the amount of range forage consumed by the CON steers, and therefore a smaller difference in intake between the CON and supplemented steers was observed in this study.

Results of diet quality analysis are presented in Tables 5 and 6. The year by treatment interaction was not significant for IVOMD ($P = 0.23$) and CP ($P = 0.16$). The main effect of year for IVOMD was significant ($P = 0.01$), with the highest digestibility observed in 2009 (Figure 2). Over the two years of the trial, IVOMD at mid-point of the grazing period was not significantly different among treatments ($P = 0.37$). There was a numeric decrease ($P = 0.09$) in IVOMD throughout the grazing period with the highest values observed early in the grazing season for the first and second paddocks (54.65 and 52.89 % respectively) and the lowest values toward the end of the season in the fifth paddock (52.18%). The protein analysis revealed significant differences ($P < 0.03$)

between the CON and the STRAW and HIGH treatments (7.87, 7.31, and 7.29% respectively). No difference was observed between CON and LOW (7.54%) ($P > 0.05$), with LOW having intermediate values between CON and HIGH and STRAW. The decrease in CP over the grazing period is illustrated in Figure 3, crude protein declined linearly from the first to the last paddock. A significant decline was observed between the first two paddocks which had the highest values (8.60 and 8.19%, respectively) and the last two paddocks with the lowest protein content (6.82 and 6.37% , respectively; $P < 0.01$). There was a significant main effect of year ($P < 0.01$) and again in 2009 the pastures presented higher CP content than in 2010 (Figure 2).

Due to significant interaction between years ($P = 0.02$) the NDF data are presented by year. In the first year, the CON and STRAW treatments contained significantly higher percentages of NDF than the LOW and HIGH treatments (74.56, 78.66, 67.30, and 69.75% respectively ($P = 0.05$). Variation in NDF did not show a consistent pattern throughout the different paddocks; it decreased from 70.85 to 67.74% from paddock 1 to 3 and then increased again to 77.59% from paddock 3 to 5; however this difference was not significant ($P < 0.32$). During the second year of the trial, NDF content of the diet samples was not different ($P = 0.43$) between CON, HIGH, LOW, or STRAW (68.99, 72.13, 68.77, and 65.25% respectively). The variation of NDF tended to be different among paddocks ($P = 0.06$). The tendency was for NDF content to increase over time (Figure 4) with the last paddock showing an increase of 17% in NDF content compared to the first paddock.

In general diet quality decreased later in the growing season. This could be attributed to the fact that as the plant becomes more mature later in the growing season nutrients such as crude protein and digestibility decrease whereas fiber increases as a consequence of lignification of the plant and a decreased leaf:stem ratio. The observed changes in forage quality are similar to those found in previous studies. Gustad et al. (2008) reported a decrease in IVOMD and CP of grazed forage from the beginning to the end of the grazing period (mid June to mid August). Results obtained by Nuttelman et al. (2010) showed the same pattern. They reported a decrease of 5.2% and 11% in IVOMD and CP respectively later in the grazing season. Geisert (2007) studied the effect of time of the year on digestibility and protein content of rangelands in the Sandhills. Her results indicated highest CP and digestibility during April and May followed by a decline throughout the summer. She also reported a decrease in NDF content of the range forage during July and August with a subsequent increase in fiber content during the rest of the dormant season. She attributed these changes to the vegetative growth of warm season grasses observed during the months of July and August.

Besides the effect of increasing plant maturity, the decrease in forage quality during the grazing period could have also been a consequence of the greater than normal rainfall that occurred during the experimental period. The abundant precipitation caused the forage to grow and mature more rapidly than normal, increasing forage availability but decreasing forage quality. Other authors have found similar effects of precipitation on forage quality. Hailim et al. (1989) observed a linear decrease in plant maturity with increasing water stress with a subsequent increase in CP and decrease in cellulose

concentration. Peterson et al. (1992) also reported increased quality in legumes during drought because of delayed maturity and greater leaf:stem ratio.

Summary

The main objective of this trial was to replace 50% of range forage intake by supplementing the animals with 50% of their expected DM intake with mixes containing low quality forage and WDGS. The findings of this study show some replacement, with the rate varying between 17.8 and 22.2% much less than the targeted 50%. The NDF content of the low quality forage should have provided the filling effect while the WDGS were added to improve palatability of the hay and straw. If the animals ate more of the mixtures, a higher replacement rate would be expected. However over the course of the entire trial the steers left on average 20% of the offered supplement in the bunks. Therefore it would be unlikely to obtain higher intakes of this type of supplement in situations where range forage is not limiting to the steers.

During the first year of the study, all supplemented treatments achieved higher average daily gains than the CON steers. During the second year, the steers supplemented with the mixes containing hay achieved similar gains as the CON while the steers in the STRAW treatment gained less than the CON and the other supplemented treatments since mix intake was lower in the STRAW treatment. The response observed in the second year was unexpected since the supplemented animals consumed on average a greater amount of total DM compared to the CON and therefore higher gains should have been achieved. In general, the supplemented animals exhibited good performance compared to the CON considering the stocking rate was doubled in the supplemented

treatments. Therefore, supplementing grazing animals with mixes containing low quality forage and WDGS could be an alternative to extend the grazing season maintaining the same stocking rate or increase stocking rates during a shorter grazing season without having a negative effect on the pastures.

Literature cited

- Aitchison, E. M., M. Gill, M. S. Dhanoa, D. F. Osbourn. 1986. The effect of digestibility and forage species on the removal of digesta from the rumen and the voluntary intake of hay by sheep. *Brit. J. Nutr.* 56:463-476.
- Dado, R. G., M. S. Allen. 1995. Intake limitations, feeding behavior, and rumen function of cows challenged with rumen fill from dietary fiber or inert bulk. *J. Dairy Sci.* 75:118-133.
- Forbes, J. M. 1995. Voluntary food intake and diet selection in farm animals. Edit Cab international. Wallingford, UK. 532 p.
- Geisert, B. G. 2007. Development of a set of forage standard to estimate in vivo digestibility of forages and prediction of forage quality of diets consumed by cattle grazing Nebraska Sandhills range pastures. PhD. Diss., Univ. Nebraska, Lincoln.
- Gustad, K. 2010. The use of dried distillers grains to extend range capacity. Univ. Neb. MS Thesis.
- Gustad, K., L. Stalker, T. Klopfenstein, W. Schacht, D. Adams, J. Musgrave, J. Volesky. 2008. Use of dried distiller's grains to extend range capacity. *Beef Cattle Rep.* M91P :25-27.
- Hailim, R.A., D.R. Buxton, M.J. Hattendorf, and R.E. Carlson. 1989. Water stress effects on alfalfa forage quality after adjustment for maturity difference. *Agron. J.* 81:189-194.
- Loy, T., T. J. Klopfenstein, G. E. Erickson, C. Macken. 2003. Value of dry distillers grains in high forage diets and effect of supplementation frequency. *Beef Cattle Rep.* MP 86:8-10.
- Meyer, T. L. 2010. Estimating livestock forage demand: defining the animal unit. Univ. Neb. MS Thesis.
- McDonald, J. C., T. J. Klopfenstein, G. E. Erickson, W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth brome grass pastures. *J. Anim. Sci.* 85:2614-2624.
- NRC. 1996. Nutrient requirement of beef cattle. 7th ed. Nat. Acad. Press, Washington D. C.
- Nuttelman, B., W. A. Griffin, T. J. Klopfenstein, W. H. Schacht, L.A. Stalker, J. A. Musgrave, J. D. Volesky. 2010. Supplementing wet distillers grains mixed with low quality forage to grazing cow/calf pairs. *Nebraska Beef Rep.* MP 93: 19-21.

- Peterson, P.R., C.C. Sheaffer, and M.H. Hall. 1992. Drought effects on perennial forage legume yield and quality. *Agron. J.* 84:774-779.
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 77:1-12.
- Stubbendieck, J. and P. E. Reece. 1992. Nebraska hand book of range management. EC-92-124-E.
- Traxler, M. J., D. G. Fox, P. J. Van Soest, A. N. Pell, C. E. Lascano, D. P. Lanna, J. E. Moore, R. P. Lana, M. Velez, A. Flores. 1998. Predicting forage indigestible NDF from lignin concentration. *J. Anim. Sci.* 76:1469-1480.
- Van Soest, P. J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. *J. Anim. Sci.* 24:831-843.

Table 1. Monthly average precipitation and long-term average precipitation (cm) at GSL before and during the months of the study.

	Jan	Feb	March	April	May	June	July	August
2009	3.0	4.07	0.57	9.62	11.22	15.85	12.70	17.20
2010	0.5	1.55	2.57	7.15	5.02	20.42	13.70	2.57
Avg (1983-2008)	0.72	0.75	1.72	4.92	7.25	8.0	7.05	4.95

Table 2. Animal performance

	Treatment				SE	P-value
	Control ¹	High ²	Low ³	Straw ⁴		
Initial BW (kg) 2009-2010	327	326	329	323	6.42	0.92
Final BW (kg) 2009-2010	362 ^a	359 ^a	370 ^a	318 ^b	12.05	0.02
ADG (kg) 2009	0.48 ^a	0.51 ^a	0.64 ^b	0.63 ^b	0.07	0.03
ADG (kg) 2010	0.53 ^a	0.46 ^a	0.56 ^a	0.32 ^b	0.04	<0.01

¹CONTROL=Cattle grazed at the recommended stocking rate (1.68AUM/ha in 2009; 1.64 AUM/ha in 2010).

²High=Cattle grazed at double the recommended stocking rate (3.26 AUM/ha in 2009, 3.25 AUM/ha in 2010) and supplemented with 70% grass hay and 30% WDGS at estimated 50% of daily DM intake.

³Low= Cattle grazed at double the recommended stocking rate (3.30 AUM/ha in 2009, 3.28 AUM/ha in 2010) and supplemented with 60% grass hay and 40% WDGS at estimated 50% of daily DM intake.

⁴Straw= Cattle grazed at double the recommended stocking rate (3.18 AUM/ha in 2009, 3.26 AUM/ha in 2010) and supplemented with 60% wheat straw and 40% WDGS at estimated 50% of daily DM intake.

^{a,b}Different letters represent differences between treatments (P < 0.05).

Table 3. Standing forage, range forage utilization, mix, and NDF intake (2009 and 2010).

	Control ¹	High ²	Low ³	Straw ⁴	SE	P-value
Standing forage						
Pre-graze (kg/ha) ⁵	1659.06	1659.06	1659.06	1659.06		
Post-graze (kg/ha) ⁶	1133.48 ^a	826.91 ^b	834.25 ^b	787.96 ^b	35.09	<0.01
DIS (Kg/ha) ⁷	538.08 ^a	845.05 ^b	837.83 ^b	884.09 ^b	34.49	<0.01
% utilization ⁸	32.6 ^a	50.75 ^b	50.1 ^b	53.25 ^b	1.91	<0.01
Supplement intake ⁹ (kg/d)		3.35	3.34	2.8	0.2	0.17
Forage intake ¹⁰ (kg/d)	7.91 ^a	6.2 ^b	6.16 ^b	6.5 ^b	0.31	0.03
Total DM intake ¹¹ (kg/d)	7.91	9.56	9.49	9.3	0.46	0.1
NDF intake ¹² (kg/d)	5.66	6.6	6.2	6.45	0.22	0.08

¹CONTROL=Cattle grazed at the recommended stocking rate (1.68AUM/ha in 2009; 1.64 AUM/ha in 2010).

²High=Cattle grazed at double the recommended stocking rate (3.26 AUM/ha in 2009, 3.25 AUM/ha in 2010) and supplemented with 70% grass hay and 30% WDGS at estimated 50% of daily DM intake.

³Low= Cattle grazed at double the recommended stocking rate (3.30 AUM/ha in 2009, 3.28 AUM/ha in 2010) and supplemented with 60% grass hay and 40% WDGS at estimated 50% of daily DM intake.

⁴Straw= Cattle grazed at double the recommended stocking rate (3.18 AUM/ha in 2009, 3.26 AUM/ha in 2010) and supplemented with 60% wheat straw and 40% WDGS at estimated 50% of daily DM intake.

⁵The amount of forage available before grazing each paddock.

⁶The amount of forage available after grazing each paddock.

⁷DIS = amount of forage that disappeared during grazing period. Calculated by subtracting the amount of forage remaining after grazing from the amount of forage available before grazing each paddock.

⁸Percent of forage utilized during the grazing period. Calculated by dividing the amount of forage that disappeared during grazing period by the amount of forage available prior to the grazing period.

⁹Average amount of supplement intake during the experimental period.

¹⁰Average amount of range forage intake. Calculated by dividing amount of forage that disappeared during grazing period by the number of days each paddock was grazed and the number of animals in each paddock.

¹¹Amount of total DM intake. Calculated by adding forage intake and supplement intake.

¹²Amount of daily total NDF intake.

^{a,b}Different letters represent differences between treatments (P < 0.05).

Table 4. Standing forage and range utilization by paddock (2009 and 2010)

	Paddocks ¹					SE	P-value
	1	2	3	4	5		
Standing forage							
Pre-graze (kg/ha) ²	1380 ^a	1622 ^b	1742 ^{bc}	1675 ^{bc}	1876 ^c	80.16	0.02
Post-graze (kg/ha) ³	693 ^a	821 ^b	977 ^c	868 ^{bc}	1117 ^d	39.22	<0.01
DIS (Kg/ha) ⁴	686 ^a	800 ^b	764 ^b	806 ^b	824 ^b	38.55	0.04
% utilization ⁵	50 ^a	49 ^a	43 ^{bc}	48 ^{ac}	42 ^{bc}	2.14	0.04

¹Order at which paddocks were grazed.

²The amount of forage available before grazing each paddock

³The amount of forage available after grazing each paddock

⁴DIS = amount of forage that disappeared during grazing period. Calculated by subtracting the amount of forage remaining after grazing from the amount of forage available before grazing each paddock.

⁵Percent of forage utilized during the grazing period. Calculated by dividing the amount of forage that disappeared during grazing period by the amount of forage available prior to the grazing period.

^{a,b,c} Different letters represent differences between treatments (P<0.05).

Table 5. Diet quality by treatment

	Treatment				SE	P-value
	Control ¹	High ²	Low ³	Straw ⁴		
IVOMD (%) 2009-2010	53.76	52.94	52.2	52.75	0.62	0.37
CP (%) 2009-2010	7.87 ^a	7.29 ^b	7.54 ^{ab}	7.31 ^b	0.14	0.03
NDF (%) 2009	74.56 ^a	69.75 ^b	67.30 ^b	78.66 ^a	2.82	0.05
NDF (%) 2010	68.99	72.13	68.77	65.25	2.87	0.43

¹CONTROL=Cattle grazed at the recommended stocking rate (1.68AUM/ha in 2009; 1.64 AUM/ha in 2010).

²High=Cattle grazed at double the recommended stocking rate (3.26 AUM/ha in 2009, 3.25 AUM/ha in 2010) and supplemented with 70% grass hay and 30% WDGS at estimated 50% of daily DM intake.

³Low= Cattle grazed at double the recommended stocking rate (3.30 AUM/ha in 2009, 3.28 AUM/ha in 2010) and supplemented with 60% grass hay and 40% WDGS at estimated 50% of daily DM intake.

⁴Straw= Cattle grazed at double the recommended stocking rate (3.18 AUM/ha in 2009, 3.26 AUM/ha in 2010) and supplemented with 60% wheat straw and 40% WDGS at estimated 50% of daily DM intake.

^{a,b}Different letters represent differences between treatments (P < 0.05).

Table 6. Diet quality by paddock

	Paddocks ¹					SE	P-value
	1	2	3	4	5		
IVOMD (%) 2009-2010	54.65	52.89	52.27	52.55	52.18	0.69	0.09
CP (%) 2009-2010	8.60 ^a	8.19 ^{ab}	7.53 ^c	6.82 ^d	6.37 ^d	0.16	<0.01
NDF (%) 2009	70.85	73.55	67.74	73.1	77.59	4.46	0.32
NDF (%) 2010	63.39	64.17	67.44	74.76	74.16	3.21	0.06

¹Order at which paddocks were grazed.

^{a,b,c}Different letters represent differences between treatments ($P < 0.05$).

Table 7. Nutrient composition of Supplements.

	CP	NDF	IVOMD
WDGS ¹	30	40	90
Grass Hay ²	7.2	77.4	51
Wheat Straw ³	4.9	79.7	45.4
Straw ⁴	14.9	63.8	63.2
High ⁵	14.04	66.1	62.7
Low ⁶	16.3	62.4	66.6

¹WDGS = WDGS nutritional composition.

²Grass Hay = Grass Hay nutritional composition.

³Wheat Straw = Wheat Straw nutritional composition.

⁴Straw = Supplement containing 60% wheat straw and 40% WDGS (DM-basis).

⁵High = Supplement containing 70% grass hay and 30% WDGS (DM-basis).

⁶Low = Supplement containing 60% grass hay and 40% WDGS (DM-basis).

Figure 1. Post-grazing standing crop by block (2009 and 2010). East block differed from West block ($P \leq 0.05$).

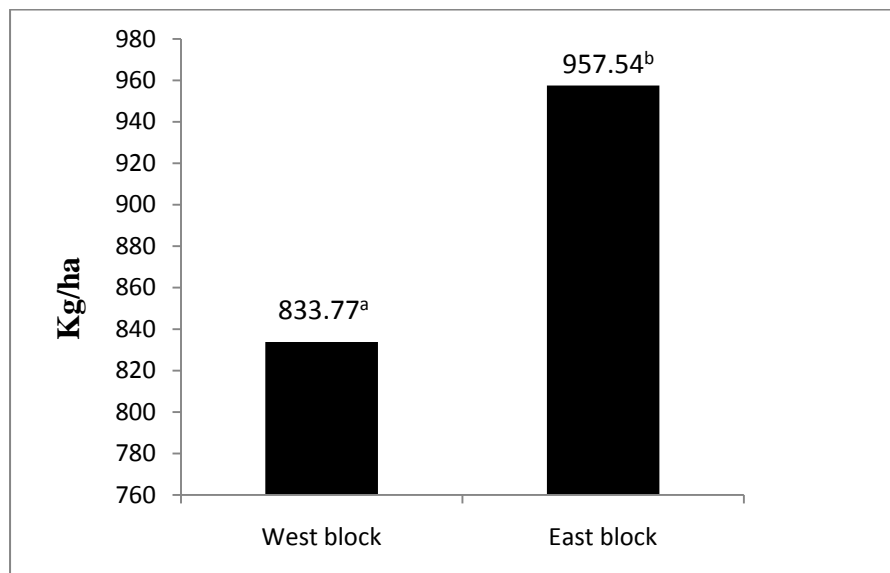


Figure 2. Diet IVOMD and CP variation between years. Year 1 differed from year 2 for IVOMD and CP ($P=0.05$ and <0.01 respectively)

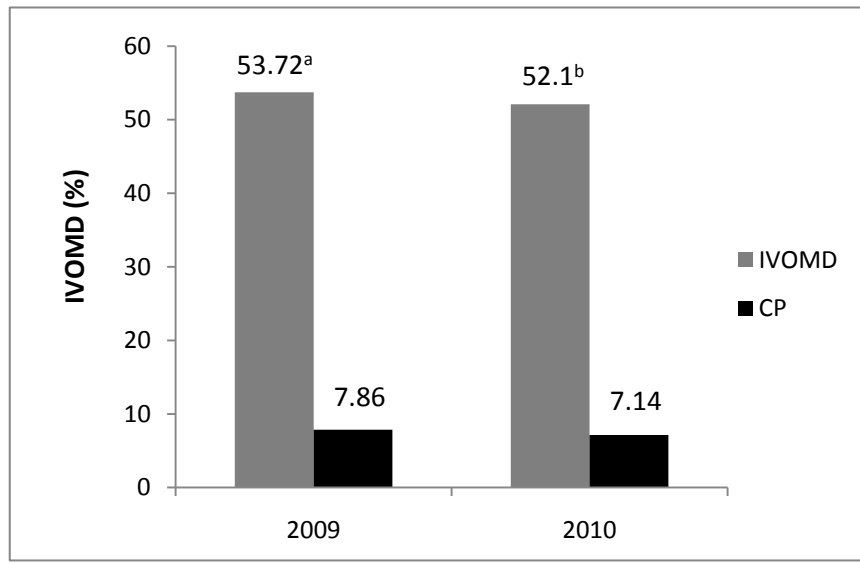


Figure 3. Significant linear response of CP of diet samples over time for 2009 and 2010 (P<0.01)

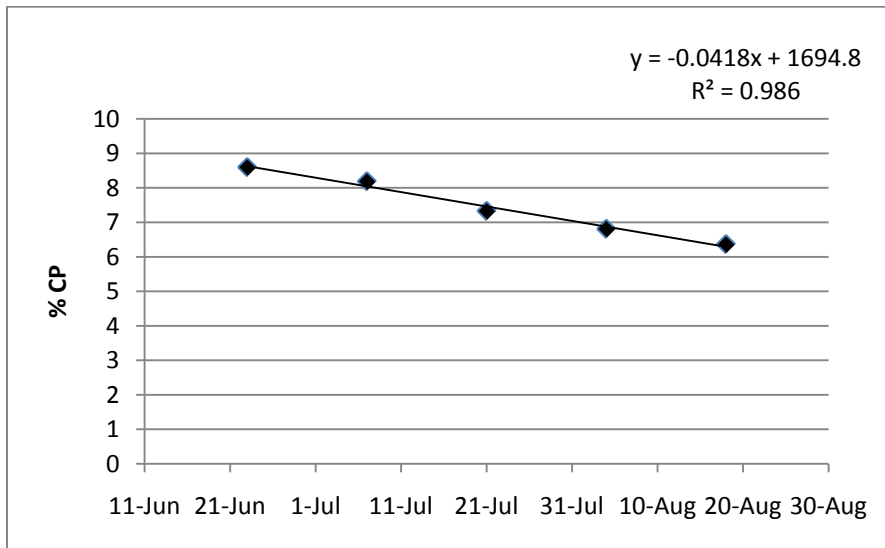


Figure 3. Significant linear response of NDF of diet samples over time for 2010 ($P < 0.01$)

