UTILIZING ANNUAL FORAGES IN A SINGLE AND DUAL CROP SYSTEM FOR LATE-SEASON GRAZING IN SOUTHCENTRAL NORTH DAKOTA

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Utilizing Annual Forages in a Single and Dual Crop System

for Late-Season Grazing in Southcentral North Dakota

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MASTER OF SCIENCE

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ABSTRACT

Utilizing annual forages to extend the grazing season can improve late-season forage production and quality, cow performance, and soil health; while providing a cost-effective alternative to drylot feeding. A four-year study tested three annual forage treatments using a single, dual, and dual crop with a herbicide burndown response variable (1 L/ha glyphosate, 250 mL/ha dicamba, 250 mL/ha 2,4-D) system. Treatments were foxtail millet (*Setaria italica*), turnip (*Brassica rapa*), a cocktail mix of six complementary species, and native range (control). Results found grazing foxtail millet in the single crop system and the dual crop with spray system, plus grazing turnip and cocktail mix in the dual crop with spray system, all provided on average cost-effective grazing options compared to grazing native range and feeding in a drylot system. The opportunity of increasing land-use efficiency was greatest with the dual crop with spray system, which was the most economical option in 2010.

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ADF……………………………………………………………..Acid Detergent Fiber

ADG……………………………………………………………...Average Daily Gain

B…………………………………………………………………………………...Boron

BCS…………………………………………………………Body Condition Score

BW………………………………………………………………………Body Weight

C………………………………………………………………………………Carbon

Ca……………………………………………………………………………..Calcium

Cl……………………………………………………………………………..Chlorine

cm……………………………………………………………………………Centimeter

CO_2……………………………………………………………………...Carbon Dioxide

CP………………………………………………………………………Crude Protein

Cu………………………………………………………………………………...Copper

d………………………………………………………………………………………..Day

D_b………………………………………………………………………Bulk Density

DM……………………………………………………………………...Dry Matter

DMI……………………………………………………………...Dry Matter Intake

EC………………………………………………………………Electrical Conductivity

g……………………………………………………………………………………Gram

GMD…………………………………………………...Geometric Mean Diameter

ha……………………………………………………………………………...Hectare

HCl……………………………………………………………………Hydrochloric

hd……………………………………………………………………………………...Head hr……………………………………………………………………………………Hour

H…………………………………………………………………………………Hydrogen

IBW…………………………………………………………………Initial Body Weight

IC………………………………………………………………...Inorganic Carbon

IVDMD…………………………………………………In Vitro Dry Matter Digestibility

IVOMD……………………………………………...In Vitro Organic Matter Digestibility

K……………………………………………………………………………Potassium

kg……………………………………………………………………………Kilogram

km…………………………………………………………………………..Kilometer

K_{sat}…………………………………………………..Saturated Hydraulic Conductivity

L……………………………………………………………………………………Liter

lb…………………………………………………………………………………..Pound

m…………………………………………………………………………………..Meter

M…………………………………………………………………………………Molarity

MAP………………………………………………………Mean Annual Precipitation

MBC……………………………………………………...Microbial Biomass Carbon

MBN…………………………………………………….Microbial Biomass Nitrogen

mL……………………………………………………………………………Milliliter

mm…………………………………………………………………………Millimeter

MWD…………………………………………………………Mean Weight Diameter

N…………………………………………………………………………..Nitrogen

NDF……………………………………………………………Neutral Detergent Fiber

O……………………………………………………………………………Oxygen

OC……………………………………………………………………Organic Carbon

ODS……………………………………………………………………Oven Dried Soil

P………………………………………………………………………...Phosphorus

s…………………………………………………………………………..Second

S…………………………………………………………………………...Sulfur

SOC…………………………………………………………………...Soil Organic Carbon

T……………………………………………………………………………...Ton

TDN………………………………………………………........Total Digestible Nutrient

TOC…………………………………………………………………Total Organic Carbon

WFS…………………………………………………………………Wetting Front Suction

WSA………………………………………………………………Water-Stable Aggregate

WSSI…………………………………………………………...Whole Soil Stability Index

Zn……………………………………………………………………………………Zinc

INTRODUCTION

As feed costs for beef cattle producers continue to rise, there is increased research in extending the grazing season utilizing annual forage crops (McCartney et al., 2008). Extending the grazing season can benefit producers by lowering beef cattle production costs (D'Souza et al., 1990; Adams et al., 1994; McCartney et al., 2009). In the northern Great Plains, grazing range and pastureland into the fall and early winter is not always an option, especially if forage availability and quality are limited by circumstances such as snow accumulation and plant senescence, respectively. Annual crops seeded later in the growing season can provide high yields (McCartney et al., 2009) and high quality forage (Neville et al., 2008) for late in the year. Some annual crops seeded for late-season use can also serve as cover crops; providing physical, chemical and biological improvements to the soil (Fageria et al., 2005).

The objective of our study was to investigate ways to provide a cost-effective alternative to late-season grazing of native range and drylot feeding. We selected high forage producing plant species with the goal of increasing carrying capacity and subsequently lowering grazing costs. Secondary objectives included studying the effect of selected forages on the performance of non-lactating beef cows in mid-gestation and increasing soil health.

LITERATURE REVIEW

Justification

Often the goal of livestock producers is to lengthen the grazing season (Entz et al., 2002), thereby, reducing the amount of time cattle are fed in more expensive drylot systems. Drylot feeding systems involve feeding harvested forages (Adams et al., 1994) such as hay and other supplemental feeds, and include the added cost of labor, facilities, machinery usage, and subsequent manure removal. Potential disease and lameness issues are reduced when cattle are grazing rather than being fed in drylots (McCartney et al., 2008).

The least expensive option for wintering pregnant beef cattle is on rangeland or pastureland (Adams et al., 1994). Allowing the cow to harvest the forage, opposed to machinery harvesting, is more economical (D'Souza et al., 1990). In late fall and early winter, environmental conditions in the Northern Plains cause plants to senesce and diminish in nutrient content. Research has found that rangeland grasses may not meet the nutrient needs of various classes of beef cattle by as early as October (Sedivec et al., 2007; Sedivec et al., 2009). In the end, extending the grazing season requires either supplementation with additional feed sources or providing of alternative forages.

Forage Type

Perennial forages do not require annual seeding and associated costs; however, when addressing late-season grazing needs, annual forages can peak in biomass production later than perennials due to variability in seeding dates (McCartney et al., 2008). Kilcher and Heinrichs (1961) demonstrated that in years of below-average precipitation annual cool-season cereal crops provided higher forage yields than perennial forage mixtures. Neville (2007) found the annual forage crop, foxtail millet (*Setaria italica*), out-produced two different perennial forage types crested wheatgrass (*Agropyron cristatum*) and big bluestem (*Andropogon gerardii*) by an average of 60% over a two-year period in south-central North Dakota.

Many annual and biennial plant species, such as members of the Brassicaceae family, are considered for forages because of the potential to graze both the tuber and foliage (Undersander et al., 1991). Almost all biennial species considered for grazing are utilized as annual crops and grazed during the vegetative growth of the first year. Generally, the above ground biomass of a turnip (*Brassica rapa*) contains 20-25, 65-80, 20, and 23% crude protein (CP), in vitro dry matter disappearance (IVDMD), neutral detergent fiber (NDF), and acid detergent fiber (ADF); respectively, with the nutrient concentration of the tuber 10-14 and 80-85% CP and IVDMD, respectively (Undersander et al., 1991).

Depending on the objective and forage type, annuals can be seeded anytime from early in the spring to late in the summer. In the southern Great Plains, winter wheat serves as a dual function crop and can be grazed in the fall and again in the spring while still being harvested for grain in the summer (Redmon et al., 1995). Klopfenstein et al. (1987) found that in regions such as the Middle Plains and Western Corn Belt, grazing corn residue by cattle served as a cost-efficient, late-season grazing alternative. Corn residue CP, IVDMD, and NDF levels averaged 6.2, 48.5, and 80.7%; respectively, suggesting protein supplementation may be warranted (Klopfenstein et al., 1987).

Swath grazing can utilize both annual (Neville 2007) and perennial forages (Volesky et al., 2002; Neville 2007). Swath grazing cereal crops is a cost-effective means of providing forage to pregnant beef cows (McCartney et al., 2008) because nutritional quality of swathed forage is retained longer through time compared to standing forage

(Neville 2007). Standing cereal crops can also be grazed, although the harvest efficiency of the forage tends to be greater when grazed by beef cattle in a swath (Entz et al., 2002).

Beef Cow Nutrient Requirements

Attempts to extend grazing from October into December are common objectives for livestock producers in the Northern Plains. At this stage of the season, most pregnant beef cows are in mid-gestation, are non-lactating, and, consequently have the lowest nutrient requirements of any time during the production cycle. However, the opportunity to improve body condition during this time is advantageous. According to the National Research Council (2000), a mature, non-lactating beef cow in mid-gestation weighing 545 kg requires approximately 11 kg/d of dry matter intake (DMI), including 0.6 kg/d (6.0%) and 4.9 kg/d (45%) CP and total digestible nutrients (TDN); respectively. Nutrient requirements will gradually increase through the pregnancy and early lactation, where they will eventually peak one month post-partum (National Research Council, 2000). Peak nutrient level is around 13 kg/d, 1.4 kg/d (10.5%), and 7.6 kg/d (60%) for DMI, CP, and TDN; respectively, for mature, lactating beef cows (National Research Council, 2000) immediately following calving. Providing cost-effective, high quality forage during the second trimester may reduce the amount of more expensive feedstuffs needed to return the cow to her next pre-calving condition stage.

Annual Forages Utilized in this Study

<u>Turnip</u>

The turnip is a cool-season broadleaf plant from the Brassicaceae family. Turnip is a drought-resistant, frost tolerant crop that is available to be grazed in as little as 60 d post-winter. Turnip crops require approximately 112 kg/ha actual N when in soils with SOC levels at 2-5%, while growing best in slightly acidic, well-aerated loam soils (Undersander et al., 1991). A turnip consists of about 90% water (McCartney et al., 2009) and has very low fiber content. Neville et al. (2008) used oat straw as a roughage supplement in order to prevent digestive upset. Undersander et al. (1991) reported production to be 6,700-9,000 kg/ha (DM basis) at 90 d growth.

Foxtail millet

Foxtail millet is a warm-season annual crop capable of producing 6.5 T/ha, and CP, ADF, NDF, calcium (Ca), and phosphorus (P) levels of a Golden German cultivar at 97, 332, 595, 3.69, and 1.58 g/kg; respectively, at the grain-filling stage in a swath grazing trial in Saskatchewan (May et al., 2007). Foxtail millet is drought-hardy, frost sensitive, and grows best in well-drained loam soils (Oelke et al., 1990). Oelke et al. (1990) recommended that 135, 34, and 337 kg/ha nitrogen (N), P, and potassium (K) levels; respectively, be present in the upper 61 cm of the soil profile in order to produce 3400 kg/ha of forage. Golden German foxtail millet out-produced cool-season cereals when precipitation, temperature, and growing degree day levels were all above average in Saskatchewan (May et al., 2007).

Sorghum-sudan grass

Sorghum-sudan grass hybrid (*Sorghum bicolor* x *S. arundinaceum* var. *sudanense*) is a cross between forage sorghum and sudangrass, and known for being a drought tolerant, warm-season forage crop (McCartney et al., 2009). Minimum soil temperature required for germination is 18^{o}C (McCartney et al., 2009). Sorghum-sudan grass had CP and Ca levels at 106 and 4.35 g/kg; respectively, at maturity (May et al., 2007). Compared to corn levels due to the fact that it contains more foliage and less grain (Undersander, 2003).

A three-year study from Saskatchewan indicated that when seeded at 22.5 kg/ha, sorghum-sudan grass was not a cost-effective late-season grazing option when swathed at the grain-filling stage (May et al., 2007). Despite sustained CP levels, forage production was minimal compared to all other treatments, producing 4.83 T/ha and failing to provide a sufficient profitable option (May et al., 2007). Prussic acid poisoning, which is a concern, is best avoided by grazing sorghum-sudan pastures once vegetation is at least 46 cm in height and by grazing for short durations, decreasing the chance of grazing crop re-growth (Undersander, 2003).

Sunflower

Sunflower (*Helianthus annuus*) is a warm-season annual crop that is very tolerant to both vernalization and dry conditions, while also being water-use efficient. The taproot of sunflower commonly extends down nearly two meters into the soil profile, retrieving soil nutrients and water sources. Average production ranges between 4500 and 6700 kg/ha, and nutrient quality is regularly greater than corn but lower than alfalfa (Putnam et al., 1990).

Forage Radish

Forage radish (*Raphanus sativus*) is a cool-season broadleaf capable of producing 5600 and 2250 kg/ha foliage and root; respectively, when using a seeding rate of 9-11 kg/ha (Weil et al., 2009). Due to the large tap-root of the radish, crop systems can relieve soil compaction via "biological tillage" (Chen and Weil, 2009). Forage radish was very comparable in its ability to scavenge residual N compared to rye (*Secale cereale*); yet because of the ability of rye and other cereal crops to provide weed suppression (e.g. mulch) and immobilize scavenged N, cover crop mixes consisting of both cereals and *Brassica* species are advantageous (Dean and Weil, 2009). According to Dean and Weil

(2009) forage radish winterkills, thus a subsequent crop should be seeded early in the spring opposed to later in order to capture the optimal amount of scavenged nutrients provided by the forage radish crop. Kunelius et al. (1987) found concentrations of CP and in vitro organic matter disappearance (IVOMD) to be 181 and 920 g/kg, respectively.

Cool Season Cereals

Forage varieties of oat (*Avena sativa*), barley (*Hordeum vulgare*), and triticale (*Triticale hexaploide*) were all examined within the annual forage cocktail mixtures in this study. Triticale is a hybrid crop that combines the forage quality, production, and disease resistance of wheat, with the hardiness of rye (Oelke at al., 1989). Over a three-year study in southcentral Wisconsin, triticale averaged 2900 kg/ha peak forage production (Oelke et al., 1989). At maturity, triticale IVDMD concentration was second to wheat at 395 g/kg in a study comparing yield and quality (Rao et al., 2000).

According to McCartney et al. (2008), barley had greater nutrient value than oat; however, oat consistently out-yielded barley and all other cereals in forage production. Carr et al. (2001) reported oat consistently out-yielded barley, but barley had higher CP levels and lower NDF and ADF concentrations in western North Dakota. However, Aasen et al. (2004) reported both barley and oat yielded similarly at 7700 kg/ha in southcentral Alberta, Canada. Aasen et al. (2004) went on to find average barley nutrient concentrations to be 586, 612, 333, and 134 g/kg for IVOMD, NDF, ADF and CP; respectively, over a three-year trial involving swathed forages when sampled in November. Oat nutrient levels were 593, 631, 355, and 128 g/kg for IVOMD, NDF, ADF and CP; respectively, in November when kept in the swath. Aasen et al. (2004) found oat had greater digestibility levels and had similar forage production when compared to barley.

Legumes

Legume species included in our cocktail mixtures over the past four years were cowpea (*Vigna unguiculata*), conventional soybean (*Glycine max*), red clover (*Trifolium pratense*), hairy vetch (*Vicia villosa*), and forage soybean (*Glycine max*). Research conducted by the University of Minnesota reported that the drought-resistant, warm-season annual crop cowpea had CP and digestibility concentrations similar to alfalfa and production levels ranging from 2900 to 4000 kg/ha at 60 d growth (Waters, 1987; Davis et al., 1991). When harvested at the pod stage for hay, conventional soybeans averaged 15% CP levels and should not be rationed at higher than 30% per d in livestock diets (Johnson et al., 2007).

A study conducted in east-central Pennsylvania found a corn crop to obtain more nitrogen from inorganic fertilizer than nitrogen provided by a legume source of red clover (Harris et al., 1994). However, the authors claimed that more nitrogen in the form of microbial biomass and non-biomass organic fraction was recovered from the legume source (red clover) in the soil. This suggests that some portion of the nitrogen provided by the annual legume crop was unavailable for use by the following corn crop, but may be available to successive crops.

Janke et al. (2002) in south-central Kansas reported that in years of adequate to high rainfall levels hairy vetch provided an average of 159 kg/ha of above ground biomass, but overall soil quality benefits such as increased soil organic carbon (SOC), total N, and mineral N were not found within a one year crop rotation cycle. When harvested at 75 d growth at the 50% bloom stage, forage soybean yielded 4100 kg/ha, while CP, IVOMD, and NDF concentrations were 17.8, 59.0, and 54.5%; respectively (Blount et al., 2009).

Review of Soil Properties

Atmospheric Nitrogen Fixation: Plant and Soil Interactions

Legume plants are important plant species because of the symbiotic relationship their roots often form with specific soil bacteria, commonly referred to as 'rhizobia'. These bacteria are commonly found in the soil and can also be inoculated in legume seed. Plant root nodules serve as a residence for these bacteria, which feed on sugars provided by the plant in exchange for converting atmospheric nitrogen into plant-available N (Lindemann and Glover, 2003).

When legumes are seeded as cover crops with or without other forage crops, they can provide additional N for the subsequent crop and reduce fertilizer costs (Fageria et al., 2005). The mutualistic relationship with the bacteria and annual legume species is advantageous to a successive annual crop because once the bacteria and related root biomass die, the fixed N becomes available for plant use (Lindemann and Glover, 2003). According to Fageria et al. (2005), legumes decompose quickly because of their low carbon:nitrogen (C:N) biomass composition, resulting in more readily-available N left for the following crop and N immobilization potential during the decomposition of the residue. Although legume plants fix nitrogen, when nitrogen is plentiful in the soil, they extract nitrogen from the soil first, then the atmosphere, thus the biological N fixation is greatly reduced when soil N levels are great (Lindemann and Glover, 2003; Fageria et al., 2005).

Soil Aggregate Stability

A soil aggregate is a naturally-formed soil body composed of soil mineral particles, water, air, and organic matter. Cohesive tension among surrounding soil particles initially forms an aggregate; however, it is the organic matter serving as the binding agent that stabilizes these aggregates from forces such as water. One measure of soil quality is the percent of WSA found in the soil. Aggregates that withstand the erosive forces of water are considered water-stable (Kemper and Rosenau, 1986).

Soil aggregates less than 0.25 mm in diameter are considered micro-aggregates, whereas aggregates greater than 0.25 mm in diameter are classified macro-aggregates (Tisdall and Oades, 1982). Favorable conditions, such as those produced by long-term reduced tillage, result in macro-aggregate formation via the agglomeration of micro-aggregates. With an increase in macro-aggregation, soil structure is improved, resulting in increased gas exchange and water movement between the soil and the atmosphere (Kemper and Rosenau, 1986). This results in a favorable medium for plant growth and root development (Fageria et al., 2005).

Increased crop cover promotes microbial activity by providing an energy source, enhances the rate of biomass decomposition, and creates a greater amount of polysaccharide matter to bind soil particles, resulting in the formation of stabile aggregates (Lynch and Bragg, 1985; Roberson et al., 1995; Liu et al., 2005). Tisdall and Oades (1982) found that the presence of organic matter in the form of polysaccharides, fungal hyphae, and plant roots is important in the creation of water-stable soil aggregates. Additionally, Edgerton et al. (1995) reported a corresponding increase between soil aggregate stability and microbial biomass the longer reclaimed soils remained undisturbed.

Silt loam soils planted to a winter cereal cover crop were tested for mean weight diameter (MWD) and percent water-stable aggregate (WSA) against a bare soil control in British Columbia. Annual ryegrass, fall rye, spring barley and bare soil had MWD levels of 1.99, 1.67, 1.35, and 1.24 mm (2-6 mm size fraction); respectively, while percent WSA was 42.5, 33.5, 25.5, and 20.5; respectively. Both annual ryegrass and fall rye demonstrated statistically different soil physical properties compared to bare soil whereas, spring barley was not significantly different from bare soil. A strong correlation was found between aggregate stability and dilute acid-extractable polysaccharide levels in these soils, inferring that the polysaccharide fragment of the organic carbon element of the soil may be providing the binding agent that stabilizes micro-aggregates, creating macro-aggregates (Liu et al., 2005).

Soil Microbial Biomass

Microbial biomass is the amount of living microorganisms in a given amount of soil (Glossary of Soil Science Terms, 2008). Soil microbes are responsible for the cycling of nutrients such as C, N, P, and sulfur (S), decomposition of crop residues and other organic matter in the soil, and maintenance of water quality (Coyne and Thompson, 2006). Cover crops can enhance these soil microbial services by providing a beneficial environment to support a large and diverse soil biological community (Fageria et al., 2005). The advantage of the cover crop environment includes extra obtainable C, buffered soil temperatures, and adequate moisture for microorganisms to reside and work (Fageria et al., 2005). Within the favorable setting of prolonged crop cover, the combination of nutrient scavenger grasses, legumes, and soil microbes provides the necessary cycling of nutrients needed to benefit the subsequent crop. Cover crop roots take up inorganic N, store it in the organic form where microbes decompose it, and eventually release it in a plant-usable form (Magdoff, 1991; Staver and Brinsfield, 1998; Dinnes et al., 2002). According to Ingram et al. (2005), microbial biomass carbon (MBC) or total C cycled was found to be greater in newly reclaimed native range sites relative to undisturbed native range sites. This is likely because of the more humified and unavailable C that is tied up in stable aggregates and excess plant litter, limiting its activity in the nutrient cycling process.

Infiltration Rate and Saturated Hydraulic Conductivity

Water infiltration rates improve as both soil organic matter content (Fageria et al., 2005) and crop residue (Baumhardt and Lascano, 1996) increase. Valzano et al. (1997) found that both hydraulic conductivity and infiltration rate will decrease when residual crop stubble is burned and removed in Australia. When residual crop stubble was not removed, infiltration rates were 60% (0.001 to 0.0004 cm/s) greater and hydraulic conductivity readings 56% (0.0004 to 0.0009 cm/s) greater than when residual crop stubble was burned and removed. The utilization of a second crop or cover crop in a crop system provides additional residue and organic matter which can be beneficial in enhancing both infiltration rate and hydraulic conductivity. Asleson et al. (2009) found saturated hydraulic conductivity readings of 0.02 cm/s on side slopes comprised of sand, while sandy loam foot slopes had values of 0.0005 cm/s. Hydraulic conductivity describes the movement of water through unsaturated soil whereas saturated hydraulic conductivity represents water moving through saturated soil.

MATERIALS AND METHODS

Study Area

This study was conducted at the Central Grasslands Research Extension Center, a North Dakota Agricultural Experiment Center located approximately 15 km northwest of Streeter, ND. Streeter is located on the eastern edge of the Missouri Coteau Region in southcentral ND. This unique area is located between the James River to the east and Missouri River to the west, and is rich in its balance of agriculture and alternative land use. The landscape consists of undulating morainic hills created during the most recent glaciation period (Lura, 1985).

The study sites were found in T 138 North R 70 West, Kidder County. The annual forage paddocks were located in Section 14 and native range paddocks in Section 25. Although bordered by a semi-humid continental climate to the east, the study area is considered a semi-arid continental climate locale with cold winters and hot summers. Annual temperature variations are considerable and range from mean monthly average daily temperatures of -13.0°C in January to 20.0°C in July, with a mean annual average daily temperature of 4°C (North Dakota Agricultural Weather Network, 2010). As in most semi-arid climates, annual precipitation is the primary factor limiting plant growth. On average, this area receives 43.4 cm of annual precipitation (North Dakota Agricultural Weather Network, 2010), with approximately 31.5 cm falling within the typical 110-135 d growing season (McNab and Avers, 1994).

Crop System Design

Nine 4-ha paddocks were developed to test three annual forage crops, each replicated three times. In addition, three 16.6-ha native range paddocks were randomly selected from 12 paddocks and used as the control. Within the annual forage crop treatment paddocks, a single crop system was tested in 2007 using a randomized complete block design. In 2008, 2009 and 2010, a single and dual crop system (cereal hay crop followed by an annual forage crop) was tested using a split-plot, randomized complete block design with three replicates. Each 4-ha paddock was split into two 2-ha halves and both crop systems were implemented using a random approach. The dual crop system included a cereal hay crop (oat or barley) seeded between late-April and mid-May, cut in July (soft-dough stage), baled, and removed. Following the removal of the bales, an annual forage crop was then seeded on both the single and dual crop halves to represent a cover crop. A spray application (1 L/ha glyphosate, 250 mL/ha dicamba, 250 mL/ha 2,4-D) was applied as a response variable on 80% of the dual crop system (after the removal of the bales) in 2009 and 2010 to compare a sprayed *vs*. unsprayed response.

Electric poly-wire fence and step-in posts were utilized as portable cross-fences within each paddock throughout the duration of the grazing study. Each treatment paddock was divided into six allotments and each allotment had a scheduled grazing period of nine to 10 d. Thus, the grazing study was based on an estimated 60 d grazing study and stocking rate was calculated accordingly. Although the grazing study was based on 60 d, actual grazing occurred from 16-October to 27-November, 2007 (42 d); 15-October to 26-November, 2008 (42 d); 20-October to 7-December, 2009 (48 d); and 19-October to 6-December, 2010 (49 d).

Water was hauled to each paddock tank daily and a propane heater used to provide continued access to water. Portable wind shelters were available for use in each paddock. Additionally, the allotment closest to the water tank was utilized first and the cross fence moved further away from the water tank, allowing for continued access to water and prior-grazed allotments. As for the native range paddocks, all of the 16.6-ha paddock was available for grazing throughout the duration of the grazing study. The native range paddocks were not grazed during the growing season so grazing commenced at the start of this grazing study each year. Well-water access and a propane-heater were utilized in the native range paddocks.

Animals

The NDSU Institutional Animal Care and Use Committee approved all planned animal handling and care processes prior to the commencement of this study. Non-lactating, mid-gestation, Simmental-Angus crossbred cow (*Bos taurus*) were utilized in this study. One-hundred fifty-nine (534 ± 43.4 kg initial BW), 114 (573 ± 36.6 kg initial BW), 81 (527 ± 46.8 kg initial BW), and 159 (585 ± 65.9 kg initial BW) cows grazed in one of the four treatments in 2007, 2008, 2009, and 2010; respectively.

Forage Treatments

Grazed treatments included: 1) foxtail millet, 2) turnip, 3) cocktail mix (six complementary species), and 4) standing native range (control). The golden German cultivar of foxtail millet was used all four years as one annual forage treatment. Within the turnip treatment, a purpletop variety was used in 2007 (Appendix E), pasja variety in 2008 (Appendix F) and 2010 (Appendix H), and both varieties in a comparison study in 2009 (Appendix G). Species within the cocktail mix were purpletop turnip, oilseed radish, cowpea, conventional soybean, sunflower, and foxtail millet in 2007 (Appendix E); pasja turnip, oilseed radish, sorghum-sudangrass, sunflower, triticale, and red clover in 2008 (Appendix F); pasja turnip, oilseed radish, sorghum-sudangrass, sunflower, forage barley, and hairy vetch in 2009 (Appendix G); and pasja turnip, oilseed radish, sorghum-sudangrass, sunflower, forage oat, and forage soybean in 2010 (Appendix H). The native range treatment plant community was comprised by Kentucky bluegrass (*Poa pratensis*), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*), sun sedge (*Carex heliophila*), and western snowberry (*Symphoricarpos occidentalis*; Hirschfield et al., 1996).

Forage Treatment Establishment

2007

The annual forage treatments were seeded 13-July using a no-till seed drill (John Deere 750; Des Moines, IO). Fertilizer was applied at the same time as seeding with 28 kg/ha urea (46% N) and 28 kg/ha 11:52 (11% N, 52% P) using a broadcasting technique. Seeding rates for foxtail millet and purpletop turnip was 33 and 4 kg/ha, respectively. The cocktail mix was seeded with a seed mixture containing 22, 16.8, 4.5, 1.1, 1.1 and 0.6 kg/ha for soybean, cowpea, foxtail millet, sunflower, radish and turnip; respectively.

2008

Each four-ha paddock was split into two 2-ha paddocks to represent a single and dual crop system. Two varieties of forage barley (Stockford and Hayes) were seeded into separate strips on the dual crop system to test for varietal differences between barleys (Appendix A). Barley was seeded at a rate of 112 kg/ha on 3-May with 23 kg/ha of urea that was broadcasted at time of seeding. The barley was swathed 11-July at the soft dough stage and baled in mid July. Prior to harvest, 10 - 0.25 m^2 quadrats were clipped from each variety in each paddock. Total forage production and nutrient analysis was obtained from these samples. Seeding of annual forage treatments for grazing occurred on 27-July for both the single and dual crop systems. Seeding rate for foxtail millet and pasja turnip was 22 and 3.4 kg/ha, respectively. The cocktail mix was seeded with a seed mixture containing 16.8, 4.5, 1.7, 1.1, 1.1 and 1.1 kg/ha of triticale, sorghum, red clover, sunflower, radish, and pasja turnip; respectively. No fertilizer was applied in 2008.

2009

The design in 2009 was similar to 2008. Forage barley (Haybet) and oat (Jerry) were tested for forage production, nutritional quality and economic value on the dual crop system (Appendix A), which was removed as a hay crop prior to seeding of the annual forage crop. Barley was seeded at a rate of 112 kg/ha and oats at a rate of 72 kg/ha on 4-May with 56 kg/ha of urea using a broadcasting technique. The cereal hay crop was swathed 10-July at the soft dough stage and baled in mid July. Prior to harvest, 10 - 0.25 m^2 quadrats were clipped for each species in each paddock. Total forage production and nutrient content was obtained from these samples. Following removal of the hay crop, 80% of this area was sprayed (1 L/ha glyphosate (Roundup), 250 mL/ha dicamba (Banvel), and 250 mL/ha 2,4-D) to kill all live plants and minimize re-growth by the cereal hay crop. Seeding of foxtail millet on the single crop system portion occurred on 2-July while all other annual forages in the single and dual crop system portions were seeded on 22-July. Seeding rates for foxtail millet and turnip (purpletop and pasja) were 22 and 3.4 kg/ha, respectively. The cocktail mix was seeded with a seed mixture containing 16.8, 2.2, 4.5, 1.7, 1.1, 1.1 kg/ha of forage barley, hairy vetch, sorghum-sudangrass hybrid, sunflower, forage radish, and pasja turnip; respectively. No fertilizer was applied in 2009.

2010

The design in 2010 was similar to 2008 and 2009. A hulless oat was seeded on the annual forage crop portion of the dual crop system and removed as a hay crop prior to seeding of the annual forage crop (Appendix A). The oat crop was seeded at 56 kg/ha on 20-April, with 67 kg/ha of urea applied using a broadcasting technique three weeks later (due to wet field conditions). The oat crop was swathed 8-July at the soft dough stage and baled 12-July. Prior to swathing, 10 - 0.25 m^2 quadrats were clipped in each paddock to determine oat production and nutrient content. Following removal of the hay crop, 80% of the area was sprayed (1 L/ha glyphosate (Roundup), 250 mL/ha dicamba (Banvel) and 250 mL/ha 2,4-D) to kill all live plants and minimize re-growth by the cereal hay crop. Additionally, a herbicide spray was applied on the single crop system (1 L/ha glyphosate (Roundup), 250 mL/ha dicamba (Banvel) and 250 mL/ha 2,4-D) on 2-June and 10-June on the oat crop of the dual crop system (708 mL/ha of clopyralid (Widematch)) for broadleaf weed control. Foxtail millet was seeded on 23-July, while both turnip and cocktail mix were seeded 29-July. Seeding rate for foxtail millet was 22 kg/ha and for turnip 3.7 kg/ha. Cocktail mix seeding rate was 1.7, 4.5, 16.0, 1.1, 0.8, and 3.4 kg/ha for sunflower, sorghum-sudangrass, oat, radish, pasja turnip, and forage soybean; respectively. Soil nutrient results revealed low soil N levels; thus, we applied 157 kg/ha urea (46% N) at the time of the annual forage treatment seeding. This fertilizer cost was split evenly between the 2010 and 2011 annual forage crop due to the benefit it will serve over both years.

Carrying Capacity and Stocking Rate

Carrying capacity was based on the predicted peak biomass production by clipping 10 – 0.25 m^2 plots during the first week of October, which was approximately 10 d prior to cattle turn out. Harvest efficiency used to calculate the carrying capacity was estimated at 70, 90, 80, 25, and 15% for foxtail millet, turnip, cocktail mix, native range grasses and native range forbs; respectively. Harvest efficiency for foxtail millet was based upon the findings of Volesky et al. (2002) and Neville (2007) and was adjusted for grazing standing crop (70%) opposed to grazing a swath (80%), which was more efficient and retained greater palatability (Neville, 2007). Turnip and cocktail mix harvest efficiency estimates were based off visual determinations of the Neville et al. (2008) study in 2008 at the Central Grasslands Research Extension Center. In 2010, harvest efficiency of the native range grasses was increased to 35% to provide a more realistic grazing situation of non-lactating beef cows on rangeland (Smart et al., 2010).

Stocking rate was determined by dividing the available forage (100% DM) by cow intake per d (DMI/d), and then dividing by 60 d (projected grazing period). The DMI/d was estimated at 15 kg/d in 2007 and 2008, 16 kg/d in 2009, and 17 kg/d in 2010 for all treatments except foxtail millet, which was reduced to 15 kg/d in 2010 to attempt to reduce forage waste. The DMI/d was raised each year because cow intake was greater than the recommended nutrient requirement as described by the National Research Council (1996) in the Beef Cattle Handbook.

Soil

Soil within the annual forage paddocks ranged from moderately sloped and moderately drained loamy soil to excessively slope and excessively drained sandy loam soils. Soil types in the native range paddocks varied from poorly drained silt loam soil to well-drained loam soil. Soil sampling was conducted within a similar soil series throughout the study area in order to reduce variation associated with soil texture, slope, or drainage class. Soil measurements in paddocks 1-6 were limited to a Barnes-Sioux sandy loam soil (3-9% slope). For paddocks 7-9, soil samples were limited to a Sioux-Arvilla sandy loam (0-9% slope). Finally, a Barnes-Svea loam (0-6% slope) and a Buse-Svea loam (3-15% slope) were used to characterize soil properties within the three native range paddocks (USDA NRCS WSS, 2010).

Sampling

<u>Forage</u>

Peak forage production of the cereal hay crop in the dual crop system was estimated by clipping 10 - 0.25 m^2 quadrats per paddock in July just prior to harvest; while peak biomass production was estimated for the second crop (annual forage crop) by clipping six 0.25 m^2 quadrats per split plot and response variable (spray *vs*. non-spray) during the first week of October. From the initiation of the grazing trial, bi-weekly clippings were conducted to monitor forage nutrient content throughout the grazing period. Cocktail mix species were separated when clipped to monitor individual species nutrient content and identify percent species composition within the mixture. Turnip foliage and tubers were separated when clipped, as were native range graminoid and forb species to distinguish nutrient content and availability. However, tuber production was not calculated into the peak production because of minimal consumption; whereas, both graminoids and forbs were used in determined total forage production.

<u>Animal</u>

Cows were stratified by average two-day initial body weight (IBW) and average two-day body condition scores (BCS) prior to turn out. Body condition score was calculated using a visual scoring system as described by Wagner et al. (1988). Mean initial BCS were 5.29 ± 0.41; 5.27 ± 0.31; 5.15 ± 0.26; and 5.25 ± 0.18; in 2007, 2008, 2009, and 2010; respectively.

<u>Soil</u>

Soil samples were collected in 2009 to characterize, identify, and monitor various physical, chemical and biological attributes of the soil. These techniques were repeated in 2010 to verify and quantify any effects resulting from the growth and decomposition of the annual forages. Sampling was completed in both the single and dual crop systems. Soil physical characteristics analyzed included bulk density, K_{sat}, and soil aggregate stability. Soil chemical properties included soil nutrient and pH levels, while the biological aspect consisted of MBC and microbial biomass nitrogen (MBN).

All soil samples were taken in early June except for soil aggregate stability which were taken in mid-August. Number of sub-samples for all measurements taken except K_{sat} was six samples per split treatment (six/single crop, six/dual crop, six/native range), while number of sub-samples for K_{sat} was three samples per split treatment (three/single crop, three/dual crop, three/native range). Samples were composited across split treatment and topographical site differences were accounted for during sampling. Above ground residue was gently removed at each sampling site prior to conducting each sampling technique.

A soil bulk density sampler (5.4 cm diameter) was used to measure soil bulk density levels at the 0-3 cm depth and 5-8 cm depth. Saturated hydraulic conductivity was determined by utilizing a single-ring infiltrometer to test the rate of water infiltration. An amount of 1500 mL of water was poured into each infiltrometer and water infiltration was measured every five minutes with the use of a tape measure and stopwatch. Before the initiation of the infiltration test, a soil sample was collected to a depth of 5 cm adjacent to the infiltrometer in order to later determine soil moisture content of the soil at time of sampling. At the conclusion of the test, a 5 cm depth of soil was removed from within the infiltrometer ring for comparison of the soil moisture content after water infiltration was completed. Sampling for nutrients, pH, MBC, and MBN was conducted utilizing a 17.8 mm diameter backsaver soil probe. Soil was sampled to a depth of 61 cm, while separating in increments of 15.24 cm. Soil aggregate stability sampling was completed by utilizing a tiling spade to minimize soil structure disruption; samples were collected to a depth of 15.24 cm.

Laboratory Analysis

Forage

Peak forage samples were oven-dried at 50°C for 48 hr. Samples were then ground through a 2 mm screen using a Wiley mill. Once ground, samples were analyzed for DM, ash, CP, NDF, ADF, Ca, P, IVDMD, and IVOMD at the North Dakota State University nutritional lab. Methods to determine DM, ash, CP, Ca, and P followed AOAC International methods (Association of Analytical Chemistry, 2010). The protocol used for determining IVDMD and IVOMD was based off the method developed by McDougall (1948). In determining NDF and ADF, methods developed by Goering and Van Soest (1970) were utilized (ANKOM Technology).

Soil

Soil Aggregate Stability.

Soil aggregate stability was calculated using the whole soil stability index (WSSI) developed by Nichols and Toro (2011). This method combines both dry- and wet-sieved aggregates, and utilizes a given quality constant that reflects the value of each aggregate size class as a soil quality indicator. By combining the dry- and wet-sieved data with the quality constant, a comprehensive WSSI was developed to facilitate identification of soil quality levels as affected by natural processes and soil management practices (Nichols and Toro, 2011). Soil samples were air dried on Kraft paper for approximately three days until a constant moisture level was reached. Soil was then dry sieved into five size classes: 8-4.75 mm, 4.75-2 mm, 2-1 mm, 1-.25 mm and .25-.053 mm. The >8 mm and <.053 mm size fractions are required and retained for the calculation of the WSSI. Inadvertently the >8 mm size fraction was discarded in 2009, so in order to complete this procedure, we utilized the average >8 mm size fraction from each sample taken in 2010 and substituted that number as our >8 mm size fraction for the 2009 samples. After dry sieving, each of the five classes of aggregates were treated with 10 minutes of capillary rewetting, followed by five minutes of mechanical wet sieving (e.g. slaking) by the apparatus utilized in the Kemper and Rosenau (1986) methodology. Soil remaining after wet-sieving was considered water-stable and was subjected to a bath of 0.5% sodium hexametaphosphate coupled with shaking in order to disrupt all aggregation. The soil particles were then washed through their respective sieve size while being dispersed with the aid of forced water and a rubber/plastic policeman. This process left only the coarse fraction of the soil sample (e.g. rocks) remaining on the sieve. The amount of water-stable aggregate from each sample could then be calculated by subtracting the coarse fraction from the total amount of sample remaining after wet sieving (e.g. water-stable aggregates). Below are the equations used to calculate proportion of dry sieved aggregates by size class (P_{ai}), WSA and WSSI (Nichols and Toro, 2011). Equation 1, 2, and 3 are derived from Nichols and Toro (2011).

Equation 1.

$$P_{ai} = \frac{[W_A - [(W_c/W_o) \times W_A]]}{W_T}$$

P_{ai} = proportion of dry sieved aggregates by size class
W_A = weight of the total amount of soil in the selected weight class after dry sieving
W_c = weight of the coarse fraction remaining after dispersion
W_o = weight of the sample prior to wet sieving
W_T = weight of the total amount of soil that was initially dry sieved
(e.g. sum of >8 to <.053 mm size classes)

Equation 2.

$$WSA_i = [(W_a - W_c) \div W_o] \times 100$$

WSA_i = water-stable aggregation
W_a = weight of sample left on sieve after wet sieving

W_c = weight of coarse fraction remaining after dispersion
W_o = weight of initial sample

Equation 3.

$$\text{WSSI} = \left[\sum_{i}^{n}[(I) \times (P_{ai}) \times ((\text{WSA}_i) \div 100)]\right] \div n$$

WSSI = whole soil stability index
WSA_i = water-stable aggregation
P_{ai} = proportion of dry sieved aggregates by size class
$_n$ = number of aggregate size classes
I = number of aggregate size classes subtracted by an increment of one every time you descend from the largest size class to the smallest

Data collected to determine WSSI were also used to calculate mean weight diameter (MWD) and GMD values. Both the MWD and the GMD indices are commonly used when identifying soil aggregate stability properties. The MWD and GMD methods utilized followed the methods of Kemper and Rosenau (1986).

Soil Bulk Density.

Samples were dried at 105^{o}C for 24 hr to achieve oven-dried soil (ODS) weight. The ring that enclosed each soil sample had a volume of 68.99 cm^3. In calculating the soil bulk density, the weight (g) of the ODS was divided by the volume of the ring that enclosed the soil sample (68.99 cm^3). This process determined the soil bulk density in g/cm^3.

Soil Saturated Hydraulic Conductivity.

The before and after field soil-water content samples were weighed wet and then dried at 105^{o}C for 24 hr to collect the ODS weight. The gravimetric water content (%) was calculated for both the before and after field moisture content measurements by subtracting the ODS weight from the wet soil weight and then dividing that value by the ODS weight. Both water content values were used in the subsequent calculation of K_{sat} and wetting front suction (WFS), plus documentation of the level of water (cm) in the single-ring infiltrometer at each five minute increment. Soil wetting front suction is described as the amount of suction potential (cm) the soil has for water at the leading edge (front) of where the water meets the soil. In addition, a computational Excel worksheet was established to determine K_{sat} and WFS (Equation 4). Infiltration over time was represented by i(t), while R(t) was the radius to the wetting front, and L_{max}^3 described the depth of insertion of the infiltrometer (Asleson et al., 2009). Equation 4 was derived from Asleson et al. (2009).

Equation 4.

$$i(t) = \frac{\pi}{3}(\theta_1 - \theta_0)\left(2[R(t)]^3 + 3[R(t)]^2 L_{\max} - L_{\max}{}^3 - 4r_0^3\right)$$

i(t) = infiltration over time
R(t) = radius to the wetting front
$Lmax^3$ = depth of infiltrometer insertion

Soil Nutrients and Chemical Properties.

Soil N and pH levels were tested at a depth of 0-60 cm, with 15 cm increments. Soil P, K, OC, IC, EC, S, Zn, Cu, Cl, and sodium levels were determined to a depth of 0-15 cm. Soil samples were placed on ice immediately after sampling and until they were taken to the laboratory and frozen until nutrient analysis was conducted. Soil was dried at 50^{o}C for a 24 hr period, ground, and passed through a 2 mm sieve prior to nutrient analysis.

All of the following procedures were completed by the NDSU Soil Testing Lab (Waldron Hall, Fargo, ND). Total N was determined with the colorimetric Olsen sodium-bicarbonate method (Olsen et al., 1954) with ascorbic acid reduction (Watanabe and Olsen, 1965) using a DU-64 spectrophotometer (Beckman Instruments, Fullerton, CA). Soil and deionized water (1:1 mixture) was utilized to calculate soil pH and soil EC (Appendix J).

Soil K (Appendix I), P (Appendix I), and sodium (Na; Appendix J) were determined through extraction with ammonium acetate, shaking, and centrifugation followed by the mercury (II) thiocyanate method developed by Adriano and Doner (1982) using an Autoanalyzer II (Technicon Industrial Systems, Tarrytown, NY). Sulfur levels (Appendix J) were determined by adding 500 ppm P as monobasic calcium phosphate ($Ca_3PO_4^2$) to the soil sample. Zinc, Cu, and Cl levels (Appendix J) were extracted with DTPA (diethylenetriminpentaacetic acid), shaken, filtered, and analyzed by an atomic emission spectrophotometer (ICP-AES). Inorganic carbon was analyzed by the addition of HCl acid and water, resulting in effervescence and removal of inorganic carbon (carbonates). Inorganic carbon concentration was determined by subtracting the HCl acid-treated soil from the non-treated soil, and then dividing the result by 0.12. Organic carbon was found through the process of combustion with a carbon-nitrogen analyzer (CN2000; DeSutter et al., 2005).

Soil Microbial Biomass Carbon and Nitrogen.

Soil samples were collected at a depth of 0-15 cm. Samples taken in 2009 were frozen for approximately 15 months prior to analysis; whereas, samples taken in 2010 were never frozen, but refrigerated and examined for MBC and MBN within 60 d of sampling. It is believed that the 2009 samples experienced adverse effects to the soil microbial population due to the extended period of freezing. According to Horwath and Paul (1994), freezing of soil samples can have negative biocidal impacts on the microbial population of the soil. Prolonged storage may have caused a relative loss of carbon due to respiration, which would have lowered the MBC values in 2009 compared to 2010 values. However, in the end, MBC values were found to be unusually high and unfortunately we are unable to account for these higher than normal values.

Once thawed, the soil was gently broken-up and any rocks removed. Gravimetric water content (% weight basis) was taken on each sample prior to analyzing. Microbial biomass was determined using a chloroform fumigation extraction method (Brookes et al., 1985; Vance et al., 1987; Gallardo and Schlesinger, 1990). Field moist soil samples (equivalent to approximately 20 g ODS) were enclosed in side-arm vacuum desiccators with a beaker containing 50 mL of chloroform; the chamber was evacuated and left for 48 hr. A separate set of samples (control) were prepared following the same procedure but were not exposed to chloroform (non-fumigated). Additionally, a blank sample was run per each sample batch to identify any background C and N present in the filter paper, extractant, or any other materials.

Once removed from the desiccators, samples were mixed with 50 mL of 0.5M K_2SO_4 (potassium sulfate), a common soil extractant, and subjected to a reciprocal shaker (200 RPM/.5 hr) followed by filtration through Whatman No. 42 filter paper. After filtration, approximately 15 mL of soil liquid extract was placed in plastic scintillation vials and frozen until being sent to North Carolina State University for TOC analysis. Analysis was completed using a flow injection analyzer (Shimadzu TOC-V Carbon Analyzer). Microbial biomass carbon was calculated by subtracting the TOC in the non-fumigated control sample (C content) from the TOC in the fumigated sample, then divided by a constant value (general factor) of 0.33 which represents the fraction of TOC that was present in the microbial biomass (Anderson and Domsch, 1978).

In calculating MBN, 5 mL of soil liquid extract from the MBC procedure was added to 5 mL of a persulfate solution (25 g $K_2S_2O_8$, 15 g H_3BO_3, 50 mL 3.75M NaOH/500mL deionized water) as described in Cabrera and Beare (1993). The persulfate solution oxidized organic N and ammonium to nitrate. The 10 mL mixture was then subjected to autoclaving for 0.5 hr to insure complete oxidation of all forms of N into nitrate. The samples were then frozen in glass scintillation vials until further analysis was completed. Analysis of dissolved organic N was completed using a total N analyzer, which identified total N in nitrate form. Microbial biomass N was determined by subtracting the N in the non-fumigated (control) sample from the N in the fumigated sample, divided by a constant value (general factor) of 0.54 which, according to Jenkinson (1988), represents the proportion of MBN mineralized to nitrate.

Economics

Economics were calculated by crop system, treatment, and year. Results were calculated as a cost to graze a non-lactating beef cow in mid-gestation per day ($/hd/d). Cost effectiveness of each treatment and crop system was figured at <$1.34/hd/d, which according to the USDA NASS NDASS (2007), is the average cost to winter a pregnant beef cow in a drylot system.

Input costs included average non-irrigated cropland and average non-irrigated pastureland cash rent for Kidder County, North Dakota and custom farming rates for North Dakota (USDA NASS NDASS, 2010). Actual costs for herbicide, fertilizer, and hay were used. Stocking rate was calculated by dividing the number of head (hd) by the total amount of hectare (ha) grazed, with calculated costs determined for hd/ha at any given time (e.g. stock density). In 2007, grazing costs were calculated by multiplying input costs by the number of ha available per hd, divided by the total number of days the cattle grazed ($/hd/d). In 2007, only a single crop system (annual forage crop) was tested; therefore, the entire sum of annual forage costs was utilized in calculating the grazing costs.

A dual crop system was added to the experimental design in 2008, 2009 and 2010, thus the land rental rate cost and all costs associated with the first crop (cereal hay crop) were offset by the value of the cereal hay crop, forming an adjusted costs value to the dual crop. Thus, only the costs directly associated with the second crop (forage crop) were used in calculating the $/hd/d cost to graze. For example, land rental rate cost is assessed to the first crop, which appropriately reduces the cost of the second crop (forage crop). In other words, the annual forage crop (second crop) serves as a fall cover crop. The use of a dual crop system has the potential to be more cost-efficient, as the majority of the costs for the second crop are offset by the first crop, resulting in a more efficient land-use system. An economic analysis was conducted for all treatments. Input costs and grazing costs were calculated in $/ha and $/hd/d. Additionally, 2007 North Dakota average custom rates for fertilizer application, no-till seeding, and herbicide application were used to represent input costs for all years of the study (USDA NASS NDASS, 2009). Cost to graze one cow per day was calculated by multiplying total input costs by amount of hectares available per head in each system (single, dual, dual with spray) and divided by number of days grazed.

Statistics

The general linear model mixed procedure of SAS 9.1 (SAS Inst. Inc., Cary, NC) with repeated measures was utilized to analyze cow performance for 2007-2010, using year as the repeated variable. The annual forage treatments were selected using a complete randomized block design with three replicates, and the native range treatment using a randomized design with three replicates. Paddock served as experimental unit, while forage type was treatment. Within the model, effects of treatment, year, and treatment X year interactions were analyzed. Multiple comparisons were shown only when treatment or year effects were present or when a treatment X year interaction occurred ($P \leq 0.05$). The tukey honesty test was used to separate means. Forage production (2007-2010) was analyzed using a split-plot, complete randomized block design with three replicates within treatment paddocks and a randomized design with three replicates within native range paddocks. Soil properties (2009-2010) were determined using a complete randomized block design with three replicates, while using a randomized design with three replicates within the native range paddocks. Initially, soil properties were analyzed by split; however, no differences were found ($P > 0.05$) so we elected to remove the split from the model. Experimental unit, treatment, and analyzed effects within the model were similar to the model used to analyze cow performance. Significance was established at $P \leq 0.05$.

RESULTS

Climate

Average monthly temperatures over the four year study were variable throughout the growing and grazing season; however, variability was minor in relation to the 30-year average (Table 1). Precipitation levels were greater than the 30-year average in each year except 2009, which was likely a main factor in the reduced forage production of the annual forage treatments in 2009 (Table 2). More importantly, July precipitation was less than average in 2009, which may have negatively impacted treatment germination and initial crop stand growth.

Table 1. Average monthly temperature (^{o}C) at the Central Grasslands Research Extension Center near Streeter, ND, in 2007-2010.

	Month											
Year	J	F	M	A	M	J	J	A	S	O	N	D
2007	-11	-15	0	4	13	18	22	18	14	8	-2	-10
2008	-13	-12	-3	4	10	16	20	20	14	7	-1	-15
2009	-15	-12	-7	3	11	16	18	18	17	3	3	-13
2010	-13	-13	0	9	12	18	20	21	13	8	-2	-12
Average[1]	-13	-9	-3	5	12	17	20	19	13	6	-3	-10

Data from the North Dakota Agricultural Weather Network, 2010.
[1]30-year long-term average

In addition, the first day of $0^{o}C$ temperature (frost) occurred on September 14, October 13, October 8, and September 18, in 2007, 2008, 2009, and 2010; respectively. Sorghum-sudan grass, foxtail millet, turnip, and radish displayed effects from weathering, senescence, and desiccation; respectively, in 2009 and 2010 following first frost.

Forage Production

Purpletop turnip was used in 2007, which produces more bulb than foliage, compared to 2007, mostly due to the use of the pasja turnip, which has higher foliage to

Table 2. Monthly precipitation levels (cm) at the Central Grasslands Research Extension Center, near Streeter, ND, during the 2007-2010 growing seasons.

	Month					
Year	April	May	June	July	August	September
2007	1.35	17.2	10.4	7.6	10	5.13
2008	1.22	0.32	12.9	7.39	6.2	7.33
2009	3.28	1.96	5.43	5.19	6.19	4.66
2010	2.9	9.93	5.61	16.4	4.66	12.3
Average[1]	3.2	4.98	7.72	7.85	6.05	5

Data from the North Dakota Agricultural Weather Network, 2010.

resulting in a lower amount of desired feed. Turnip production was greater in 2008 bulb ratio. Triticale, a cool season cereal crop, was added in 2008 to provide small grain forage to the cocktail mixture, boosting overall forage production by 25%. Native range production remained similar throughout all four years, despite variable precipitation.

Within the single crop system, foxtail millet out-produced both turnip and cocktail mixture treatments in 2007, 2009, and 2010 (Table 3). Despite being the highest producing treatment in 2008, turnip had the lowest production of the annual forage crop treatments in 2009 and 2010. Production from the legume species within the cocktail mix was very poor each year (Appendix B). Both the cocktail mix and native range treatments remained very constant in forage production over the four years of this study.

Treatments did not differ within the single crop system in 2008 (P = 0.21), and trended to be different in 2007 (P = 0.06). Within the dual crop system in 2008 annual forage crop treatments were not different; however, when comparing the single crop system and dual crop system in 2008, all treatments were greater in the single crop system compared to the dual crop system (P < 0.001) and a treatment X system interaction occurred (P < 0.001). In 2009, there was a treatment effect (P = 0.01) and treatment X system interactions between the single and dual crop systems (P = 0.04). Within the single

Table 3. Forage production[1] (kg/ha; 100% DM) and SE of the annual forage and native range treatments at the Central Grasslands Research Extension Center near Streeter, ND, from 2007-2010.

Year and Treatment	Single Crop System	Dual Crop System	Dual Crop with Spray System
2007			
Millet	5,671 ± 535[a]		
Turnip[2,3]	2,990 ± 1,047[a]		
Cocktail	2,946 ± 319[a]		
Native Range	3,046 ± 237[a]		
2008			
Millet	3,638 ± 325[az]	604 ± 133[ay]	
Turnip[2,4]	4,799 ± 408[az]	338 ± 76[ay]	
Cocktail	3,945 ± 796[az]	987 ± 256[ay]	
Native Range	3,138 ± 234[a]		
2009			
Millet	3,095 ± 561[az]	405 ± 110[ax]	888 ± 81[ay]
Turnip[2,4]	908 ± 247[by]	336 ± 153[ax]	1,005 ± 187[ay]
Cocktail	2,548 ± 519[az]	219 ± 83[ax]	926 ± 51[ay]
Native Range	3,169 ± 388[a]		
2010			
Millet	5,157 ± 503[az]	568 ± 487[ay]	3,343 ± 328[az]
Turnip[2,4]	4,019 ± 553[az]	177 ± 122[ay]	3,262 ± 366[az]
Cocktail	4,402 ± 417[az]	297 ± 172[ay]	4,176 ± 38[az]
Native Range	3,920 ± 358[a]		

[1]Production was sampled in the first week of October prior to grazing in 2007-2010.
[2]Turnip production reflects foliage only.
[3]Purpletop turnip variety used.
[4]Pasja turnip variety used.
[abc]Means within the same year and system that share the same letter do not differ ($P > 0.05$).
[xyz]Means within the same year but different system that share the same letter do not differ ($P > 0.05$).

crop system in 2009, foxtail millet ($P = 0.01$), cocktail mix ($P = 0.04$), and native range ($P = 0.01$) all produced greater forage compared to turnip. Forage production in the dual crop system in 2009 was not different among annual forage crop treatments, but when the single crop system was compared to the dual crop system, foxtail millet and cocktail mix in the single crop system were greater ($P < 0.05$) than the dual crop system treatments. In general, production within the dual crop with spray system was greater than the dual crop system, but was lower than the single crop system in 2009. The exception was production of the turnip in the single crop system which was similar to the dual crop with spray system. In 2010, a treatment effect was evident when comparing the single crop system and dual crop system ($P < 0.001$), the dual crop and dual crop with spray system ($P = 0.01$), and the single crop and the dual with spray crop system ($P = 0.01$); but no treatment X system interaction ($P = 0.80$) was identified among the single, dual, or dual with spray systems. Generally, treatments within the single crop system and the dual with spray system out-produced treatments within the dual crop system in 2010. Notably, treatments within the single crop system were similar to treatments within the dual crop with spray system in 2010 ($P = 0.88$).

Forage Quality

Crude protein concentration of forages sampled during the first week of October (4-Oct) was different among treatment ($P < 0.001$) and year ($P < 0.001$), plus treatment X year interactions ($P = 0.001$) occurred over the four year study (Table 4). Generally, native range had the lowest CP content across all treatments and years, and was lower than turnip in 2007 ($P < 0.001$), 2008 ($P = 0.02$), 2009 ($P < 0.001$), and 2010 ($P < 0.001$), cocktail mix in 2007 ($P = 0.02$), 2008 ($P = 0.005$), 2009 ($P < 0.001$), and 2010 ($P < 0.001$). Native range was lower than foxtail millet in 2007 ($P = 0.002$) and 2010 ($P < 0.001$), but not different in 2008 ($P = 0.58$) and 2009 ($P = 0.46$). Additionally, turnip was greater in 2009 ($P < 0.001$) and 2010 ($P = 0.002$) when compared to turnip in 2008. Crude protein concentration of the cocktail mix was greatest in 2010 lower in 2007 ($P = 0.01$) and 2008 ($P = 0.007$), but was similar to 2009 ($P = 0.84$).

Crude protein levels were different by treatment (*P* = 0.003) but not year (*P* = 0.06), while treatment X year interactions (*P* = 0.002) were evident on the 30-Nov clipping date (Table 4). Native range was lower than turnip in 2008 (*P* = 0.01), 2009 (*P* = 0.01), and 2010 (*P* = 0.02), and lower than cocktail mix in 2008 (*P* = 0.01), 2009 (*P* = 0.03), and 2010 (*P* = 0.05). Native range had similar CP content compared to foxtail millet in 2007 (*P* = 0.75), 2008 (*P* = 0.19), 2009 (*P* = 0.83), and 2010 (*P* = 0.14); turnip in 2007 (*P* = 0.68); and cocktail mix in 2007 (*P* = 0.23). Foxtail millet was lower than both turnip (*P* = 0.01) and cocktail mix (*P* = 0.02) in 2009. Turnip in 2007 was lower than turnip in 2008 (*P* = 0.007), 2009 (*P* = 0.004), and 2010 (*P* = 0.01).

Neutral detergent fiber (NDF) content on 4-Oct was different among treatment (*P* < 0.001) and year (*P* = 0.001), and a treatment X year interaction occurred (*P* < 0.001; Table 5). The turnip NDF in 2009 was greater than 2007 (*P* < 0.001) and 2008 (*P* < 0.001) and similar in 2010 (*P* = 0.07). Cocktail mix NDF in 2008 was different from 2007 (*P* < 0.001) and 2010 (*P* < 0.001), but not different in 2009 (*P* = 0.22). Foxtail millet NDF was greater than turnip in 2007 (*P* < 0.001), 2008 (*P* < 0.001), 2009 (*P* < 0.001), and 2010 (*P* < 0.001); and cocktail mix in 2007 (*P* < 0.001), 2008 (*P* < 0.001), 2009 (*P* < 0.001), and 2010 (*P* < 0.001). Likewise, native range NDF was greater than turnip in 2007 (*P* < 0.001), 2008 (*P* < 0.001), 2009 (*P* < 0.001), and 2010 (*P* < 0.001); and greater than cocktail mix in 2007 (*P* < 0.001), 2008 (*P* < 0.001), 2009 (*P* < 0.001), and 2010 (*P* < 0.001).

Treatment (*P* < 0.001) and year (*P* = 0.03) effects were identified for NDF content at the 30-Nov clipping date (Table 5). Treatment X year interactions (*P* = 0.002) were also present for NDF content. Turnip had significantly lower NDF levels than foxtail millet (*P* < 0.001), cocktail mix (*P* < 0.001), and native range (*P* < 0.001) in each of the four years

Table 4. Crude protein concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

			4-Oct[2]		
Treatment	2007	2008	2009	2010	SE
Millet	12.6[az]	8.6[aby]	9.6[cy]	12.8[az]	1.06
Turnip[1]	13.7[axy]	10.4[ax]	18.0[az]	17.0[ayz]	1.70
Cocktail	11.5[ay]	11.3[ay]	14.8[byz]	17.2[az]	1.44
Native Range	7.0[bz]	6.3[bz]	7.0[cz]	6.6[bz]	0.16
SE	1.50	1.10	2.50	2.50	
			30-Nov[3]		
Treatment	2007	2008	2009	2010	SE
Millet	7.1[az]	9.2[abz]	5.5[bz]	9.2[abz]	0.91
Turnip[1]	6.8[ay]	15.1[az]	14.9[az]	13.5[az]	1.96
Cocktail	9.3[az]	12.5[az]	13.3[az]	11.1[az]	0.89
Native Range	5.7[az]	5.2[bz]	5.0[bz]	4.9[bz]	0.17
SE	0.76	2.14	2.59	1.89	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (*P* = 0.001).
[3]Treatment X year interaction occurred (*P* = 0.002).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters differ ($P \leq 0.05$).

of the study. Treatment ($P < 0.001$) and year ($P < 0.001$) on 4-Oct were different when comparing acid detergent fiber (ADF) content, and a treatment X year interaction (P <0.001) occurred (Table 6). Turnip ADF content in 2009 was greater than in 2007 (P =0.01), 2008 ($P < 0.001$), and 2010 ($P = 0.01$). In 2010, native range had greater ADF concentration than native range in 2007 ($P = 0.02$) and similar in 2008 ($P = 0.99$) and 2009 ($P = 0.59$).

Treatment ($P = 0.003$) was different at the 30-Nov clipping date, but year (P = 0.10) was not different for ADF content (Table 6). Treatment X year ($P < 0.001$) interactions were present. Acid detergent acid content of foxtail millet was similar to native range in 2008 ($P = 0.95$), 2009 ($P = 0.61$), and 2010 ($P = 0.40$), but different in

Table 5. Neutral detergent fiber concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

			4-Oct[2]		
Treatment	2007	2008	2009	2010	SE
Millet	60.8^{az}	61.0^{az}	62.8^{az}	61.2^{az}	0.45
Turnip[1]	23.0^{cyz}	19.7^{cy}	27.1^{cz}	21.5^{cyz}	1.57
Cocktail	38.0^{by}	48.8^{bz}	43.3^{byz}	37.4^{by}	2.67
Native Range	57.8^{az}	59.5^{az}	56.4^{az}	63.0^{az}	1.42
SE	8.90	9.58	7.89	9.98	
			30-Nov[2]		
Treatment	2007	2008	2009	2010	SE
Millet	42.8^{ay}	74.3^{az}	76.5^{az}	76.1^{az}	8.22
Turnip[1]	25.6^{bz}	21.8^{bz}	29.2^{bz}	27.3^{bz}	1.58
Cocktail	48.1^{az}	49.8^{az}	50.9^{az}	54.0^{az}	1.25
Native Range	63.9^{az}	61.7^{az}	74.3^{az}	75.8^{az}	3.58
SE	7.90	11.20	6.00	6.50	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred ($P < 0.001$).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters are different ($P \leq 0.05$).

2007 ($P = 0.02$). In 2007, the foxtail millet ADF level was lower than in 2008 ($P = 0.03$), 2009 ($P = 0.01$), and 2010 ($P = 0.01$).

Calcium content was different among treatment ($P < 0.001$) and year ($P = 0.002$), and treatment X year interactions ($P < 0.001$) occurred on 4-Oct (Table 7). Generally, turnip had the greatest Ca concentrations in each of the four years, while cocktail mix was greater ($P \leq 0.05$) than foxtail millet and native range. Native range Ca levels were greater in 2008 ($P = 0.001$) and 2009 ($P = 0.01$) compared to 2007, while similar to 2010 ($P = 0.02$), and 2010 ($P = 0.004$). Calcium concentration within forages varied from 0.2% in foxtail millet in 2007 to 3.3% in turnip in 2009 during the 4-Oct sampling period ($P < 0.001$).

Calcium levels were different among treatments on the 30-Nov clipping date ($P <$

Table 6. Acid detergent fiber concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

			4-Oct[2]		
Treatment	2007	2008	2009	2010	SE
Millet	32.7^{az}	31.4^{bz}	36.4^{az}	30.2^{bz}	1.34
Turnip[1]	16.5^{cy}	15.2^{cy}	20.3^{cz}	15.5^{cy}	1.17
Cocktail	23.8^{bcy}	27.2^{bz}	27.5^{bz}	21.9^{cy}	1.37
Native Range	34.1^{ay}	37.6^{az}	35.7^{az}	39.0^{az}	1.09
SE	4.10	4.72	3.81	5.12	
			30-Nov[2]		
Treatment	2007	2008	2009	2010	SE
Millet	24.3^{by}	38.2^{az}	42.8^{az}	40.6^{abz}	4.16
Turnip[1]	19.1^{bz}	14.7^{cy}	21.1^{cz}	19.0^{cz}	1.35
Cocktail	32.6^{ayz}	29.3^{by}	31.6^{byz}	34.0^{bz}	0.98
Native Range	40.8^{ayz}	37.6^{ay}	48.0^{az}	49.4^{az}	2.83
SE	4.80	5.50	6.00	6.50	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (P < 0.001).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters are different ($P \leq 0.05$).

0.001; Table 7). No year ($P = 0.73$) effect was evident and no treatment X year interaction ($P = 0.42$) occurred. Overall, turnip maintained the greatest Ca levels among treatments, followed by the cocktail mix treatment. Phosphorus concentration was different among treatment ($P < 0.001$) and year ($P < 0.001$), and treatment X year interactions ($P < 0.001$) occurred in the 4-Oct collection period (Table 8). In 2010, turnip was greater than 2007 ($P < 0.001$), 2008 ($P < 0.001$), and 2009 ($P = 0.004$). Cocktail mix had greater P concentrations among treatments and across all four years.

Phosphorus concentration on 30-Nov was different among treatment ($P = 0.001$), and year ($P = 0.003$; Table 8). No treatment X year interaction ($P = 0.23$) occurred for P on 30-Nov. Foxtail millet and native range were consistently lower than turnip and cocktail mix when comparing P content at the 30-Nov clipping date, and were

Table 7. Calcium concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

			4-Oct[2]		
Treatment	2007	2008	2009	2010	SE
Millet	0.2[dx]	0.5[cz]	0.4[dyz]	0.3[dxy]	0.08
Turnip[1]	3.2[az]	2.8[az]	3.3[az]	3.1[az]	0.11
Cocktail	1.9[bz]	1.1[bx]	1.9[bz]	1.5[by]	0.18
Native Range	0.6[cy]	1.0[bz]	1.0[cz]	0.8[cyz]	0.09
SE	0.67	0.49	0.62	0.60	
			30-Nov		
Treatment	2007	2008	2009	2010	SE
Millet	0.3	0.5	0.4	0.5	0.04
Turnip[1]	3.0	2.5	3.6	4.1	0.36
Cocktail	1.7	1.3	1.5	1.0	0.15
Native Range	0.7	1.1	0.5	0.8	0.12
SE	0.60	0.40	0.80	0.90	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (P < 0.001).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).

similar to each other.

Treatment ($P < 0.001$), year ($P < 0.001$), and treatment X year interactions ($P < 0.001$) occurred for IVDMD on 4-Oct (Table 9). Overall, turnip had the greatest IVDMD levels over the four year study and across all treatments, except in 2008 when cocktail mix had similar levels. Native range had the lowest IVDMD across all years and treatments. In 2008, foxtail millet was greater than 2007 ($P = 0.01$), 2009 ($P < 0.001$), and 2010 ($P = 0.002$).

The IVDMD concentration was different among treatment ($P = 0.004$) and treatment X year interactions ($P = 0.01$) occurred on 30-Nov (Table 9). Year was not different ($P = 0.12$). Foxtail millet, cocktail mix, and native range remained similar across all four years of the study when comparing IVDMD levels on 30-Nov, while turnip was

Table 8. Phosphorus concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

		4-Oct[2]			
Treatment	2007	2008	2009	2010	SE
Millet	0.2^{by}	0.2^{by}	0.4^{az}	0.3^{bz}	0.03
Turnip[1]	0.3^{ay}	0.3^{ay}	0.4^{ay}	0.6^{az}	0.06
Cocktail	0.3^{ay}	0.3^{ay}	0.4^{ayz}	0.5^{az}	0.03
Native Range	0.2^{bz}	0.1^{cy}	0.2^{bz}	0.2^{cz}	0.01
SE	0.04	0.05	0.06	0.09	
		30-Nov			
Treatment	2007	2008	2009	2010	SE
Millet	0.1	0.2	0.2	0.2	0.01
Turnip[1]	0.2	0.4	0.3	0.4	0.06
Cocktail	0.3	0.4	0.3	0.3	0.02
Native Range	0.	0.2	0.1	0.1	0.03
SE	0.04	0.06	0.05	0.07	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (P < 0.001).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters are different ($P \leq 0.05$).

more variable due to a low value in 2007.

Cow Performance

Due to limited variability in stratifying cows for treatment paddock in 2007, initial BW was different among treatments (P < 0.001; Table 10). However, this difference did not impact any post-trial measurements. No differences in initial BW occurred (P > 0.05) among treatments post-trial in 2007 or 2008. Final BW (P = 0.02) and final BCS (P =0.04) were affected by treatment in 2009. Final BW and final BCS increased with each treatment, with the turnip treatment greatest in BW and BCS gain at 86 kg and 0.5 BCS; respectively. Average daily gain was not different among treatment (P = 0.19) in 2009. In 2010, final BW, final BCS and ADG (P = 0.0017, P = 0.0037, P = 0.0019; respectively) were affected by treatment.

Table 9. In vitro dry matter disappearance concentration (%) of the annual forage treatments and native range by selected dates at the Central Grasslands Research Extension Center near Streeter, ND from 2007-2010.

Treatment	2007	2008	2009	2010	SE
			4-Oct[2]		
Millet	68.2^{cy}	76.2^{bz}	63.9^{by}	68.2^{cy}	2.55
Turnip[1]	88.4^{az}	89.3^{az}	82.2^{az}	90.7^{az}	1.87
Cocktail	77.7^{bz}	78.0^{bz}	77.2^{az}	82.3^{bz}	1.19
Native Range	52.0^{dz}	48.6^{cz}	48.5^{cz}	41.9^{dy}	2.12
SE	7.71	8.64	7.54	10.70	
			30-Nov[3]		
Treatment	2007	2008	2009	2010	SE
Millet	40.5^{az}	56.2^{abz}	60^{az}	56.1^{abz}	4.31
Turnip[1]	51.5^{ay}	89.4^{az}	79^{az}	83^{az}	8.34
Cocktail	69.0^{az}	73.3^{az}	73.5^{az}	71.2^{az}	1.06
Native Range	43.5^{acz}	44.7^{bz}	34.1^{bz}	35.1^{bz}	2.76
SE	6.40	9.80	10.00	10.30	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (P < 0.001).
[3]Treatment X year interaction occurred (P = 0.01)
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters are different ($P \leq 0.05$).

Soil Health

Soil bulk density (D_b) was different between native range and each annual forage treatment at both depths, with the annual forage treatments being more compacted (Table 11). Soil D_b at the 0-3 cm and 5-8 cm depth had a treatment effect ($P < 0.001$). A year effect occurred for D_b at the 0-3 cm depth ($P = 0.002$) and 5-8 cm depth (P < 0.001); however, no treatment X year interactions were found at the 0-3 cm ($P = 0.94$) or the 5-8 cm ($P = 0.86$) depths. Soil organic carbon levels differed between treatment ($P < 0.001$) and year ($P = 0.04$), while no treatment X year interactions ($P = 0.88$) were present.

Soil K_{sat} was not different between treatment ($P = 0.33$) or year ($P = 0.27$), and there was not a treatment X year interaction ($P = 0.75$; Table 12). Soil WFS was different between treatment (P = 0.05) and no year (P = 0.13) or treatment X year interactions (P = 0.74) were identified from 2009-2010.

Whole soil stability index data was affected by treatment (P = 0.004), but was not different between year (P = 0.41) and no treatment X year interactions (P = 0.16) were found (Table 13). Soil GMD was affected by treatment (P < 0.001), year (P < 0.001), and treatment X year interactions (P = 0.02) occurred. Soil GMD differed among years for each annual forage treatment; as foxtail millet (P < 0.001), turnip (P < 0.001), and cocktail mix (P < 0.001) all increased, while native range (P = 0.14) remained the same. Soil MWD were not affected by year (P > 0.05) or treatment (P = 0.13) and no treatment X year interactions (P = 0.77) were identified.

Soil microbial biomass carbon levels were different between year (P < 0.001; Table 14), possibly because of the storage of the 2009 samples compared to fresh extraction of 2010 samples. No treatment (P = 0.08) or treatment X year interactions (P = 0.96) occurred. It is important to note that the reported soil MBC levels are unusually greater than other research reported, and unfortunately we cannot account for these greater levels. However, MBN levels are consistent with other studies and were different between year (P< 0.001); but neither treatment effects (P = 0.17) or treatment X year interactions (P = 0.70) were found.

Soil N levels were not different between treatment (P = 0.76) or year (P = 0.10) and treatment X year interactions did not exist (P = 0.80); therefore, soil N was presented as an average level by annual forage treatment, opposed to individual annual forage treatment (Table 15). Additionally, pH levels were not different between treatment (P = 0.86). Soil N levels in the annual forage crop treatments were identical in 2009 and 2010 at 62 kg/ha within a 0-61 cm depth. Soil N levels within native range paddocks were

Table 10. Initial and final body weight (BW), body condition score (BCS), and average daily gain (ADG) for beef cattle grazing annual forage treatments and native range at the Central Grasslands Research Extension Center from 2007-2010.

	Treatment					
	Millet	Turnip	Cocktail	Native Range	SE	*P*-value
2007						
Initial BW, kg	539[a]	532[b]	535[a]	532[b]	2.2	< 0.001
Final BW, kg	570	575	573	572	9.6	0.85
ADG, kg	0.8	1	0.9	0.9	0.2	0.29
Initial BCS	5.3	5.2	5.3	5.4	0	0.15
Final BCS	5.6	5.5	5.6	2.5	0.1	0.31
2008						
Initial BW, kg	573	574	573	574	4.4	0.95
Final BW, kg	605	614	606	616	11.1	0.33
ADG, kg	0.7	0.9	0.8	1	0.2	0.36
Initial BCS	5.3	5.3	5.3	5.3	0.1	0.93
Final BCS	5.4	5.5	5.5	5.4	0.1	0.66
2009						
Initial BW, kg	527	530	533	527	8.7	0.68
Final BW, kg	586[b]	616[a]	605[ab]	590[b]	12.9	0.02
ADG, kg	1.2	1.8	1.5	1.3	0.4	0.19
Initial BCS	5.1	5.2	5.2	5.2	0.1	0.71
Final BCS	5.4[b]	5.7[a]	5.6[ab]	5.4[b]	0.1	0.04
2010						
Initial BW, kg	585	584	585	586	1.9	0.46
Final BW, kg	543[c]	569[b]	594[a]	601[a]	16	< 0.001
ADG, kg	(0.9)[c]	(0.3)[b]	0.2[ab]	0.3[a]	0.3	< 0.001
Initial BCS	5.2	5.2	5.3	5.3	0.1	0.39
Final BCS	4.9[b]	5.0[b]	5.4[a]	5.6[a]	0.1	< 0.001

[abc]Means within the same row having differing letters are different ($P \leq 0.05$).

nearly identical at 50 and 49 kg/ha at the 61 cm soil depth in 2009 and 2010; respectively (Table 16). Soil pH levels varied from 6.4 to 7.6 within native range paddocks in 2009 and 2010.

Table 11. Soil bulk density (g/cm^3) and soil organic carbon (% weight in 0-15 cm) concentration by annual forage treatments and native range at the Central Grasslands Research Extension Center in 2009 and 2010.

	Bulk Density 0-3 cm[1]		
Treatment	2009	2010	SE
Millet	1.4	1.2	0.11
Turnip	1.3	1.1	0.08
Cocktail	1.4	1.1	0.10
Native Range	0.9	0.7	0.06
SE	0.12	0.10	
	Bulk Density 5-8 cm[1]		
Treatment	2009	2010	SE
Millet	1.4	1.3	0.07
Turnip	1.4	1.3	0.05
Cocktail	1.4	1.3	0.03
Native Range	1.1	1.0	0.02
SE	0.09	0.07	
	Soil Organic Carbon[1]		
Treatment	2009	2010	SE
Millet	2.7	2.8	0.37
Turnip	2.5	2.8	0.00
Cocktail	2.2	2.9	0.14
Native Range	4.1	4.6	0.02
SE	0.37	0.45	

[1]No treatment X year interaction occurred between 2009 and 2010 ($P > 0.05$).

Economics

The economic returns in this study were calculated by crop system, treatment, and year. We determined a treatment to be cost-effective if the cost to graze was < $1.34/hd/d, which according to USDA NASS NDASS (2007) is the average cost to winter a pregnant beef cow in a drylot feeding system.

2007

Foxtail millet ($1.03/hd/d), turnip ($1.04/hd/d), and native range ($1.21/hd/d) treatments were all cost-effective alternatives compared to drylot feeding ($1.34/hd/d) using a single crop system in 2007 (Table 17). A combination of poor legume species production coupled with the greatest input costs among treatments boosted the cost to graze the cocktail mix treatment to $2.27/hd/d. The foxtail millet treatment had the greatest

Table 12. Soil saturated hydraulic conductivity (cm/s) and soil wetting front suction (cm) by annual forage treatments and native range at the Central Grasslands Research Extension Center in 2009 and 2010.

	Saturated Hydraulic Conductivity[1]		
Treatment	2009	2010	SE
Millet	0.1	0.2	0.05
Turnip	0.0	0.0	0.01
Cocktail	0.0	0.1	0.08
Native Range	0.1	0.1	0.02
SE	0.26	0.23	
	Wetting Front Suction[1]		
Treatment	2009	2010	SE
Millet	10.6	8.9	1.24
Turnip	7.4	7.5	0.07
Cocktail	9.2	6.8	0.86
Native Range	7.0	5.5	0.02
SE	2.11	1.73	

[1]No treatment X year interaction occurred between 2009 and 2010 ($P > 0.05$).

forage production and consequently the greatest stock density among treatments (4.25 hd/ha). Additionally, grazing foxtail millet and turnip was more cost-effective than grazing native rage.

2008

Within the single crop system in 2008, turnip had the greatest stock density among annual forage treatments and native range due to high forage production (5.24 hd/ha; Table 18). Cost to graze turnip and foxtail millet was $0.70/hd/d and $0.82/hd/ha; respectively, in the single crop system. The single crop cocktail mix treatment was again not cost-effective at $1.47/hd/d compared to the drylot feeding alternative. The native range treatment was a cost-effective option at $1.31/hd/d. Both the foxtail millet and turnip single crop treatments were economical alternatives compared to grazing native range in 2008.

With poor production from the annual forage crop of the dual crop system, low stock densities occurred with cost to graze foxtail millet, turnip, and cocktail at $1.48/hd/d, $12.46/hd/d, and $3.20/hd/d, respectively. Cost to graze turnip was elevated because of lower than average cereal hay crop production on the turnip treatment, as well as overall poor turnip forage production. Below average cereal crop production may be caused in

Table 13. Whole soil stability index, geometric mean diameter (mm), and mean weight diameter (mm) by annual forage treatments and native range at the Central Grasslands Research Extension Center in 2009 and 2010.

	Whole Soil Stability Index[1]		
Treatment	2009	2010	SE
Millet	0.2	0.3	0.06
Turnip	0.2	0.3	0.02
Cocktail	0.3	0.3	0.01
Native Range	0.4	0.3	0.05
SE	0.05	0.01	
	Geometric Mean Diameter		
Treatment	2009	2010	SE
Millet	0.97[b]	1.28[a]	0.14
Turnip	0.97[b]	1.26[a]	0.15
Cocktail	1.06[b]	1.33[a]	0.15
Native Range	0.96[b]	1.08[b]	0.02
SE	0.03	0.07	
	Mean Weight Diameter[1]		
Treatment	2009	2010	SE
Millet	1.5	2.1	0.05
Turnip	1.4	2.2	0.13
Cocktail	1.8	2.3	0.15
Native Range	1.5	1.9	0.02
SE	0.23	0.28	

[1]No treatment X year interaction occurred between 2009 and 2010 ($P > 0.05$).
[abc]Means within the same row having differing letters are different ($P \leq 0.05$).

Table 14. Soil microbial biomass carbon (kg/ha) and soil microbial biomass nitrogen (kg/ha) by annual forage treatments and native range at the Central Grasslands Research Extension Center in 2009 and 2010.

	Microbial Biomass Carbon[1]		
Treatment	2009	2010	SE
Millet	2897	4318	301.11
Turnip	2484	4295	367.30
Cocktail	2687	4169	247.80
Native Range	3563	5557	583.45
SE	168.70	184.20	
	Microbial Biomass Nitrogen[1]		
Treatment	2009	2010	SE
Millet	28	44	11.27
Turnip	31	39	11.20
Cocktail	27	39	9.78
Native Range	20	20	0.02
SE	9.48	14.53	

[1]No treatment X year interaction occurred between 2009 and 2010 ($P > 0.05$).

Table 15. Average soil nitrogen (kg/ha) and soil pH concentration by depth for the annual forage crops combined in early June at the Central Grasslands Research Extension Center near Streeter, ND, in 2009 and 2010.

2009	**N**	***2009***	**pH**
0-15.5 cm	24	0-15.5 cm	6.3
15.5-30.5 cm	14	15.5-30.5 cm	6.9
30.5-46 cm	16	30.5-46 cm	7.0
46-61 cm	8	46-61 cm	5.6
Total N (61 cm)	**62**	Mean pH (61 cm)	**6.5**
SE	1.93	SE	0.50
2010		***2010***	
0-15.5 cm	24	0-15.5 cm	6.5
15.5-30.5 cm	17	15.5-30.5 cm	7.0
30.5-46 cm	14	30.5-46 cm	7.2
46-61 cm	8	46-61 cm	7.3
Total N (61 cm)	**62**	Mean pH (61 cm)	**7.0**
SE	1.73	SE	0.72

part by a lack of subsoil moisture following the turnip crop, because turnips are high-water use species.

2009

Foxtail millet ($0.96/hd/d) and cocktail mixture ($1.24/hd/d) treatments were cost-effective, late-season grazing alternatives compared to drylot feeding using a single crop system in 2009 (Table 19). All treatments were negatively affected by below-average moisture levels in 2009, while low soil N levels are believed to have adversely affected the annual forage treatments, especially turnip ($3.37 hd/d). Despite dry conditions later in the growing season, plentiful spring moisture aided in high native range forage production, driving down the grazing cost ($1.03/hd/d) of this treatment. Foxtail millet had the greatest stock density among treatments at 3.24 hd/ha.

Table 16. Average soil nitrogen (kg/ha) and soil pH concentration by depth for the native range sites in early June at the Central Grasslands Research Extension Center near Streeter, ND, in 2009 and 2010.

2009[1]	**N**	***2009***	**pH**
0-15.5 cm	25	0-15.5 cm	6.4
15.5-30.5 cm	10	15.5-30.5 cm	6.7
30.5-46 cm	9	30.5-46 cm	7.1
46-61 cm	6	46-61 cm	7.2
Total N (61 cm)	**50**	Mean pH (61 cm)	**6.8**
SE	4.13	SE	0.92
2010[1,2]		***2010***	
0-15.5 cm	27	0-15.5 cm	6.5
15.5-30.5 cm	8	15.5-30.5 cm	7.1
30.5-46 cm	9	30.5-46 cm	7.2
46-61 cm	5	46-61 cm	7.6
Total N (61 cm)	**49**	Mean pH (61 cm)	**7.1**
SE	5.08	SE	0.75

[1]Nitrogen levels reflect the nitrogen application on the cereal hay crop (67 kg/ha) in May.
[2]Nitrogen levels do not reflect the July nitrogen application (157 kg/ha).

Growing season precipitation was 35% below average in 2009, reducing forage production, particularly within the annual forage crop. Lack of precipitation, sub-soil moisture, and high cereal crop re-growth impacted annual forage treatments within the dual crop system. Stock density for the foxtail millet treatment was 89% less in the dual

Table 17. Input ($/ha) and grazing costs ($/hd/d) by treatment at Central Grasslands Extension Center in 2007.

	Single Crop System			
Item	Millet	Turnip	Cocktail	Native Range
Costs, $/ha				
Land rent[1]	66.94	66.94	66.94	36.80
Herbicide (July)[2]	16.06	16.06	16.06	-
Herbicide application[*]	11.93	11.93	11.93	-
Annual forage seed	14.82	13.71	38.83	-
No-till seeding with application[*]	31.44	31.44	31.44	-
Fertilizer (July)[3]	25.32	25.32	25.32	
Other[4]	-	8.89	-	-
Annual Forage Costs, $/ha	166.50	174.28	190.51	36.80
Stock density, hd/ha	*4.25*	*4.00*	*2.00*	*0.72*
Grazing cost, $/hd/d[5]	*0.93*	*1.04*	*2.27*	*1.21*

[1] Non-irrigated cropland & pasture mean rental rate for Kidder County, ND (USDA NASS NDASS, 2007)

[2] Herbicide burn-down spray(1 L/ha glyphosate, 89 mL/ha dicamba, 250 mL/ha 2,4-D)

[3] 28 kg/ha urea nitrogen & 28 kg/ha 11:52

[4] Oat straw bale supplement to prevent digestive upset (2 – 680 kg bales @ $18.00/each)

[5] (annual forage costs)*(hectare/head) / (# of days grazed)

[*] North Dakota custom rate values (USDA NASS NDASS, 2007)

crop than in the single crop system. Cost to graze annual forages using the dual crop system ranged from $3.08/hd/d for foxtail millet to $5.93/hd/d in the turnip treatment.

We implemented a spray application in 2009 that was utilized between the harvest of the cereal hay crop and seeding of the annual forage crop. The spray application was designed to minimize re-growth of the cereal hay crop, conserve moisture, and maximize the economic return of the annual forage crop used as a dual crop.

Despite being a dry year, both the foxtail millet ($1.05 hd/d) and cocktail mix ($1.26/hd/d) treatments provided cost-effective grazing alternatives to drylot feeding in 2009. Turnip was not a cost-effective option, even with the addition of the spray application ($1.57/hd/d). Stock density was similar between foxtail millet and cocktail mix at 1.01 and 0.99 hd/ha, while 0.74 hd/ha for turnip. Interestingly, the perennial-based native range treatment, which capitalized on the excess spring moisture, provided the most economical late-season grazing option in the below-average moisture year of 2009 ($1.03/hd/d).

2010

The cost of the N application (157 kg/ha) to the annual forage crop was split between years 2010 and 2011 (Table 20). We believe that the abundant amount of nitrogen will benefit the site for at least two years, resulting in no need for additional application in 2011. This is appropriate because the annual forage crop or cover crop should scavenge most leachable nitrogen and aid in the re-cycling of these nutrients in the upper soil profile through at least the next season. The cost of the fertilizer application and low production from the cereal hay crop (due to late fertilizer application and excess field moisture) was offset by the excess forage production from the annual forage crop due to above average growing season moisture (33% > average) and the fertilizer application.

Cost to graze foxtail millet, turnip, and cocktail mix within the single crop system was $0.70, $1.08, and $1.07 hd/d, respectively. Stock densities ranged from 3.87 hd/ha to 5.90 hd/ha on the turnip and foxtail millet; respectively. Cost to graze native range was at its lowest cost among the four years of this study at $0.84 hd/d. Foxtail millet produced

5,157 ± 535 lb/kg in the single crop system, driving down grazing costs and creating a more cost-effective grazing alternative than grazing native range and feeding in a drylot system. Both the single crop system turnip and cocktail mix treatments resulted in more economical late-season alternatives than drylot feeding.

Within the dual crop system, the turnip treatment had the lowest production due to high cereal crop re-growth. This led to a stock density of 0.24 hd/ha and a grazing cost of $6.11/hd/d. The foxtail millet treatment within the dual crop system had a grazing cost of $2.82 hd/d, while the cocktail mix was $5.81 hd/d.

Stock densities of the dual crop with spray system were less than or equal to those within the single crop system; however, because of high second crop production and addition of the cereal hay crop return, grazing costs were low within the dual crop with spray system. Stock density ranged from 3.14 hd/ha to 3.87 hd/ha in the turnip and cocktail mix treatment, respectively. The cost to graze a beef cow on the foxtail millet, turnip, and cocktail mix within a dual crop with spray system was $0.45 hd/d, $0.53 hd/d, and 0.49 hd/d, respectively in 2010. Notably, these grazing costs were lower than the drylot feeding system, native range system, and the annual forage single crop systems in 2010.

Table 18. Input costs ($/ha), returns ($/ha) and grazing costs ($/hd/d) by treatment at Central Grasslands Research Extension Center near Streeter, ND, in 2008.

	Single Crop System			Dual Crop System			Native Range
Item	Millet	Turnip	Cocktail	Millet	Turnip	Cocktail	
Costs, $/ha							
Cereal crop seed	-	-	-	27.00	27.00	27.00	-
No-till seeding with application[*]	-	-	-	31.44	31.44	31.44	-
Fertilizer (April)[1]	-	-	-	25.32	25.32	25.32	-
Swath/baling[*]	-	-	-	36.70	36.70	36.70	-
Herbicide (July)[2]	10.50	10.50	10.50	-	-	-	-
Herbicide application[*]	11.93	11.93	11.93	-	-	-	-
Land rent[3]	75.09	75.09	75.09	75.09	75.09	75.09	40.76
Annual forage seed	6.80	16.67	36.06	6.80	16.67	36.06	-
No-till seeding w/o application[*]	29.99	29.99	29.99	29.99	29.99	29.99	-
Other[4]	-	8.89	-	-	8.89	-	-
Returns, $/ha							
Cereal crop hay[5]	-	-	-	62.28	36.27	72.94	-
Adjusted Costs, $/ha	134.31	153.07	163.57	36.79	55.55	66.05	40.76
Stock density, hd/ha	*3.41*	*5.24*	*2.66*	*0.59*	*0.11*	*0.49*	*0.74*
Grazing cost, $/hd/d[6]	*0.94*	*0.70*	*1.47*	*1.48*	*12.46*	*3.20*	*1.31*

[1] 56 kg/ha urea nitrogen (46% N)
[2] Herbicide burn-down spray (1 L/ha glyphosate, 89 mL/ha dicamba, 250 mL/ha 2,4-D)
[3] Non-irrigated crop and non-irrigated pasture average rental rates for Kidder County, ND (USDA NASS NDASS, 2008)
[4] Oat straw bale supplement to prevent digestive upset (2 – 680 kg bales @ $18.00/each)
[5] Cereal hay crop production (premature oat hay: $35.00/680 kg bale) – total cereal hay crop costs
[6] (adjusted costs)*(hectare/head) / (# of days grazed)
[*] North Dakota custom rate values (USDA NASS NDASS, 2007)

Table 19. Input costs ($/ha), returns ($/ha) and grazing costs ($/hd/d) by treatment at Central Grasslands Research Extension Center near Streeter, ND, in 2009.

	Single Crop System			Dual Crop System			Dual Crop with Spray System			Native Range
Item	Millet	Turnip	Cocktail	Millet	Turnip	Cocktail	Millet	Turnip	Cocktail	
Costs, $/ha										
Cereal crop seed	-	-	-	14.82	14.82	14.82	14.82	14.82	14.82	-
No-till seeding w/ fert. app.[*]	-	-	-	31.44	31.44	31.44	31.44	31.44	31.44	-
Fertilizer (April)[1]	-	-	-	25.32	25.32	25.32	25.32	25.32	25.32	-
Swath/baling[*]	-	-	-	36.7	36.7	36.7	36.7	36.7	36.7	-
Herbicide (July)[2]	11.12	11.12	11.12	-	-	-	11.12	11.12	11.12	-
Herbicide application	11.93	11.93	11.93	-	-	-	11.93	11.93	11.93	-
Land rent[3]	75.09	75.09	75.09	75.09	75.09	75.09	75.09	75.09	75.09	40.76
Annual forage seed	21.74	18.06	31.12	21.74	18.06	31.12	21.74	18.06	31.12	-
No-till seeding w/o fert. app.[*]	29.99	29.99	29.99	29.99	29.99	29.99	29.99	29.99	29.99	-
Other[4]	-	8.89	-	-	8.89	-	-	8.89	-	-
Returns, $/ha										
Cereal crop hay[5]	-	-	-	-24.23	-26.25	-12.37	-47.32	-49.31	-35.62	-
Annual Forage Costs, $/ha	149.87	155.08	159.25	51.73	56.94	61.11	51.73	56.94	61.11	40.76
Stock density, hd/ha	*3.24*	*0.96*	*2.67*	*0.35*	*0.2*	*0.4*	*1.01*	*0.74*	*0.99*	*0.82*
Grazing cost, $/hd/d[6]	*0.96*	*3.37*	*1.24*	*3.08*	*5.93*	*3.18*	*1.05*	*1.57*	*1.26*	*1.03*

[1] 56 kg/ha urea nitrogen (46% N)
[2] Herbicide burn-down spray (Cereal crop: 1 L/ha glyphosate, 250 mL/ha dicamba, 250 mL/ha 2,4-D)
[3] Non-irrigated cropland and non-irrigated pasture average rental rates for Kidder County, ND (USDA NASS NDASS, 2010)
[4] Oat straw bale supplement to prevent digestive upset (680 kg bale @ $18.00)
[5] Cereal hay crop production (premature oat hay: $35.00/680 kg bale) – total cereal hay crop costs
[6] (adjusted costs)*(hectare/head) / (# of days grazed)
[*] North Dakota custom rate values (USDA NASS NDASS, 2007)

Table 20. Input costs ($/ha), returns ($/ha) and, grazing costs ($/hd/d) by treatment at the Central Grasslands Research Extension Center in 2010.

	Single Crop System			Dual Crop System			Dual Crop w/ Spray			Native Range
Item	Millet	Turnip	Cocktail	Millet	Turnip	Cocktail	Millet	Turnip	Cocktail	
Costs, $/ha										
Cereal crop seed	-	-	-	15.44	15.44	15.44	15.44	15.44	15.44	-
No-till seeding w/ fert. app.*	-	-	-	31.44	31.44	31.44	31.44	31.44	31.44	-
Fertilizer (April)[1]	-	-	-	30.38	30.38	30.38	30.38	30.38	30.38	-
Swath/baling*	-	-	-	36.7	36.7	36.7	36.7	36.7	36.7	-
Herbicide (June)[2]	11.12	11.12	11.12	23.47	23.47	23.47	23.47	23.47	23.47	-
Herbicide application*	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	-
Herbicide (July)[3]	11.12	11.12	11.12	-	-	-	11.12	11.12	11.12	-
Herbicide application	11.93	11.93	11.93	-	-	-	11.93	11.93	11.93	-
Land rent[4]	74.84	74.84	74.84	74.84	74.84	74.84	74.84	74.84	74.84	41.99
Annual forage seed	17.29	15.46	27.98	17.29	15.46	27.99	17.29	15.46	27.99	-
No-till seeding w/ app.*	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	-
Fertilizer (July)[5]	35.44	35.44	35.44	35.44	35.44	35.44	35.44	35.44	35.44	-
Other[6]	-	4.45	-	-	4.45	-	-	4.45	-	-
Returns, $/ha										
Cereal crop hay (oat)[7]	-	-	-	-124.6	-157.8	-30.6	-158.8	-192	-64.8	-
Annual Forage Costs, $/ha	205.1	207.7	215.8	84.2	86.8	94.9	84.2	86.8	94.9	42
Stock density, hd/ha	*5.9*	*3.87*	*4.07*	*0.6*	*0.17*	*0.33*	*3.75*	*3.14*	*3.87*	*1.05*
Grazing cost, $/hd/d[8]	*0.71*	*1.1*	*1.08*	*2.86*	*10.42*	*5.87*	*0.46*	*0.56*	*0.5*	*0.82*

[1] 67 kg/ha urea nitrogen (46% N)
[2] Weed control (Non-crop: 1 L/ha glyphosate, 89 mL/ha dicamba, 250 mL/ha 2,4-D) (Cereal crop: 600 mL/ha clopyralid)
[3] Herbicide burn-down spray (Non-crop and cereal crop: 1 L/ha glyphosate, 250 mL/ha dicamba, 250 mL/ha 2,4-D)
[4] Non-irrigated cropland and non-irrigated pasture average rental rates for Kidder County, ND (USDA NASS NDASS, 2010)
[5] 157 kg/ha urea nitrogen (46% N) (total cost: $63.14/ha, divided over two years @ $31.57/ha for 2010 & 2011)
[6] Oat straw bale supplement to prevent digestive upset (680 kg bale @ $18.00)
[7] Cereal hay crop production (premature oat hay: $35.00/680 kg bale) – total cereal hay crop costs
[8] (adjusted costs)*(hectare/head) / (# of days grazed)
* North Dakota custom rate values (USDA NASS NDASS, 2007)

DISCUSSION

Precipitation levels were a main factor in determining annual forage crop production as indicated in the below-average precipitation in 2009 and above-average precipitation in 2010. Average forage production was lowest in 2009 and greatest in 2010. Meanwhile, native range production was similar across all four years despite variable precipitation. The cocktail mix yielded the greatest forage production in 2010 coinciding with above-average rainfall and fertilization. Interestingly, forage production from the legume species within the cocktail mix was poor each year (comprising an average 2% of the total production). The legumes comprised as much as 50% of the total cost of the cocktail mixture, creating an expensive mixture with limited return (Appendix B). A cost-effective legume species needs to be identified in order to produce a cost-effective cocktail mixture (Appendix B).

Sufficient soil fertility, particularly nitrogen, was required to produce high amounts of forage. For example, foxtail millet produced the greatest amount of forage among all single crop system treatments using a four year average, and produced the greatest yields in years fertilization was conducted (2007 and 2010). Turnip production was similar to that reported by Undersander et al. (1991) when fertilization occurred; however, turnip production was very low when fertilization was omitted. Koch et al. (2002) also reported improved turnip production when increased levels of N fertilizer were used.

Average soil N levels did not differ between annual forage crop treatments or year, resulting in an average of 62 kg/ha within a 61 cm depth in both 2009 and in 2010 prior to the urea N application (157 kg/ha). It is expected that the cocktail mix treatment will eventually provide the highest level of soil nitrogen in the top 61 cm because of the nitrogen fixation potential and the complementary crop growth which features deep-rooted plants scavenging more N in the soil profile. Kristensen and Thorup-Kristensen (2004) reported higher levels of scavenged N when using rye than when using forage radish within a 0-100 cm depth, and greater levels of gathered N when using forage radish compared to when using rye at a depth greater than 0-100 cm, suggesting that a mixture of both crops would be more effective in retrieving an optimal level of N.

Forage production of foxtail millet was lowest in 2009 (3,095 $\pm$ 561 kg/ha) when soil N levels were only 62 kg/ha in a 61 cm profile prior to treatment seeding. Oelke et al. (1990) reported 3,400 kg/ha of foxtail millet production when 134 kg/ha N was available in a 61 cm soil profile. In order to achieve adequate turnip production, Undersander et al. (1991) recommended 112 kg/ha N be applied to soil with SOC levels between 2-5%. Soil organic carbon levels within our turnip paddocks averaged 2.65% over 2009 and 2010, while turnip production greatly increased with fertilization (72 kg/ha actual N) in 2010 when compared to no-fertilization in 2009.

Our study utilized a no-till system with the addition of a herbicide spray application to control weed pressure and cereal crop re-growth. Both weed pressure and cereal crop re-growth in the dual crop with spray system was successfully controlled in 2009 and 2010 with a spray application conducted between the harvest of the single crop and seeding of the annual forage crop. Therefore, the need for tillage in reducing weed pressure and cereal crop re-growth was eliminated by the use of the spray application. May et al. (2007) also utilized a spray application whenever tillage was not conducted in order to successfully maintain weed control prior to annual cereal crop seeding.

Several indicators of forage quality were measured over time and by treatment in this study. The CP content of each treatment trended downward from the 25-Oct (Appendix D) to the 30-Nov. Plant senescence is believed to be the primary contributing factor that leads to this trend (Sedivec et al., 2007; Sedivec et al., 2009). For example, turnip had the greatest level of CP at each clipping date over the four year period, followed by cocktail mix, foxtail millet, and native range. In our study, CP content of turnip peaked at 18.0% in October 2009, and was as low as 6.8% in late November of 2007. As far as foxtail millet, Neville (2007) reported CP levels of 8.5% in October of a swath grazing trial in south central ND, while in our study, foxtail millet CP levels were as great as 7.0% in October (2007 and 2009) and as low as 4.9% in early December (2010).

The primary plant constituent in our cocktail mix was a cereal grain (varied by year), which amounted to 36% of the total cocktail mix forage production. Crude protein levels for the cereal grain crop within our cocktail mixture treatment ranged from 9.3% in November of 2007 to 17.2% in October of 2010. This was comparable to the findings of Aasen et al. (2004) who reported barley having a CP concentration of 13.4% in November of a swath grazing trial near Alberta, Canada. As for native range, CP concentrations were slightly lower than the 8.3% level found by Neville (2007) in October. Overall, all annual forage crop treatments effectively maintained CP levels above the minimum requirement for beef cattle in mid-gestation (6.0%; National Research Council, 2000); however, native range levels were consistently at or below this threshold, but no adverse effects to cow performance were identified.

Research has shown both NDF and ADF concentrations increase as the grazing season progresses, which corresponds with our findings. Neutral detergent fiber levels for turnip in our study ranged from 19.4 to 35.6%, which was similar to the 20.0% stated by

Undersander et al. (1991). Foxtail millet ranged from 42.8 to 76.4%, comparable to the 59.5% reported by May et al. (2004). Acid detergent fiber ranged from 32.7 to 36.5% in October and November for foxtail millet, while turnip levels ranged from 16.9 to 18.5% during the same period.

Calcium levels of the turnip (0.31-0.33%) were greatest among all treatments each year. Meanwhile, P concentrations were greatest in the cocktail mix in October at peak forage production (0.40). Turnips had the greatest level of IVDMD compared to all other treatments (87.7%), which was greater than the 65-80% levels reported by Undersander et al. (1991). Furthermore, we found oats in the 2010 cocktail mix to have an IVOMD concentration of 75.5% in November, which was greater than the 59.3% levels reported by Aasen et al. (2004) for oats in November.

The implementation of high forage-producing annual crops creates above and below ground organic matter (e.g. plant residue and root biomass) which is expected to increase soil porosity while decreasing the mineral matter density of the soil. Liu et al. (2005) reported that spring barley when seeded as a winter cover crop for an eight-month period increased SOC levels by 4% (1.74-1.82 %) in a silty clay loam soil in southwest British Columbia. When comparing SOC levels in a native range system, Franzluebbers and Stuedemann (2010) reported a similar level of 4.76% compared to the 4.59% found in 2010. Overall, SOC levels in the native range were greater compared to the annual forage crop system. This can be explained by the steady, yearly organic carbon inputs in the form of plant residue and root biomass that is present in the native range system. No treatment differences in SOC were found among annual forage crops; however, the data reported only represents two years of a five year project. Similarly, no differences in K_{sat} values between annual forage crop treatments were documented over the first two years of this study. However, Valzano et al. (1997) found K_{sat} readings to be 56% greater when crop residue was left in Australian cropping systems, thus with the utilization of high forage-producing crops in a no-tillage system measurable results may be found in the future.

In order to best represent soil aggregation in this study, we followed a new procedure (WSSI) but also supported the data by utilizing the more commonly reported values of MWD and GMD. According to Nichols and Toro (2011), idle native rangeland had a WSSI value of approximately 0.40, which was similar to the findings in this study (0.30-0.40). The WSSI values from our no-till annual forage crop treatments varied from 0.20-0.30, which is comparable to the findings of Nichols and Toro (2011) in a rye-spring wheat-safflower rotation. When looking at MWD values, Liu et al. (2005) reported annual ryegrass (1.99 mm) and fall rye cover (1.67 mm) crops to have higher MWD than the spring barley (1.35 mm) and bare soil treatments (1.24 mm). Our study found MWD levels range from 1.46 to 2.28 mm, but were not different. Interestingly, a significant increase in soil aggregate stability was identified in our study. The GMD index of soil aggregate stability indicated that all three annual forage crop treatments increased soil aggregate stability from 2009 to 2010. This is notable, because Regvar et al. (2003) stated that in general, plant species in the Brassicaceae family are not known to form mutualistic relationships with arbuscular mycorrhizal fungi, which is the source of glomalin in soil and which is believed to be the binding agent that stabilizes soil aggregates (Wright and Upadhyaya, 2008). Turnip and radish (cocktail mix) are both members of the Brassicaceae family and were shown to improve soil aggregate stability in our study. It is also possible biological activity may have positively influenced soil structure.

Edgerton et al. (1995) reported a linear relationship between soil aggregate stability and soil microbial biomass, similar to what we found in this study. Even though soil MBC levels in our study were high in both 2009 and 2010, levels still corresponded positively with the GMD soil aggregate stability levels. Our MBC are high compared to Ingram et al. (2005), who identified soil MBC levels from a two-year old restored mine site and an undisturbed native prairie site (both with sandy loam soil and located in southeast WY) to be 1,537 kg/ha and 2,410 kg/ha; respectively, compared to 3390 kg/ha and 4560 kg/ha in our turnip and native range treatments, respectively.

The high quality and highly palatable forage of the *Brassica* species improved cow performance in the turnip and cocktail mix in three of four years. In 2010, there was notable desiccation due to an early frost (18-September) and the addition of approximately 30 cm of snow by the first week of December which negatively affected cow BW and BCS within the turnip and foxtail millet treatments.

The native range treatment had sufficient cool-season plant growth due to excess late-season moisture which provided highly nutritious forage, and a great amount of topographic variation within these native range paddocks provided areas of easier grazing due to less snow cover. Despite grazing forage with CP levels below the required level (6.0%; National Research Council, 2000), cows grazing native range gained BW and BCS in all four years of the study. Similar to our results, Neville (2007) found that cows grazing standing native range increased BW by 0.5 kg/d while gaining BCS (+ 0.7) over a two year study. Kirby and Parman (1986) suggested that extended periods of grazing forage that was below the minimum CP level could have adverse effects on cow performance. However, based on the findings of Neville (2007) and of this study, the cow's ability to graze selectively to maintain a diet adequate in quality is common with an extended growing season through late November and early December. In addition, Kirby and Parman (1986) documented IVOMD of native range dropped < 50.0%; whereas, IVOMD content dropped as low as 39.5% over this four year study (Appendix C). Finally, across all treatments, final BW, final BCS, and ADG was considerably less in 2010 compared to the previous three years due to snow cover, which likely negatively impacted grazing selectivity and efficiency.

Our economic costs associated with the single and dual crop systems were variable between years; however, when compared with grazing native range or custom drylot feeding rates, the single crop system of foxtail millet was cost-effective in all years, turnip was two out of four years, and cocktail mix was one out of four years. The utilization of grazing annual forages late in the season provides the potential to increase native range grazing efficiency during the growing season (when the ratio of plant growth to plant senescence and nutrient quality are at the highest levels) thus increasing use of available feed for livestock (Sedivec et al., 2007; Sedivec et al., 2009).

When the dual crop with spray system was coupled with above average precipitation levels, annual forage production of the second crop (cover crop) was comparable to the single crop system. Under these conditions, the dual crop with spray system was the most cost-effective program for late-season grazing.

SUMMARY AND CONCLUSION

Despite foxtail millet having the greatest forage production on average from 2007-2010, ADG by cows grazing foxtail millet was lower than all other treatments in 2010. When soil N levels were sufficient, both turnip and cocktail mixtures had the ability to out-produce foxtail millet forage production, while always yielding higher quality forage across the four years. Meanwhile, forage production of native range remained similar across the four years, despite varying environmental conditions.

Annual forage crop systems, especially the dual crop with the herbicide burndown spray application system, have the ability to increase use-efficiency and profitability from marginal cropland. However, in a dual crop system it was essential to implement a spray application between crops in order to be profitable. Overall, these forage crop systems may be particularly appealing to livestock producers with cropland.

Soil aggregate stability increased in the foxtail millet, turnip, and cocktail mix treatments from 2009 to 2010, but did not change in the native range treatment. Placing monetary values on increased soil aggregate stability levels is difficult in the short-run; however, notable soil improvements in the form of enhanced soil structure and increased SOC levels from annual forage crops will be beneficial to future crop production on that site. Other soil properties did not see significant changes throughout the first two years of this study.

In general, all annual forage treatments effectively produced high quality forage (2007, 2008, 2010), increased cow performance (2007, 2008, 2009), improved soil properties (2010), and provided cost-effective single and dual crop grazing systems when compared to drylot feeding and grazing native range (2010). Above average rainfall and adequate fertilization on marginal ground in a semi-arid climate locale were most responsible for cost-effective single and dual crop systems in 2010. The implementation of an economical dual crop system (e.g. cover crop) in which landowners can receive two crops from the same land base in a single growing season will remain an attractive alternative, encouraging future research in this field.

In conclusion, utilizing annual forage crops for extending the grazing season has the potential to be a cost-effective option in ND as a single crop and dual crop with a spray system when compared to drylot feeding and grazing native range late in the year.

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APPENDIX A. CEREAL HAY CROP PRODUCTION BY YEAR, SPECIES, AND VARIETY (2008 - 2010) IN SOUTH CENTRAL NORTH DAKOTA

Table 21. Cereal hay crop production (kg/ha; DM basis) by species and variety using a dual crop system at the Central Grasslands Research Extension Center, 2008-2010.

	Biomass Production			
Treatment	2008	2009	2010	SE
Barley – Hayes	5037	-	-	266.03
Barley – Stockford	4773	-	-	144.02
Barley – Haybet	-	3555	-	1049.10
Oat – Jerry	-	3422	-	841.40
Oat – Jerry	-	-	2328	665.44

APPENDIX B. PERCENT SPECIES COMPOSITION BASED ON FORAGE PRODUCTION OF THE COCKTAIL MIX (2009-2010) IN SOUTH CENTRAL NORTH DAKOTA

Table 22. Percent species composition based on forage production (DM basis) of the cocktail mix at the Central Grasslands Research Extension Center in early October in 2009 and 2010.

Species	2009	2010	Average
Cereal[1]	39	34	36
Turnip	20	18	19
Sunflower	18	16	17
Sorghum-sudan grass	12	11	12
Radish	9	8	8
Legume[2]	2	2	2

[1]Cereal crop was barley in 2009 and oat in 2010.
[2]Legume species was hairy vetch in 2009 and forage soybean in 2010.

APPENDIX C. IN VITRO ORGANIC MATTER DISAPPEARANCE (%) CONCENTRATION OF ANNUAL FORAGE AND NATIVE RANGE TREATMENTS (2007-2010) IN SOUTH CENTRAL NORTH DAKOTA

Table 23. In vitro organic matter disappearance concentration of the annual forage treatments and native range at the Central Grasslands Research Extension Center from 2007-2010.

			4-Oct[2]		
Treatment	2007	2008	2009	2010	SE
Millet	68.1[az]	76.9[az]	64.9[az]	68.1[az]	2.57
Turnip[1]	86.4[az]	91.7[az]	83.7[az]	89.9[az]	1.77
Cocktail	77.2[az]	78.3[az]	76.8[az]	81.1[az]	0.97
Native Range	51.0[bz]	47.8[bz]	46.5[bz]	40.0[bz]	2.30
SE	7.57	9.25	8.16	10.88	
			30-Nov[2]		
Treatment	2007	2008	2009	2010	SE
Millet	40.5[by]	56.2[abyz]	60.0[az]	56.1[abyz]	4.31
Turnip[1]	51.5[aby]	89.4[az]	78.9[az]	83.0[az]	9.24
Cocktail	69.0[az]	73.3[az]	73.5[az]	71.2[az]	0.99
Native Range	43.5[bz]	44.7[bz]	34.1[bz]	35.1[bz]	2.82
SE	6.90	9.60	10.90	10.50	

[1]Nutrient quality of the turnip species represents foliage only.
[2]Treatment X year interaction occurred (P < 0.001).
[abc]Means within the same column having differing letters are different ($P \leq 0.05$).
[xyz]Means within the same row having differing letters are different ($P \leq 0.05$).

APPENDIX D. ANNUAL FORAGE CROP AND NATIVE RANGE NUTRIENT QUALITY FROM SECOND CLIPPING DATE (25-OCT)

Table 24. Nutrient quality (%) of the annual forage treatments and native range sampled 25-Oct at the Central Grasslands Research Extension Center in south central ND (2007-2010).

Treatment	CP	NDF	ADF	Ca	P	IVDMD	IVOMD
Millet – 2007	12.2	61.8	34.9	0.4	0.2	64.1	63.0
Turnip – 2007	15.0	27.2	20.4	3.6	0.3	69.2	80.9
Cocktail - 2007	10.2	48.0	42.8	1.2	0.3	70.1	68.8
Native Range - 2007	6.5	61.1	37.7	0.9	0.1	49.2	48.2
Millet - 2008	9.6	67.6	32.6	0.4	0.2	66.5	66.4
Turnip – 2008	14.7	19.4	12.9	2.8	0.4	90.3	87.7
Cocktail - 2008	12.8	44.4	23.9	1.6	0.3	78.7	76.6
Native Range - 2008	6.3	68.9	38.0	0.5	0.2	29.9	47.8
Millet - 2009	5.9	75.3	43.6	0.5	0.2	60.9	61.1
Turnip – 2009	15.4	35.6	26.0	2.9	0.3	72.3	77.1
Cocktail - 2009	13.8	50.2	30.6	1.7	0.3	72.3	75.0
Native Range - 2009	6.1	62.5	38.6	0.9	0.1	41.0	39.4
Millet - 2010	11.3	70.2	36.0	0.5	0.2	58.4	59.5
Turnip – 2010	14.5	28.4	20.2	3.9	0.5	82.4	81.3
Cocktail - 2010	12.6	43.5	24.9	1.7	0.3	76.5	75.8
Native Range - 2010	5.8	68.8	43.5	0.9	0.1	36.6	35.1

APPENDIX E. ANNUAL FORAGE CROPS AND NATIVE RANGE NUTRIENT QUALITY FROM EARLY OCTOBER TO LATE NOVEMBER IN 2007 IN SOUTH CENTRAL NORTH DAKOTA

Table 25. Nutrient quality of annual forage crops and native range mix at the Central Grasslands Research Extension Center in 2007.

		Cocktail Mix Species						Native Range		Turnip		Foxtail Millet
Date	(%)	Cowpea	Radish	Soybean	Sunflower	Turnip[1,2]	Foxtail Millet[2]	Grass	Forb	Top[1,2]	Bulb	Foxtail Millet[2]
10/4/2007	CP	15.28	11.28	10.53	12.44	12.29	8.97	7.21	6.75	13.73	11.4	12.58
	NDF	30.79	22.52	40.66	30.71	21.68	62.02	64.34	51.32	22.98	17.97	60.84
	ADF	21.27	16.89	28.6	23.23	15.51	33.23	34.68	33.46	16.52	14.22	32.68
	Ca	2.36	3.63	1.7	1.38	3.17	0.34	0.27	0.99	3.16	0.32	0.18
	P	0.49	0.31	0.29	0.37	0.3	0.28	0.14	0.16	0.29	0.4	0.22
	IVDMD	80.05	90.56	74.05	76.36	90.79	70.07	50.71	53.32	88.36	94.06	68.17
	IVOMD	77.05	87.96	71.05	72.78	88.47	71.03	51.71	50.12	86.42	95.05	68.02
10/24/2007	CP	7.58	11.59	6.75	12.53	12.22	7.99	6.01	6.99	14.97	13.2	12.23
	NDF	-	-	-	29.21	-	64.76	64.31	53.21	27.17	18.96	61.84
	ADF	-	-	-	20.95	-	64.76	36.63	38.19	20.36	15.74	34.89
	Ca	-	-	-	1.55	-	0.31	0.37	1.5	3.6	0.49	0.44
	P	-	-	-	0.37	-	0.32	0.12	0.15	0.33	0.41	0.24
	IVDMD	-	-	-	74.76	-	66.07	47.57	52.41	69.22	90.48	64.08
	IVOMD	-	-	-	71.12	-	67.11	47.9	49.07	80.87	91.73	62.98
11/21/2007	CP	7.01	10.65	9.35	4.49	12.33	8.73	5.54	5.77	10.21	-	10.67
	NDF	70.49	29.52	52.17	54.27	29.21	66.14	67.12	60.71	38.39	-	64.15
	ADF	55.65	20.32	38.63	40.84	21.77	37.18	38.17	43.35	28.59	-	36.49
	Ca	1.09	2.34	1.49	0.68	3.66	0.54	0.41	1.31	4.45	-	0.47
	P	0.26	0.37	0.35	0.23	0.27	0.26	0.09	0.1	0.23	-	0.22
	IVDMD	45.1	86.36	62.15	59.17	80.1	61.95	43.49	43.45	68.83	-	60.81
	IVOMD	40.71	83.92	58.5	56.43	83.73	63.72	44.56	40.81	70.15	-	60.9

[1] Represents turnip foliage only
[2] Same crop variety was used

APPENDIX F. ANNUAL FORAGE CROPS AND NATIVE RANGE NUTRIENT CONTENT FROM EARLY OCTOBER TO LATE NOVEMBER IN 2008 IN SOUTH CENTRAL NORTH DAKOTA

Table 26. Nutrient quality of annual forage crops and native range mix at the Central Grasslands Research Extension Center in 2008.

		Cocktail Mix Species						**Native Range**		**Turnip**		**Foxtail Millet**
Date	(%)	Red Clover	Radish	Sorgh-sudan	Sunflower	Turnip[1,2]	Triticale	Grass	Forb	Top[1,2]	Bulb	Foxtail Millet
10/6/2008	CP	11.03	15.51	10.43	9.83	11.18	14.81	6.42	6.19	11.18	8.34	9.07
	NDF	45.92	22.72	59.59	32.47	20.26	48.67	65.54	53.5	20.26	21.79	60.96
	ADF	27.31	17.55	28.39	24.44	15.69	25.77	36.4	38.88	15.69	17.71	31.39
	Ca	1.49	3.75	1.05	1.62	3.04	0.56	0.59	1.46	3.04	0.8	0.53
	P	0.26	0.33	0.29	0.29	0.34	0.38	0.1	0.12	0.34	0.4	0.22
	IVDMD	77.38	88.79	82.1	76.93	89.97	81.1	46.52	50.52	89.97	83.5	75.97
	IVOMD	80.13	88.47	82.19	74.49	91.56	81.41	47.7	47.62	91.56	91.11	76.55
10/30/2008	CP	-	16.6	14.02	10.09	14.78	12.56	6.31	5.88	14.78	13.23	9.59
	NDF	-	23.02	66.53	43.47	20.41	47.22	68.57	47.07	20.41	16.83	67.65
	ADF	-	15.7	30.43	30.23	13.6	22.55	37.71	29.89	13.6	12.88	32.65
	Ca	-	3.8	1.06	1.19	2.76	0.37	0.51	-	2.76	0.56	0.44
	P	-	0.34	0.31	0.31	0.37	0.31	0.16	-	0.37	0.41	0.16
	IVDMD	-	88	77.09	69.23	89.93	80.23	30.72	-	89.93	90.83	66.49
	IVOMD	-	84.19	75.66	65.64	87.35	78.77	48.85	-	87.35	90.63	66.43
11/18/2008	CP	-	21.6	13.68	4.85	14.28	12.08	4.44	6.08	14.28	-	9.05
	NDF	-	25.86	65.26	62.98	22.14	57.09	71.65	51.5	22.14	-	74.42
	ADF	-	16.57	33.98	47.68	14.84	28.59	40.14	35.11	14.84	-	38.41
	Ca	-	1.89	1.03	0.7	2.9	0.2	0.47	1.72	2.9	-	0.49
	P	-	0.53	0.42	0.18	0.41	0.33	0.12	0.29	0.41	-	0.2
	IVDMD	-	87.99	74.72	50.31	89.18	74.18	37.82	-	89.18	-	58.3
	IVOMD	-	84.66	73.62	46.32	86.03	72.86	36.99	55.14	86.03	-	57.26

[1] Represents turnip foliage only

[2] Same crop variety was used

APPENDIX G. ANNUAL FORAGE CROPS AND NATIVE RANGE NUTRIENT CONTENT FROM EARLY OCTOBER TO LATE NOVEMBER IN 2009 IN SOUTH CENTRAL NORTH DAKOTA

Table 27. Nutrient quality of annual forage crops and native range mix at the Central Grasslands Research Extension Center in 2009.

		Cocktail Mix Species						Native Range		Turnip				Foxtail Millet
Date	(%)	Hairy Vetch	Radish	Sorghum-sudan	Sunflower	Turnip[1,2]	Barley	Grass	Forb	Pasja Top[1,2]	Pasja Bulb	Purpletop Top[1]	Purpletop Bulb	Foxtail Millet[2]
10/1/2009	CP	17.58	16.14	11.61	13.41	16.84	15.26	6.97	6.96	17.03	8.84	18.45	12.71	9.55
	NDF	46.74	21.12	59.84	35.99	27.12	57.49	65.9	46.97	22.6	24.79	21.48	18.11	62.79
	ADF	35.68	18.19	30.98	26.57	20.43	31.5	37.72	33.77	17.83	21.89	17.47	15.42	36.38
	Ca	1.59	3.7	1.04	1.83	3.44	0.59	0.42	1.47	2.6	0.71	3.79	0.57	0.44
	P	0.31	0.38	0.35	0.41	0.44	0.4	0.16	0.21	0.41	0.42	0.36	0.43	0.36
	IVDMD	63.16	87.32	77.62	72.47	82.74	71	44.79	52.26	87.59	71.6	86.5	92.39	63.94
	IVOMD	69.7	87.12	76.73	68.64	84.08	71.39	44.71	48.2	88.78	89.4	86.35	94.17	64.9
10/28/2009	CP	16.1	17.66	11.43	9.26	15.97	12.93	6.34	5.78	15.26	-	15.6	-	5.87
	NDF	42.04	33.54	71.87	52.19	31.21	62.51	68.63	56.43	34.83	-	36.41	-	75.33
	ADF	29.79	24.18	38.23	37.29	21.75	33.07	38.3	38.96	25.36	-	26.59	-	43.62
	Ca	0.8	3.24	0.66	1.58	2.96	0.35	0.44	1.33	2.94	-	2.94	-	0.45
	P	0.34	0.4	0.22	0.3	0.39	0.36	0.13	0.13	0.37	-	0.31	-	0.17
	IVDMD	55.43	81.56	74.69	67.59	78.48	67.39	37.62	43.94	73.41	-	71.5	-	60.63
	IVOMD	74.55	79.8	75.5	64.09	79.85	66.48	38.05	40.66	77.28	-	76.86	-	61.1
11/29/2009	CP	12.7	21.35	10.68	5.79	16.78	12.06	5.28	4.64	-	-	-	-	5.47
	NDF	44.05	26.64	71.51	64.33	24.81	61.11	73.39	75.15	-	-	-	-	76.38
	ADF	29.21	18.03	38.52	49.58	15.85	31.56	41.47	54.45	-	-	-	-	42.81
	Ca	-	1.98	0.71	1.05	3.32	0.79	0.39	0.63	-	-	-	-	0.39
	P	-	0.53	0.2	0.17	0.35	0.26	0.12	0.13	-	-	-	-	0.15
	IVDMD	72.33	84.32	73.06	55.56	84.54	70.54	38.54	29.5	-	-	-	-	60.25
	IVOMD	67.53	84.01	74.79	52.95	84.24	70.13	38.07	26.52	-	-	-	-	60.36

[1] Represents turnip foliage only*

[2] Same crop variety was used

APPENDIX H. NUTRIENT QUALITY OF ANNUAL FORAGE CROPS AND NATIVE RANGE FROM EARLY OCTOBER TO LATE NOVEMBER IN 2010 IN SOUTH CENTRAL NORTH DAKOTA

Table 28. Nutrient quality of annual forage crops and native range mix at the Central Grasslands Research Extension Center in 2010.

		Cocktail Mix Species						**Native Range**		**Turnip**		**Foxtail Millet**
Date	(%)	Soybean	Radish	Sorgh-sudan	Sunflower	Turnip[1,2]	Oat	Grass	Forb	Top[1,2]	Bulb	Foxtail Millet
10/5/2010	CP	17.83	22.65	17.92	13.07	17.9	15.1	7.25	5.83	17.9	14.6	12.72
	NDF	35.84	22.54	58.27	33.33	21.55	47.1	67.09	58.75	21.55	18.64	61.42
	ADF	22.44	16.9	26.24	23.16	15.46	26.07	37.13	40.95	15.46	14.78	30.2
	Ca	1.26	2.86	0.93	1.47	2.78	0.32	0.52	1.03	2.78	1.04	0.36
	P	0.44	0.6	0.42	0.31	0.59	0.38	0.15	0.17	0.59	0.54	0.32
	IVDMD	76.15	89.88	78.62	75.81	90.86	79.03	44.56	39.41	90.86	88.15	67.98
	IVOMD	74.42	88.62	80.47	73.38	89.81	78.43	44.47	35.8	89.81	91.88	67.85
11/6/2010	CP	13.93	17.89	14.97	8.25	14.52	8.18	5.84	5.7	14.52	-	11.49
	NDF	52.05	25.43	63.94	42.73	28.18	48.1	70.02	67.54	28.18	-	70.5
	ADF	37.27	18.28	31.23	29.43	28.18	24.44	40.18	46.79	28.18	-	36.23
	Ca	1.8	3.57	1.05	1.23	3.61	0.32	0.59	1.27	3.61	-	0.54
	P	0.33	0.43	0.4	0.26	0.46	0.22	0.13	0.15	0.46	-	0.25
	IVDMD	59.17	86.86	70.41	67.29	83.2	76.35	36.58	36.54	83.2	-	57.78
	IVOMD	58.09	85.18	71.21	64.43	82.28	75.5	36.33	33.94	82.28	-	58.92
12/2/2010	CP	-	17.32	14	7.05	13.52	5.86	5.27	4.57	13.52	-	9.21
	NDF	-	25.42	65.76	59.28	27.27	65.65	75.92	75.71	27.27	-	76.1
	ADF	-	17.65	34.73	43.86	18.86	39.63	43.26	55.54	18.86	-	40.62
	Ca	-	2.17	0.9	0.91	4.11	0.19	0.5	1.03	4.11	-	0.47
	P	-	0.43	0.33	0.19	0.41	0.24	0.08	0.07	0.41	-	0.16
	IVDMD	-	87.41	72.99	59.49	82.98	65.05	36.78	33.36	82.98	-	56.13
	IVOMD	-	85.81	72.28	56.23	82.25	64.86	36.17	29.84	82.25	-	56.25

[1] Represents turnip foliage only
[2] Same crop variety was used

APPENDIX I. SOIL PHOSPHORUS (P) AND POTASSIUM (K) LEVELS BY TREATMENT IN 2009-2010 IN SOUTH CENTRAL NORTH DAKOTA

Table 29. Soil P and K levels by treatment at the Central Grasslands Research and Extension Center in 2009 and 2010.

Treatment	P	K
2009		
Millet	6	188[b]
Turnip	5	153[b]
Cocktail	11	165[b]
Native Range	3	325[a]
SE	1.33	31.40
2010		
Millet	12	260[b]
Turnip	4	203[b]
Cocktail	14	272[b]
Native Range	4	453[a]
SE	2.27	41.40

[abc]Means within the same row having differing letters are different ($P \leq 0.05$).

APPENDIX J. ADDITIONAL SOIL NUTRIENT CONCENTRATIONS AND ELECTRICAL CONDUCTIVITY LEVELS BY TREATMENT IN 2009-2010 IN SOUTH CENTRAL NORTH DAKOTA

Table 30. Soil S, Na, Zn, Cu, CL, and EC levels within treatment paddocks at the Central Grasslands Research and Extension Center in 2009 and 2010.

Treatment	S*	Na**	Zn***	Cu***	Cl*	EC**
2009						
Millet	12.3	37.8	1.0	0.6	7.5	1.5
Turnip	8.0	10.5	0.9	0.6	7.8	1.0
Cocktail	10.0	16.8	0.6	0.6	4.1	0.8
Native Range	13.3	28.0	1.7	1.0	10.7	0.7
SE	1.00	3.89	0.14	0.06	1.00	0.19
2010						
Millet	94.0	79.8	3.2	1.1	7.2	0.2
Turnip	92.3	67.3	1.3	1.2	5.4	0.3
Cocktail	95.0	68.6	1.5	1.0	4.2	0.2
Native Range	89.3	124.6	5.3	1.2	17.2	0.4
SE	0.84	8.24	0.77	0.1	1.71	0.03

Data are from a 0-15 cm depth.

*Unit is kg/ha.

**Unit is mmhos/cm.

***Unit is ppm.