THE EVALUATION OF SOIL CARBON LEVELS ON POST-CONTRACT CONSERVATION RESERVE PROGRAM LANDS IN SOUTHWESTERN NORTH DAKOTA USING MULTIPLE AGRICULTURAL USE PRACTICES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Sebesta, Eva L. M.S., Program of Natural Resources Management, College of Graduate and Interdisciplinary Studies, North Dakota State University, April 2010. The Evaluation of Soil Carbon Levels on Post-contract Conservation Reserve Program Lands in Southwestern North Dakota using Multiple Agricultural Use Practices. Major Professors: Dr. Christopher Schauer and Dr. Kevin Sedivec.

The Conservation Reserve Program (CRP) removes highly erodible lands from production for a contract period of 10 to 15 years. During the contract period permanent vegetation cover is established, allowing biological, chemical, and physical soil properties to stabilize and potentially improve. As CRP contracts expire, these idle lands may return to agricultural use. Understanding the influence of various agricultural practices on post-contract CRP lands will enable landowners to make the best management choices. This four-year study focused on the potential impacts of livestock grazing, cropping systems, and vegetative cover on soil carbon levels and species composition on post-contract CRP lands in a semi-arid climate. A randomized complete block design (n = 2) was developed using four treatments, including season-long grazing (SL), a one-cut haying system (HAY), barley: corn rotational cropping system (CROP), and non-use simulating idle CRP (CTRL). Moderate grazing targeting 50% herbage disappearance occurred on the SL treatment from mid-June through early January. Barley was harvested as hay in mid-July. Corn was left as standing stockpiled forage. Cattle grazed the barley stubble and standing corn from early January through mid-April. Four 100-meter transects were established in each treatment and were used to collect vegetation and soil data. Soil samples were analyzed for inorganic, organic, and total carbon. Results indicate that grazing, haying, and cropping systems do not adversely affect soil carbon levels after 4 years of agricultural use when compared to idle CRP.

Species composition on grasslands also did not change during the study due to grazing, haying, or non-use. The findings of this study support the use of no-till cropping, one-cut haying, and moderate grazing for maintaining soil carbon levels and species composition on post-contract CRP lands.

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INTRODUCTION

Soil is the foundation of most terrestrial ecosystems (Gurevitch et al. 2006). For farmers and ranchers, soil is the lifes blood of their operation. Crop, hay, and livestock operations are dependent on soil quality and resiliency (Brady and Weil 2008). Soil quality is an indicator of the potential of ecological soil functions, while resiliency denotes a soil's ability to rebound from degradation. The proper management of soil aids in maintaining it as a reusable resource (Brady and Weil 2008).

The Conservation Reserve Program (CRP) was established by the 1985 Food Security Act (Steiner 1990). The objective of CRP is to remove highly erodible lands (HEL) from production by planting those lands to a perennial vegetative cover. Vegetation anchors the soil by its roots, acting as an interception layer to slow down precipitation (Brooks et al. 2003), facilitate infiltration (Brady and Weil 2008), and minimize the effects of wind and water as erosional forces (Holecheck et al. 2004).

Currently, there are 12,386,657 hectares (ha) enrolled in the CRP (United States Department of Agriculture, Farm Service Agency 2009). North Dakota is ranked fourth in the nation for CRP land enrollment with 1,070,305 ha. Texas has the highest amount of land in CRP at 1,321,841 ha, Montana second with 1,231,929 ha, and Kansas third with 1,110,855 ha. When CRP contracts expire on September 30, 2010, the nationwide acreage coming out of the CRP will be 1,902,933 ha. North Dakota will have 104,633 ha removed from CRP in 2010. The current CRP program will continue to enroll and renew contracts until 2012 when the program expires.

The North Dakota Department of Agriculture (2009) estimated that in 2006 there were 30,100 farms throughout North Dakota with an average farm size of 524 ha. Over

15.8 million ha of land is used for agricultural production in North Dakota. Agricultural revenue for North Dakota exceeded $4.4 billion, representing 25% of North Dakota's overall revenue in 2006. Wheat comprised 26.6% of those receipts, followed by corn (6.8%), barley (2.8%), and hay (1.4%). North Dakota produces 37% of the nation's barley crop, 2% of the nation's corn for ethanol production, and 5% of the nation's alfalfa.

The United States Department of Agriculture, National Agricultural Statistical Service (2009) reported 10,500 cattle operations in North Dakota in 2007. A total of 1,810,000 cattle were documented in January of 2007, with 922,000 as beef cows. Cattle operations account for approximately 18% of North Dakota's annual agricultural income.

As CRP contracts expire, land use on HEL will change. Knowledge of potential impacts due to land use changes for post-CRP lands is vital. Determining the best management methods and options to maintain soil quality and resiliency under cropping, haying, and grazing regimes will be beneficial to land owners and managers.

The purpose of this study was to evaluate sustainable livestock production on post-CRP lands in a semi-arid area of the Northern Great Plains using cropping, haying, and season-long grazing. The objectives of this study on post-CRP lands were to 1) determine if plant species composition changes occur in conjunction with livestock grazing, non-use, or haying and 2) determine if any changes in soil carbon levels occur due to cropping, haying, or grazing.

LITERATURE REVIEW

History of Soil Conservation

Government supported soil conservation began in 1933 under the National Industrial Recovery Act created during the Great Depression and severe drought (Batie 1985). The Soil Erosion Service (SES) was a direct result of the 1933 legislation. A portion of the SES funding was designated for scientific research (Kelly 1985). From those funds, a soil erosion project was developed in Mexican Springs, New Mexico, located on a Navajo Reservation. Overgrazing by sheep and goats lead to severe soil erosion over much of the Navajo lands. During the study, officials learned an important lesson regarding soil conservation – people are part of the soil conservation process. Understanding the needs, culture, and goals of landowners is an integral part of creating a soil conservation program that is truly useful to landowners. While research is valuable, finding ways to translate research findings into useful land use practices is key to successful soil conservation projects.

The Soil Conservation Act of 1935 passed into law following the 1933 legislation as a result of massive wind erosion in the 1930s (Batie 1985). This legislation created the Soil Conservation Service (SCS), which was specifically designed to work with farmers on soil erosion issues. The Soil Conversation and Domestic Allotment Act of 1936 provided funds for farmers willing to plant crops promoting soil conservation. Subsequent acts followed, with each act encouraging soil conservation through monetary incentives.

Technology that enhanced agricultural production flourished after World War II (Helms and Flader 1985). Incentive programs previously encouraging retirement of marginal lands and reduction in agricultural production now promoted increased production. By the early 1950s, agricultural surpluses were common. The Agricultural Act of 1956 contained the Soil Bank Program (SBP; Steiner 1990). Enrollment in the SBP was voluntary and farmers could choose between two areas of reserve, including acreage reserve and conservation reserve (Helms and Flader 1985). The acreage reserve focused on reducing production, while the conservation reserve placed erodible land in retirement for contract periods of three to 15 years (Helms and Flader 1985; Johnson and Clark 2001). The SBP program was terminated by 1965 (Steiner 1990).

Major soil conservation measures were contained within the 1985 Food Security Act under the Conservation Reserve Program (CRP; Steiner 1990). While HEL was the focus of the CRP, curbing agricultural production and reducing sediment-laden runoff were secondary goals. The SCS concentrated its efforts on soil erosion through research, surveys, preventative measures, and public assistance (Public Law 99-198, 99 1985; Steiner 1990). The contract period for CRP lands was 10-15 years (United States Department of Agriculture, Farm Service Agency 1997).

The Food, Agriculture, Conservation, and Trade Act of 1990 continued the CRP (Public Law 101-624, 104 Statute 3359 1990). As with the 1985 legislation, the 1990 Act sought to remove lands from agricultural use that may degrade land productivity or impair water resources. Additional lands considered for the program included marginal pasturelands. Alternate uses for these lands under the CRP included wetlands, wildlife habitat, and tree plantings associated with riparian areas. The Act also allowed lands for CRP consideration if they impaired water quality on or off-site, or provided some form of permanent grass filter strip, waterway, or similar structure. Permanent living structures such as snow fences, shelterbelts, and wildlife habitat improvement areas could be considered as land conservation measures. Sites with salinity problems that may impede productivity were also listed. Contracts for CRP were 10-15 years (United States Department of Agriculture, Farm Service Agency 1997).

The Federal Agriculture Improvement and Reform Act of 1996 (Public Law 104-127 1996) continued the CRP with further refinements such as a conservation plan. This new legislation defined a conservation plan as a document outlining a conservation system uniquely created to fit the landowner, land, land uses, and contract period. A conservation system consisted of measures or management used in the conservation plan. Conservation measures used had to meet two main criteria. The first criteria must consider area resources in conjunction with available conservation technology, as well as Natural Resource Conservation Service guidelines. The second criteria must be cost effective and minimize soil erosion, thus improving soil conditions.

In 2002, the Farm Security and Rural Investment Act renewed the CRP and other conservation programs through 2007 (Public Law 107-171 2002). Terms under the CRP remained the same, with emphasis on soil erosion control, improving water quality, and wildlife habitat uses. Additions to the CRP included strict guidelines of harvesting or grazing on contract lands. The only harvesting allowed was in conjunction with wildlife habitat under specific vegetation management criteria or under times of extreme drought. CRP lands could also be used for wind turbines based on specific land use guidelines.

The Food, Conservation, and Energy Act of 2008 is the most current Act and also included the CRP (House Resolution 6124 2008). Similar to the 2002 bill, harvesting and grazing of CRP lands is restricted. Grazing is allowed for control of invasive species using specific criteria based on climate, soil, area resources, and grazing system. A new subsection is included for new and socially disadvantaged farmers or ranchers. This section is designed to allow incoming farmers or ranchers to buy out the current CRP contract from the retiring farmer or rancher, incorporate any desired conservation-based improvements, create a conservation plan, and allow for enrollment in some form of conservation program. The current legislation is in force through 2012.

Conservation Reserve Program Soil Benefits

A key requirement of the CRP program is the conversion of agricultural lands to permanent cover vegetation. Any form of permanent planting consisting of perennial grasses, forbs, and legumes meets the requirements for CRP. Permanent vegetation plays an important role in maximizing interception (Brooks et al. 2003) and infiltration (Brady and Weil 2008), while minimizing runoff and potential erosion (Holechek et al. 2004).

Brooks et al. (2003) defines interception as precipitation captured by vegetation and ground litter. The captured moisture is either slowly released back into the atmosphere as evaporation or travels down vegetation and litter to the soil surface as stem flow (Brady and Weil 2008). Vegetation acts as a physical barrier, slowing the speed of falling precipitation and allowing increased infiltration (Holechek et al. 2004). Approximately 10-20% of precipitation is intercepted by mature grassland vegetation (Brooks et al. 2003). Knapp and Seastedt (1986) determined the vegetation and litter interception rate was 40% of precipitation in grasslands. The greater the litter cover, the better the interception rate.

Throughfall is precipitation not intercepted by any form of vegetation or litter (Brooks et al. 2003). Together, throughfall and stem flow comprise the precipitation reaching the soil surface. Once precipitation reaches the soil surface, it may infiltrate the soil and percolate downward to lower horizons or runoff. The intensity of the precipitation event, soil properties, available pore space, and vegetation cover all influence infiltration (Holechek et al. 2004). Fine-textured soils have smaller pore spaces and consequently lower infiltration rates compared to coarser-textured soils. Compacted soils also have lower infiltration rates.

Brady and Weil (2008) noted vegetation aids precipitation movement into the soil through root channels and enhanced soil structure. Wienhold and Tanaka (2000) found uncropped plots had higher rates of infiltration due to increased pore space. No-till cropped and hayed plots in their study had higher infiltration rates compared to conventional tillage. Shapiro et al. (2001) found the increased residue levels in CRP aided in reducing erosion and increasing infiltration. Willms et al. (1993) found removal of litter had a negative impact on plant growth forms, biomass production, and soil water availability. Gilley et al. (1997) also reported removal of vegetation and litter decreased infiltration rates with cropping.

Runoff is the result when interception and infiltration mechanisms are exceeded (Brooks et al. 2003; Holechek et al. 2004; Brady and Weil 2008). Water movement, either in the form of raindrops or overland flow, contains the energy to dislodge soil particles and surface debris and cause erosion. Erosion transports nutrient laden soils to other areas causing a deficiency in the area of loss (Holechek et al. 2004). Areas of deposition may benefit from increased productivity due to increased soil nutrients (Aguilar and Heil 1988), however the area of loss will experience reduced productivity over time (Holechek et al. 2004). Gilley et al. (1997) found runoff was decreased on control CRP lands compared to cropped sites due to increased litter and vegetation cover. Mausbach (1996) also found CRP improved soil quality through increased vegetation cover that minimized erosion and runoff.

Soil carbon is a component of organic matter. Soil carbon is comprised of both organic and inorganic components (Gurevitch et al. 2006) and includes plant, animal, and microbial contributions (Rasmussen et al. 1980; Post and Kwon 2000). The amount of organic matter accumulation, and consequently soil carbon, is dependent on vegetative inputs, disturbance, and soil conditions (Post and Kwon 2000). Vegetative inputs are influenced by either quality or quantity of vegetation (Wright and Hons 2005). Vegetation can contain high levels of stored carbon and nutrients, yet overall vegetation production maybe low resulting in small carbon additions to the soil. Conversely, high levels of vegetation production may occur; however, its carbon content and nutrient quality is relatively low. Vegetation input, whether quality or quantity, must match or exceed the losses occurring in the soil.

Disturbance includes both natural and anthropogenic causes (Gurevitch et al. 2006; Radosevich et al. 2007). Natural disturbances can include fire, wind, flood, and drought (Ricklefs 1990; Gurevitch et al. 2006; Radosevich et al. 2007). Anthropogenic disturbances can include cropping, haying, and grazing systems (Gurevitch et al. 2006; Radosevich et al. 2007). Both natural and anthropogenic disturbances modify vegetation and soil conditions (Brooks et al. 2003) causing changes to vegetation communities, inputs to soil organic matter and carbon, and potentially increasing rates of erosion (Brady and Weil 2008).

Soil conditions are influenced by climate (Jenny 1994; Bolinder et al. 2007), which drives chemical, biological, and physical processes occurring in the soil and impacts organic matter and carbon levels (Lal et al. 1997). Chemical processes can include cation exchange and pH buffering ability (Brady and Weil 2008). Biological processes include decomposition, respiration, nutrient cycling (Brady and Weil 2008), and plant-organism productivity (Brewer 1994; Jenny 1994).

Physical processes include soil formation factors such as aggregate formation and stability (Gale et al. 2000a, 2000b), soil color (Brady and Weil 2008), and water retention. Climate controls these processes through precipitation and temperature levels, often measured as mean annual precipitation (MAP) and mean annual temperature (MAT).

Hendrickson (2003) determined that temperature influenced plant production and decomposition rates, both of which increased with temperature. Redmann (1975) and Passey and Hugie (1962) found distinct relationships existing between soil formation, vegetation types, and climate. MacDougall et al. (2008) noted climate influenced plant species presence (Fissore et al. 2008), which in turn influenced organic matter and carbon inputs and associated processes. Biondini et al. (1998) determined plant composition and net primary production (NPP) was directly influenced by rainfall. Higher levels of rainfall increased the potential for plant productivity. Griffiths and Birch (1961) determined that after a period of drought higher levels of rainfall increased decomposition rates.

Jenny (1994) listed topography as one of the five major influences of soil formation. VandenBygaart et al. (2002) identified both erosion and topography as key factors in soil carbon location and stability. Clay soils contain higher organic matter levels and are less likely to erode due to aggregate formation than sandy soils (Burke et al. 1989). Clay particles form complexes with humus, which slows decomposition rates (Schaetzl and Anderson 2007). Sand particles are larger in size and weight, making transport by water or wind more difficult (Burke et al. 1995). Sand does not form complexes with humus, so humus is more easily transported from the site. Reeder et al. (1998) found sandy loam sites consistently contained less soil carbon when compared to other soil types in their study.

Landscape position influences the rate of soil carbon loss or deposition (Schaetzl and Anderson 2007). Hilltop locations are most prone to wind and water erosion, potentially decreasing soil carbon levels. In contrast, low-lying areas such as depressions and toeslopes receive and retain sediment leading to an increase in soil carbon levels (Aguilar and Heil 1988). Gentle slopes may also be sites of deposition (Lal 2007). Landscape position also influences water movement, erosion, and sediment redistribution.

Brady and Weil (2008) suggest soil is both a reusable and renewable resource. Brady and Weil further point out that while soil is renewable, the time required to regenerate severely degraded soils may not occur within desirable time constraints. Therefore, land use and management should focus on soil from the reusable perspective. Wienhold et al. (2001) suggest using soil quality as a tool for the measurement of ecosystem health. Soil quality includes chemical, physical, and biological processes associated with ecological functions (Brady and Weil 2008). Determining the functionality of these processes can be used as an indicator of soil quality and ultimately the reusable nature of the soil.

In a broader context, soils may be viewed as resistant or resilient (Brady and Weil 2008). Resistant soils are able to withstand improper use and degradation. Resilient soils may become degraded with the impaired soil influencing chemical, physical, and biological processes (Lal et al. 1997). However, resilient soils can be restored to previous levels with modifications to land use practices. Reeder et al. (1998) found sandy loam soils to be easily influenced and degraded by land use, and very resilient to changes in soil carbon levels when land use changes occurred. Lal et al. (1997) found fragile soils easily degraded or exhausted causing decreased productivity. Additional amendments added to these soils do not improve or maintain productivity. Only changes to management strategies can restore a system to previous soil quality levels.

Conservation Reserve Program Grazing

Grazing systems influence species composition, litter accumulation, soil carbon and nitrogen distribution, and root mass abundance (Milchunas and Laurenroth 1993). Short-term grazing can influence species composition during a particular growing season. Long-term grazing can modify both the vegetation and soil, depending on grazing intensity. Fuhlendorf et al. (2001) found heavy or intense grazing causes short stature grasses to become the dominant species. Vermeire et al. (2008) found intense grazing increased forb production, while early season grazing promoted increased production of cacti. Biondini et al. (1998) found all levels of grazing increased forb diversity and density. Johnston et al. (1971) noted an increase in forbs and shrubs as grazing intensity was increased.

In a mixed grass prairie long-term grazing trial conducted near Mandan, North Dakota, Wienhold et al. (2001) found non-grazed plots became dominated by threadleaf sedge (*Carex filifolia*), sun sedge (*Carex heliophilia*), and Kentucky bluegrass (*Poa pratensis*). Moderately grazed plots maintained a mix of native species consisting of blue grama (*Bouteloua gracilis*), needleandthread (*Hesperostipa comata*), and prairie junegrass (*Koelaria macrantha*). Heavily grazed plots were dominated by the short grass blue grama. A trial near Cheyenne, Wyoming in a mixed grass prairie found western wheatgrass (*Pascopyron smithii*) and forbs dominated non-grazed sites (Schuman et al. 1999), with western wheatgrass dominance increasing under light grazing pressure. Under heavy grazing pressure, blue grama dominated the plot. Under moderate grazing, species composition was maintained at a rate comparable to non-grazed plots (Frank et al. 1995).

A study in southwestern Alberta by Willms et al. (2002) found grazing increased decomposition levels due to animal hoof action breaking up litter. Mills and Adl (2006) conducted a long-term study in Truvo, Nova Scotia, Canada, that documented an increase in bare ground as grazing intensity increased. A study outside of Streeter, North Dakota, (Biondini et al. 1998) determined litter decomposition rates were higher across all levels of grazing compared to ungrazed plots, with moderate grazing having the highest levels of decomposition. Donkor et al. (2001) conducted a study in the Ministik Wildlife Research Station in Alberta, Canada. Donkor et al. (2001) also found a decrease in litter quantity due to animal movements, along with some increase in soil compaction. In a study near Mandan, North Dakota, compaction rates were highest in heavily stocked grazing systems based on increased bulk density (Wienhold et al. 2001).

Changes in soil carbon levels were noted by Schuman et al. (1999) who found lower soil carbon levels in the non-grazed plots compared to the other grazing treatments in the upper 30 centimeters of soil. The Schuman et al. (1999) took place within the High Plains Grasslands Research Station outside of Cheyenne, Wyoming. Soil nitrogen levels followed a similar pattern in this study with lower concentrations in the heavily grazed plots compared to lightly grazed plots. Manley et al. (1995), who also conducted research within the High Plains Grassland Research Station, found lower levels of soil carbon and organic nitrogen in the upper 7.6 centimeters of soil in the non-grazed sites. In the 3.8 – 7.6 centimeter zone, soil carbon levels were lowest in the lightly grazed plots. Wienhold et al. (2001) in their Mandan, North Dakota, study, observed the highest levels of soil carbon in heavily grazed plots, with the lowest levels in the non-grazed sites. Inorganic nitrogen followed a similar pattern during the trial, while organic nitrogen was lowest in the heavily grazed plots and highest in the non-grazed.

Schuman et al. (1999) found root mass was highest in non-grazed plots and decreased with grazing intensity in the upper 15 centimeters of soil. Root mass was highest in lightly grazed plots within the 15-30 centimeter zone and lowest in the non-grazed plot for the same range. Milchunas and Lauenroth (1993) noted a positive response to root mass abundance in most of their plots in response to all levels of grazing.

Moderate grazing was the most beneficial intensity for maintaining plant community composition, minimizing compaction, and protecting soil quality (Wienhold et al. 2001). Heavy grazing treatments tended to have lower species diversity and productivity as well as a decrease in animal production. Moderate grazing produced the highest level of forage and animal gain compared to heavy grazing and crested wheatgrass plots. Patton et al. (2007) found production on silty range sites was highest under light intensity grazing. Overflow sites within the same study had the highest level of production under heavy grazing intensity although production was not different at overflow sites under any of the grazing treatment types.

Conservation Reserve Program Haying

Vegetation composition and production influence soil composition. Guo et al. (2000) found hayed sites produced the highest levels of biomass in May (approximately 70 g/m^2) compared to grazed sites (40 g/m^2) or CRP sites (70 g/m^2) within the study. In contrast, by July grazed sites (approximately 345 g/m^2) were consistently producing higher levels of biomass than hayed (260 g/m^2) and CRP sites (235 g/m^2). Grass aerial cover within the CRP land was 24% higher than grazed sites, with approximately 69% of the overall cover consisting of grass in the CRP compared to 45% in the grazed. Hayed sites within the same study had a 22% higher level of grass cover, with a total cover of 66% compared to 45% at grazed sites. Forb species cover was higher at grazed sites, with approximately 24%, compared to CRP (10%) and hayed (18%) treatments, although the total cover was similar across all three sites ranging between 78-82%. Wienhold and Tanaka (2001) found reference hayed sites within their study contained both higher organic carbon and nitrogen in the upper 15 centimeters of soil compared to the reference non-use sites. Wienhold and Tanaka (2001) suggested removal of above ground vegetation caused an increase in below ground decomposition rates.

Sedivec and Soiseth (1998) determined crude protein content for forage at CRP sites based on haying history and alfalfa composition. Sites with 33% or higher alfalfa content with a three year or less history of haying contained the highest rate of crude protein at 11.5%, while forage at sites with less than 33% alfalfa composition and more than 3 years of haying history had the lowest crude protein content at 7.7%. In the same study, Sedivec and Soiseth (1998) determined the acid detergent fiber content was consistently lowest in forage at sites with greater than three years of haying history, regardless of the alfalfa composition.

Productivity of CRP sites was documented by Printz (1993). Sites in southwestern North Dakota produced yields ranging from 1,793 to 4,483 kg/ha, however actual hay yields varied depending on location. Hay was harvested after the traditional harvest date, affecting the crude protein levels. Sedivec and Soiseth (1998) noted alfalfa will have crude protein levels higher than grasses even when alfalfa is harvested prior to or at full bloom.

Conservation Reserve Program Crop Production

Changes in land use from CRP to a cropping system can potentially influence soil carbon levels and soil quality. Reeder et al. (1998) found total carbon was reduced in the A horizon six years after a cropping system was implemented on native prairie. Native prairie maintained a rate of 26,652 kg/ha of organic carbon in the upper 28 centimeters of a sandy loam soil, while the cropped plot contained 24,386 kg/ha of organic carbon. This trial also contained a cropped site cultivated for over sixty years and showed long-term cropping maintained carbon levels at 25,810 kg/ha. Organic carbon levels for the clay loam sites were 53,710 kg/ha, 50,535 kg/ha, and 51, 436 kg/ha, respectively for native, cropped, and long-term cropped sites. Organic carbon was consistently lower in the short-term cropped sites and consistently higher in the native sites. Mixing of the soil changes the location of carbon. Sandy soils have a deeper penetration of water, thus potentially enabling movement of carbon deeper into the soil horizon. Malo et al. (2005) found soil carbon levels were higher at the surface, while cultivated soils contained higher levels of soil carbon deeper in the soil horizon. Reeder et al. (1998) showed both sandy loam and clay loam soils were somewhat resistant to cultivation. However, the sandy loam soils were more resilient when compared to the clay loam soils.

Salinas-Garcia et al. (1997) found soil organic carbon levels to be lowest in the upper 20 cm of soil when moldboard plowing was used compared to other types of cropping methods. Olson et al. (2005) determined no-till methods minimized the loss of soil carbon compared to conventional tillage methods at all soil depths. The study found no-till systems minimized leaching of nutrients and erosion. Henrickson et al. (2001) noted cultivation accelerated decomposition rates. Gilley et al. (1997) and Lindstrom et al. (1994) found no-till systems minimized soil erosion. Lindstrom et al. (1994) also found soil structure changed and aggregate stability decreased when CRP lands were converted to cropped systems. No-till systems minimized the changes to soil structure and aggregate stability. Conversion to cropping decreased infiltration rates (Lindstrom and Onstad 1984; Gilley et al. 1997), increased soil compaction (Davidson and Ackerman 1993), and decreased litter cover (Shapiro et al. 2001). Wienhold and Tanaka (2001) noted hayed and no-till cropping systems have comparable levels of litter cover. Zheng et al. (2004) also found similar litter cover levels for hayed and no-till systems, creating the same soil erodibility levels between systems.

Conservation Reserve Program Wildlife Benefits

The CRP not only minimizes soil loss on HEL, but provides important habitat for a number of wildlife species including deer, pheasants, and ducks. Gould and Jenkins

(1993) noted deer usage of CRP lands increased during the winter and spring seasons. Additionally, does and fawns used CRP lands more heavily in the spring and summer due to availability of increased vegetation production. Gould and Jenkins (1993) suggested minimizing haying when possible to sustain desirable deer habitat.

The CRP can also provide lands with desirable cover for upland game birds. Geaumont (2009) found pheasants selected nest sites away from no-till barley and corn due to a lack of nest cover, preferring to nest in control sites simulating extended CRP conditions. Riley (1995) also had similar findings with pheasants selecting CRP sites due to increased availability of cover and nest sites.

Reynolds et al. (2001) determined CRP increased duck nest success and recruitment. Larger undisturbed sites aided in increasing nest success by 30-46% compared to nests located in and near croplands. Geaumont (2009) found 17.6 nests/100 ha in simulated CRP lands compared to 12.6 nests/100 ha in season long grazed pastures and 1.0-1.5 nests/100 ha in no-till barley and corn.

Conservation Reserve Program Economics

The CRP offers economic incentives to landowners to remove HEL from production. A secondary benefit of CRP is the increase in hunter revenue to communities and states. Bangsrud et al. (2004) estimated annual hunter revenues for the state of North Dakota at $12.8 million dollars, with half of the revenue generated from waterfowl hunters and one-quarter of the revenue from pheasant hunters. Hunter revenues aid in off-setting agricultural losses occurring when lands are enrolled in CRP.

Taylor et al. (1994) suggested crop prices increase per unit as production levels decrease through the enrollment of lands in CRP. While crop income would be less for those with lands enrolled in CRP, the overall income of remaining producers would be greater. However, lower crop incomes would occur for all producers if all lands were removed from CRP. This study (Taylor et al. 1994) suggested that the benefits of having all lands in production included lower feed and food costs. Bangsrud et al. (2004) created a model using 16 counties from various parts of North Dakota. Bangsrud et al. (2004) found that if lands in all 16 counties were released from CRP contracts, approximately $123.6 million more would be generated in agricultural revenues from crop production alone. Revenue increases varied from $8.7 to $33.1 million depending on the area surveyed.

STUDY AREA

This study was conducted near Hettinger, North Dakota, in Adams County. This region lies in the unglaciated portion of the Missouri Plateau in the Great Plains (Ulmer and Conta 1987). The overall landscape is gently rolling terrain with occasional buttes and ridges. Parent materials are either calcareous shale or sandstone.

Two privately owned sites were used in the study. The Clement site was 259 ha in size and located on sections 19 and 30, T129N, R95W, and 24, T129N, R96W, approximately four km south of Hettinger. The Fitch site was also 259 ha and located on sections 31 and 32, T130N, R96W, approximately eight km west of Hettinger. These study sites were developed to represent two replicates.

Climate

A continental, semiarid climate defines the study area (Ulmer and Conta 1987). Annual precipitation is 394 mm with 87% of the precipitation falling between April and October based on the 30-year average (NDAWN 2009). May through July are the peak months for precipitation with 50% falling during this period. The area receives on average 45 mm of precipitation from November through March, which coupled with prairie winds creates drifting and areas of bare ground. The average yearly temperature is 6°C.

A range of 119 to 136 frost-free days occurs within the region, with 139 to 157 freeze-free days (United States Department of Agriculture, Natural Resource Conservation Service 2010a, b, c). Growing degree days (GDD) were calculated for both corn and barley. The formula used to calculate the barley GDD was ((Daily maximum temperature °C + Daily minimum temperature °C) / 2) - 0°C (NDAWN 2009). Barley was harvested in mid-July annually. Values for barley GDD were 1578, 1480, 1304, 1270 for 2006, 2007, 2008, and 2009 respectively. The formula used to calculate the corn GDD was ((Daily maximum temperature °C + Daily minimum temperature °C) / 2) – 32 °C. Corn was left as standing crop and the GDD was calculated through November 15, the approximate date for the first killing frost each year. Values for corn GDD from 2006 to 2009 were 1523, 1504, 1358, and 1211.

The year prior (2005) to the inception of the study had temperatures close to the 30-year average. Temperatures in 2006 were higher than average for the months of January, April, and July (Table 1). For 2007, January, March, and July were higher than average, while February was lower than average. Temperatures in 2008 were close to average with the exception of December, which was lower than average (Table 2). March and October had lower than normal temperatures in 2009, and September and November higher than average temperatures (Table 2).

The Standard Precipitation Index (SPI) is used to forecast both short and long-term droughts by the National Climatic Data Center (2009a, 2009b). The SPI forecasts potential precipitation at 1-24 month intervals. The SPI uses cumulative totals to compare historic levels of precipitation with the average cumulative total based on the desired period of observation. Positive SPI values indicate a wet period and negative values a dry period (Table 3; National Climatic Data Center 2009a, 2009b). Periods of extended drought can detrimentally impact agricultural systems through decreased production (National Climatic Data Center 2009a). The SPI values calculated for three or more month intervals can aid in predicting short and long-term drought conditions.

Table 1. Monthly temperatures (°C) for Hettinger, North Dakota from 2005- 2007 and the 30-year average with the standard deviation (SD; NDAWN 2009).

Year	**2005**		**2006**		**2007**		**30 Year**
Month	Average	SD	Average	SD	Average	SD	**Average**
January	-11.0	1.1	-1.2	5.9	-6.4	2.2	-9.4
February	-2.9	2.3	-5.8	0.2	-9.5	2.4	-6.1
March	0.6	1.2	-1.7	0.4	3.4	3.2	-1.1
April	7.6	1.5	8.8	2.3	4.6	0.7	5.6
May	9.9	1.3	12.8	0.8	13.0	0.9	11.7
June	17.4	0.2	18.5	0.9	18.1	0.6	17.2
July	21.3	0.5	23.9	2.4	23.9	2.4	20.6
August	18.9	0.7	21.3	0.9	20.2	0.1	20.0
September	15.2	1.3	12.9	0.3	14.7	1.0	13.3
October	6.8	0.3	4.4	2.0	7.9	0.5	7.2
November	0.8	1.8	-0.7	0.7	-0.2	1.1	-1.7
December	-7.2	0.4	-5.1	1.9	-7.2	0.4	-7.8

Table 2. Monthly temperatures (°C) for Hettinger, North Dakota from 2008, 2009, and the 30-year average with the standard deviation (SD; NDAWN 2009).

Year	**2008**		**2009**		**30 Year**
Month	Average	SD	Average	SD	**Average**
January	-9.3	0.1	-10.4	0.7	-9.4
February	-8.3	1.5	-8.5	1.7	-6.1
March	-0.3	0.5	-4.3	2.2	-1.1
April	4.8	0.5	3.8	1.2	5.6
May	11.2	0.3	11.3	0.3	11.7
June	15.8	1.0	15.2	1.5	17.2
July	21.8	0.9	18.1	1.7	20.6
August	21.1	0.7	17.9	1.5	20.0
September	13.6	0.2	16.9	2.6	13.3
October	6.7	0.4	2.0	3.7	7.2
November	-0.3	0.9	2.8	3.1	-1.7
December	-12.7	3.5	--[1]	--[1]	-7.8

[1]--, data unavailable.

Table 3. Standard Precipitation Index values and drought classifications (National Climatic Data Center 2009a, table).

SPI Value	Drought Category
2.00 and higher	Extremely wet
1.50 to1.99	Very wet
1.00 to1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 or lower	Extremely dry

The SPI values for Hettinger, based on one month increments, show the year preceding the study had six months of near normal, one month of moderately dry, one month of severely dry, three months of moderately wet, and one month of very wet conditions (Table 4). In 2005, the primary growing months of April through August had near normal conditions with May and June receiving above normal precipitation. A higher level of precipitation was received in December, creating a higher level of moisture available for spring growth in 2006. During the first year (2006) of the study, SPI values reflected eight months of near normal, one month of very wet, two months of moderately dry, and one month of severely dry conditions. Precipitation levels for April were above normal; however, below average precipitation occurred in June and July, potentially impacting crop and forage production. Values for 2007 showed seven months of near normal, two months of moderately wet, two months of moderately dry, and one month of severely dry conditions. The SPI values for January 2007 show lower than normal precipitation, with much of the growing season receiving near normal precipitation. The year ended with lower than normal levels of precipitation. The SPI values for 2008 had eight months of near normal, one month of very wet, and three months of moderately dry conditions. A moisture deficit existed through April of 2008.

Near normal levels existed throughout the growing season, with the year ending with one month of higher than normal levels of precipitation. The SPI values for 2009 included eight months of near normal, one month of extremely wet, one month of very wet, and one month of extremely dry. The year began with near normal tending towards wet conditions. March received higher than normal levels of precipitation, creating a moisture surplus for early spring growth. The remainder of the year was at near normal levels with November receiving much lower than normal precipitation.

Looking at SPI values for three month periods, which is valuable in predicting short-term droughts potentially impacting agricultural production (National Climatic Data Center 2009a; Table 5), pre-study conditions in 2005 showed four months of near normal, three months of moderately wet, one month of very wet, three months of moderately dry, and one month of severely dry conditions. The year (2005) began with drought conditions; however, in May precipitation began to increase and June through August received above average precipitation. December received higher than average precipitation.

The SPI values for 2006, based on three month intervals, showed nine months of near normal, one month of very wet, and two months of severely dry conditions. The two severely dry months occurred during July and August potentially impacting forage and crop production. The SPI values for 2007 also had nine months of near normal, one month of moderately wet, one month of severely dry, and one month of extremely dry conditions. January 2007 was a month with severely dry conditions and the year ended with below normal precipitation levels. Values for 2008 reflected seven months of near normal precipitation, one month of moderately wet, one month of severely dry, and three months of extremely dry conditions. January through April of 2008 were in the severe to extremely dry categories creating a moisture deficit going into the growing season. May through November had near normal precipitation levels with the year ending with above

Table 4. Standard Precipitation Index values for one month increments for Hettinger, North Dakota from 2005-2009 (High Plains Regional Climate Center 2009).

Year	2005	2006	2007	2008	2009
January	-1.03	-0.45	-1.83	-1.37	-0.49
February	-1.68	-0.85	0.91	-0.27	1.84
March	0.18	0.82	1.12	-1.25	2.18
April	-0.85	1.53	0.02	-1.39	-0.58
May	1.34	-0.39	1.37	0.36	-0.38
June	1.63	-1.60	-0.68	-0.36	0.14
July	-0.19	-1.43	-0.36	-0.35	0.37
August	-0.14	0.16	0.61	-0.39	0.17
September	-0.81	0.96	-0.09	-0.07	0.14
October	1.11	0.61	-0.37	0.99	0.80
November	0.94	-1.45	-1.35	1.60	-2.07
December	1.37	-0.88	-1.11	0.84	--[1]

[1]--, data unavailable.

Table 5. Standard Precipitation Index values for three month increments for Hettinger, North Dakota from 2005-2009 (High Plains Regional Climate Center 2009).

Year	2005	2006	2007	2008	2009
January	-1.27	0.91	-2.37	-2.15	1.30
February	-1.74	0.10	-0.74	-1.60	1.18
March	-1.10	0.10	0.69	-2.19	2.33
April	-1.21	1.51	0.71	-2.05	1.43
May	0.70	0.75	1.29	-0.69	0.27
June	1.67	-0.58	0.35	-0.63	-0.50
July	1.96	-1.85	0.14	-0.41	-0.15
August	1.11	-1.74	-0.58	-0.77	0.19
September	-0.86	-0.21	-0.16	-0.73	0.23
October	0.03	0.80	-0.10	0.13	0.38
November	0.45	0.58	-0.86	0.96	0.07
December	1.41	-0.25	-1.57	1.54	--[1]

[1]--, data unavailable.

average precipitation. The SPI values for 2009 had seven near normal months, three moderately wet, and one extremely wet month. Precipitation levels during the winter were above average creating surplus moisture conditions through April. From May through the remainder of the year near normal precipitation occurred.

Vegetation

Lands held in the CRP are required to meet specific vegetation cover requirements. In 1988, the area designated as season-long pasture within the Clement site was enrolled in CRP and seeded at a rate of 60% intermediate wheatgrass (*Elymus hispida* (P. Opiz) Melderis), 30% alfalfa (*Medicago sativa* L.), and 10% yellow sweetclover (*Melilotus officinalis* (L.) Lam.) (Geaumont 2009). The Fitch site was enrolled in CRP in 1989 and seeded that autumn also using a rate of 60% intermediate wheatgrass, 30% alfalfa, and 10% yellow sweetclover. The remainder of the Clement site was enrolled in CRP in 1992 and seeded at a rate of 30% intermediate wheatgrass, 30% alfalfa, 30% crested wheatgrass (*Agropyron cristatum* (L). Gaertn), and 10% yellow sweetclover.

Plant nomenclature was referenced from the Great Plains Flora Association (1986) with updated names referenced from the United States Department of Agriculture, Natural Resource Conservation Service, Plant Database (2009).

Ecological Sites

Ecological site classifications are designed to aid with land management (Ulmer and Conta 1987; Froemke and Sedivec 2007). Each ecological site takes into consideration climate, biota, topography, available soil moisture, soil texture, and soil depth. Climate dictates the amount of precipitation and temperature of a given area.

Topography can influence infiltration and runoff, which in turn affects available soil moisture. In addition, topography directly influences soil depth based on erosion. Plant growth is dependent on precipitation, temperature, available soil moisture, soil texture, and soil depth. Micro and macro fauna presence and abundance, critical in soil formation and nutrient cycling, are dependant on these same criteria. Each ecological site combines similar soils, lists native species likely to be present, site limitations, and management considerations.

North Dakota has eighteen major ecological sites (Froemke and Sedivec 2007). Of these, seven were found in the study areas. The three dominant ecological sites used for clipping and to determine stocking rates include loamy overflow, sandy, and shallow sandy.

Loamy Overflow

Loamy overflow site plant composition consists of 80% grasses, 5% grass-like, 10% forbs, with the remainder as shrubs (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resources Conservation Service 2010a). Production rates for loamy overflow sites can vary from 1067 to 2844 kg/ha depending on the vegetation community. Loamy overflow sites can be easily overgrazed creating gullies and changing the plant community. Maintaining proper stocking rates and controlling grazing in these areas can aid in returning the range to a more native state (Ulmer and Conta 1987).

Sandy

Plant composition on sandy ecological sites includes 75% grasses, 10% upland sedges, 10% forbs and the remainder as shrubs (Ulmer and Conta 1987; United States

Department of Agriculture, Natural Resources Conservation Service 2010b). Production rates for sandy sites can vary from 533 to 2135 kg/ha depending on the vegetation community. Soil erosion by wind is a concern for this ecological site. Maintaining vegetative cover can minimize losses (Ulmer and Conta 1987).

Shallow Sandy

Shallow sandy ecological sites contain 75% grasses, 10% upland sedges, 10% forbs, with shrubs filling in the remaining plant composition (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resources Conservation Service 2010c). Production rates for shallow sandy sites can vary from 444 to 1244 kg/ha depending on the vegetation community. Grazing on shallow sandy sites should be carefully managed to avoid the creation of open areas that are prone to erosion causing difficulties when restoring vegetation (Ulmer and Conta 1987).

Land Capability Classifications

Soil type can be an indicator of a site's suitability for cropping (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). Land capability classification is a value system designed to aid landowners and managers in selecting the proper level of agricultural land use. Capability classes with low numbers reflect a site's capacity to maintain soil quality and properties under cropping. Higher numbers reflect a need for special management considerations if the site is cropped. Land classes of six or more have severe limitations and are not appropriate for cultivation.

Capability subclasses reflect further modification of the land class system (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource

Conservation Service 2009a). Lower case *e* indicates erosion by wind or water is a concern, so vegetative cover is recommended. Lower case *s* depicts soils that are shallow, rocky, or prone to doughtiness. Plant production will be limited in these areas. A lower case *c* indicates climate is a limiting factor. The soil may exist in either an extremely cold or dry location limiting productivity. Land capability classifications are a valuable management tool for determining both potential land use and potential limitations of soils.

Soils

Three dominant and several minor soils exist within the study areas. At the Clement site, Vebar-Flasher and Vebar-Parshall were the dominant soils with Shambo loam, Harriet loam, and Arnegard minor soils (United States Department of Agriculture, Natural Resource Conservation Service 2009a). Vebar-Parshall and Vebar-Flasher soils were the series sampled for soil carbon at the Clement site. Combinations of those soils and the minor soils were located at the noted ecological sites.

The Fitch site was dominated by Vebar-Parshall and Harriet loams with Belfield-Savage-Daglum and Daglum-Rhoades minor soils (United States Department of Agriculture, Natural Resource Conservation Service 2009a). Vebar-Parshall was the primary soil sampled for soil carbon. Combinations of the noted soils were located at the Fitch ecological sites.

Vebar-Flasher soils are fine sandy loams on gently to moderate sloping terrains of 3-9% (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). Vebar-Flasher soils are well-drained and may appear as either short or long smooth, convex slopes with slow runoff and rapid (Flasher) to moderately rapid (Vebar) permeability. Approximately 45-65% of the site soil will consist of the Vebar series and 25-35% Flasher. Parshall and Arnegard soils can also be interspersed within Vebar-Flasher soils. Vebar soils have a surface layer of grayish brown to a depth of 20.3 cm and a subsurface layer of 66 cm with an underlying layer of soft sandstone (Ulmer and Conta 1987). Flasher soils consist of a grayish brown surface layer 15.2 cm deep and an underlying subsurface layer 28 cm thick. Soft sandstone bedrock is commonly found at a depth of 43.2 cm creating a root depth restriction. Organic matter levels are moderately low in Vebar and low in Flasher. Native range species include western wheatgrass, little bluestem (*Schizachyrium scoparium*), needleandthread, and prairie sandreed (*Calamouilfa longifolia*). Additional types of cover suitable for the Vebar-Flasher soils include intermediate wheatgrass, crested wheatgrass, yellow sweetclover, and alfalfa. Land capability classes are 4e for Vebar and 6e for Flasher (United States Department of Agriculture, Natural Resource Conservation Service 2009a). The ecological site is sandy for Vebar and shallow sandy for Flasher.

Vebar-Parshall soils are fine sandy loams found on level to gently sloping terrains of 1-6% (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). These upland soils are well-drained with moderately rapid permeability and slow runoff. The Vebar component comprises from 35-55%. The Parshall portion of the soil comprises 30-50% of the location and has a dark grayish brown surface layer approximately 25.4 cm thick and an underlying subsurface layer 63.5 cm deep (Ulmer and Conta 1987). Organic matter levels are typically low in Vebar and high in Parshall. Arnegard and Flasher soils may also be interspersed within the Vebar-Parshall soils. Native range species associated with this soil type include prairie sandreed and needleandthread. Other vegetation types adapted to this soil type include smooth brome (*Bromus inermis*), crested wheatgrass, intermediate wheatgrass, sweet clover, and alfalfa. Recommended cultivated crops include small grains, legumes, and grasses. Vebar-Parshall soils have a land capability class of 3e and a sandy ecological site classification (United States Department of Agriculture, Natural Resource Conservation Service 2009a).

Harriet loams are found in low-lying areas that are poorly drained (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). These areas tend towards alkaline and saline conditions. Permeability and runoff are very slow. Both salinity and the high level of clay can restrict plant and root growth and development. Harriet loam soils have a surface layer color of gray approximately 7.6 cm thick with an underlying subsurface 109.2 cm thick (Ulmer and Conta 1987). Mottling occurs at depths of 40.6 cm to 116.8 cm. The organic matter level is moderate. Other soils associated with Harriet loams include Parshall, Daglum, and Straw. Native range vegetation may include western wheatgrass, inland saltgrass (*Distichilis spicata*), and Nuttall alkaligrass (*Puccinellia nuttalliana*). Most grasses and forbs are not suited to these sites due to the alkalinity and salinity levels. Overgrazing during wet periods can cause soil compaction. Land capability class is 6s and the ecological site classification saline lowland (United States Department of Agriculture, Natural Resource Conservation Service 2009b).

Shambo loams are associated with upland and terraced sites with 1-3% slopes (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). Permeability for Shambo soils is moderate and runoff slow. Surface soil is a dark grayish brown 22.9 cm inches thick and a subsurface layer 81.3 cm thick (Ulmer and Conta 1987). The organic matter level is moderate. Belfield, Grail, and Ruso soils may be intermixed within Shambo sites. This soil is best suited for cultivated crops or rangeland. Native range consists of western wheatgrass and needleandthread (*Hesperostipa spartea*). Additional species suited to Shambo soils include green needlegrass (*Nassella viridula*), crested wheatgrass, slender wheatgrass (*Elymus trachycaulus*), smooth brome, sweet clover, and alfalfa. Shambo soils have a land capability class of 2e and loamy ecological site classification (United States Department of Agriculture, Natural Resource Conservation Service 2009a).

Arnegard soils are well-drained and associated with level to nearly level sites with a 1-3% slope (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009a). Permeability is moderate and runoff from surrounding sites common. Arnegard has a dark grayish brown surface layer 22.9 cm thick with an underlying layer 83.8 cm thick (Ulmer and Conta 1987). The organic matter level is high. Grail, Belfield, Amor, and Vebar soils can occur in areas containing Arnegard. This series supports cultivated crops, rangelands, pasture, and haylands. Native range species include western wheatgrass, big blue stem (*Andropogon gerardii*), and green needlegrass. Additional species suitable for Arnegard soils are smooth brome, Russian wild rye (*Psathyrostachys juncea*), Altai wild rye (*Leymus angustus*), sweet clover, and alfalfa. Land capability class is 2c and ecological site classification loamy overflow (United States Department of Agriculture, Natural Resource Conservation Service 2009a).

Belfield-Savage-Daglum soils occur on 1-3% slopes and are well-drained, thick soils (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009b). Permeability for Belfield and Savage is slow and Daglum very slow. Runoff for all three soils is low and organic matter level moderate. Belfield comprises 30-45%, Savage 30-45%, and Daglum 10-40% of the complex. Belfield soils are alkali and have a grayish brown surface color to a depth of 22.9 cm with a 53.3 cm subsurface horizon (Ulmer and Conta 1987). Savage soils are non-alkaline with a surface color of grayish brown to six inches and a subsurface layer of 76.2 cm. Daglum soils are alkaline with a dark grayish brown surface horizon to 17.8 cm and a subsurface horizon of 61 cm. Other soils associated with these soils include Rhoades, Grail, and Shambo. Both Daglum and Belfield soils create root restrictions due to salts and dense subsoil layers. Native range species include green needlegrass, needleandthread, western wheatgrass, and blue grama. Other suitable species include smooth brome, crested wheatgrass, intermediate wheatgrass, yellow sweet clover, and alfalfa. Land capability class for Belfield is 3s, Savage 2c, and Daglum 4s (United States Department of Agriculture, Natural Resource Conservation Service 2009b). Ecological site classifications are clayey for Belfield and Savage, and claypan for Daglum.

Daglum-Rhoades soils form on level and gently sloping sites with 1-6% slopes (Ulmer and Conta 1987; United States Department of Agriculture, Natural Resource Conservation Service 2009b). These alkaline soils are well to moderately well drained with a very slow permeability and medium runoff. Daglum soils make up 50-60% of the area, while Rhoades comprises 25-45%. Daglum soils have a dark grayish brown surface horizon of 17.8 cm with a subsurface horizon 61 cm thick (Ulmer and Conta 1987).

Rhoades soils are light brownish gray 7.6 cm in thickness with an underlying horizon 109.2 cm thick. Other soils found with Daglum-Rhoades include Savage, Ekalaka, Belfield, and Harriet. Cultivated Daglum-Rhoades soils tend to form crusts after sufficient rainfall events. The fine-textured soils form dense layers and alkaline conditions that limit root growth. Suggested land use is range. Native plant species include blue grama and western wheatgrass. Land capability class for Daglum is 4s and Rhoades 6s (United States Department of Agriculture, Natural Resource Conservation Service 2009b). Ecological site classification is claypan for Daglum and thin claypan for Rhoades.

METHODS AND DESIGN

Treatments

This study was developed using a randomized complete block design with four treatments and two replicates. Treatments included 1) season-long grazing, 2) one-cut haying, 3) a rotation cropping system, and 4) non-use to simulate continued CRP.

Season-long Grazing

Season-long grazing (SL) occurred from June 1 through January 1 or until 50 percent disappearance of vegetation was achieved. The 50 percent disappearance level represents a moderate or full use stocking rate. Between 33 to 45 cow-calf pairs were used with numbers adjusted annually to meet this stocking rate target (Geaumont 2009). Each SL replicate was 129 ha in size.

Stocking Rates. The suggested stocking rates include 2.5 AUM/ha for loamy overflow, 2.0 AUM/ha for sandy, and 1.3 AUM/ha for shallow ecological sites (Sedivec and Vannurden 2007). Stocking rates were 1.5 AUMs/ha in 2006, 2.4 AUMs/ha in 2007, 2.1 AUMs/ha in 2008, and 1.9 AUMs/ha (Fitch) and 2.3 AUMs/ha (Clement) in 2009. Stocking rates were adjusted between years to achieve the 50 percent disappearance of vegetation. Stocking rates in 2006, 2007, 2008, and 2009 for the crop treatment were 1.5, 2.4, 2.1, and 2.2 AUMs/ha, respectively, at both sites. Animals grazed the barley and corn crop treatments from January 1 through mid-April.

Livestock Performance. Livestock use for this study was approved by the North Dakota State University Institutional Animal Care and Use Committee. All procedures were approved prior to the start of the study.

Weights of cows and calves were recorded to determine performance. Initial cow weights were recorded just prior to the June 1 turn out on the SL. Calf weights were recorded at the time of weaning. Two different weaning dates were used and included early September (early weaning date) and mid-November (traditional weaning date).

Haying

The one-cut haying system (HAY) was completed in early July using an 18-foot MacDon Model #9350 swather to cut standing vegetation. Once dried, the vegetation was baled and stored at the Hettinger Research Extension Center (HREC) for use as livestock feed when cattle returned to the HREC in mid-April. Each HAY replicate was 32 ha in size.

Crop

The perennial vegetation cover on the CRP land was destroyed in May 2006 from 64 ha at each study site using glyphosate applied at a rate of 5.22 l/ha. Each 64 ha plot was split evenly into two 32 ha subplots to represent a rotational no-till cropping system. Barley and corn were the two crops planted annually using the rotational cropping system.

Barley. The barley crop (BC) was seeded at a rate of 43 kg/ha using a John Deere Model #1590 no-till seeder. Once the barley reached the milk phase, the crop was harvested for hay using an 18-foot MacDon Model #9350 swather. The dried crop was bailed and stored at the HREC and used as feed for cattle when they returned to the station in mid-April. Barley stubble was grazed from early January to mid-April while cattle were in the CROP treatment.

Corn. The corn crop (CC; Round-up™ ready) was seeded at a rate of 6,000 seeds/ha in 2006, 7,300 seeds/ha in 2007, and 7,200 seeds/ha in 2008 and 2009 using a John Deere Model #1590 no-till seeder. The CC was sprayed on average twice annually (pre-planting and post-emergence) with Round-up™. Corn plots were left as a standing crop that gestation, dry cows grazed with the barley residue from January through mid-April.

Control

The control plot (CTRL) represented a non-use treatment simulating continued CRP enrollment. Each CTRL replicate was 32 ha in size.

Vegetation Sampling

Three ecological sites were selected for vegetation sampling that dominated the study sites. Shallow sites were located on hilltop and knoll areas. Sandy sites were located on either hillsides or gently rolling slopes of 1-9%. Loamy overflow sites were located in the swale area at the base of hill slopes.

Season-long Grazing Treatment

Two locations for each ecological site (shallow sandy, sandy, and loamy overflow) were identified in each SL replicate for a total of six sites. Five cages were placed at each ecological site for 30 total cages per SL replicate to determine herbage disappearance and peak standing crop.

Crop, Control, and Hay

One shallow sandy, sandy, and loamy overflow site was identified for each HAY, CTRL, and BC replicate. Five frames were clipped at each clipping site for a total of 15 frames per plot. Peak standing crop was determined for the HAY, CTRL, and BC plots using a 0.25m^2 quadrat. Five randomly selected 1.0 m^2 quadrats were used on the CC treatment to determine peak standing crop.

Herbage Disappearance

Paired-plot clipping was used to determine the degree of herbage disappearance on the SL in early January each year (Milner and Hughes 1968). A 0.25m^2 quadrat was clipped to ground level inside each cage, which reflected total production, and a second frame clipped outside the cage to determine degree of herbage disappearance. The degree of herbage disappearance was determined based on the difference between the paired-plot frames inside and outside.

Clipped vegetation was separated into grasses and forbs for each frame and dried at 55°C for 48 hours. Dried weights were recorded for each site to determine herbage production.

Peak Standing Crop

Peak standing crop for BC was collected in early July just prior to harvest. Clipped vegetation was separated into barley, grass, and forbs. HAY and CTRL plots were clipped in early July and separated by grass and forbs. The SL was clipped in mid-July. One frame was clipped in each of the five SL cages and separated by grass and forbs. Corn was clipped in November after the first killing frost.

Clipped vegetation was separated by like form, and dried at 55°C for 48 hours. Dried weights were recorded for each site to determine biomass production.

Basal Cover and Species Composition

Vebar-Parshall and Vebar-Flasher were the dominant soils found throughout both study sites. Treatments were stratified by dominant soil types. Four 100 m transects were randomly placed on similar soil series in each of the SL, HAY, CTRL, and CROP treatments. A 0.25m^2 quadrat was placed every five meters along each transect and grass presence/absence determined from a nested 0.1m^2 quadrat, while forb density was recorded from the entire frame in the SL, HAY, and CTRL plots. A ten-pin point frame was placed every meter along each transect and bareground, litter, and vegetative species recorded to determine species frequency, richness, diversity (Shannon-Weiner index), and evenness (Levy and Madden 1933; Smith 1959; Mueller-Dombois and Ellenburg 1974). Quadrats and ten-pin point frame data was collected in the SL, HAY, and CTRL plots annually.

Soil Carbon

Soil core samples were collected annually in July along the same four 100 m transects in each treatment replicate. Seven cores were randomly extracted along each transect and separated into depths of 0-15 cm and 15-30 cm. Soil samples were weighed and then dried at 105°C for 48 hours, with dried weights recorded. Samples were combined based on specific site, plot, transect, and depth, then ground to $\leq$ 0.15 mm. A Skalar Primacs ™ solid carbon analyzer was used to identify total carbon levels for each combined sample. The Skalar Primacs™ analyzer was also used to identify inorganic carbon in the samples using an additional acid step that allowed for the measurement of released CO_2. Organic carbon was determined by subtracting the amount of inorganic carbon from the total carbon value.

Statistical Analysis

PC ORD 5.10 was used to calculate species evenness, richness, and Shannon diversity (McCune and Mefford 2006) using 10-pin point data from the plot level. A

Permanova model was used to test for community species composition differences between SL, HAY, and CTRL treatments. A $P \leq 0.05$ was considered significant. The permutation MANOVA utilized the PerMANOVA program (Anderson 2001) as implemented in PC–ORD version 5.1. This method partitions the multivariate variation from a particular distance measure according to the experimental factors with the significance tests derived from permutations of the original data, and is analogous to a fully balanced randomized block design MANOVA. Three options were used for this test: 1)Sørensen distance measure, 2) 9,999 permutations of the data, and 3) pair-wise comparisons of the treatments using 9,999 permutations. Because the *p*-values from the pair-wise comparisons are not corrected for multiple comparisons, the Hochberg correction for multiple comparisons (Legendre and Legendre 1998) was used as implemented in the PROC MULTTEST SAS software procedure, Version 9.1.3 of the SAS System for Windows (Copyright © 2000-2004 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Although the Hochberg procedure for the multiple comparisons was used, a relaxation of the *p*-value to the 0.1 level was chosen for the various comparisons.

Treatment and year effects for peak standing crop, basal ground cover, species composition (richness, evenness, and Shannon-Weiner index for diversity), and soil carbon were analyzed using a randomized block, repeated measure design. The PROC MIXED procedure (Version 9.1.3 of the SAS System for Windows, Copyright © 2000-2004 SAS Institute Inc.) was used for analysis with the repeated year effects modeled with an autoregressive covariance structure (AR1). Multiple comparisons used the

LSMEANS procedure with the overall *p*-values adjusted by using the Tukey procedure. A $P \leq 0.05$ was considered significant. All proportional data were transformed using an arcsine square-root transformation. A square-root transformation was used for all data collected on a unit area basis.

RESULTS

Livestock Performance

Early weaning weights for 2006, 2007, 2008, and 2009 were 184, 182, 224, and 213 kg, respectively, for Clement, and 195, 181, 232 and 222 kg for Fitch, respectively (Table 6). Traditional weaning weights were 250, 250, 282 and 256 kg for 2006 through 2009 at the Clement site and 254, 254, 299, and 265 kg at the Fitch site, respectively. A full listing of cow and calf weights appear in Appendix A.

Table 6. Weights (kg; ± SE) for early and late weaned calves on the Clement and Fitch sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

	Clement		**Fitch**	
Year	Early	Traditional	Early	Traditional
2006	184 ± 5.7	250 ± 6.2	195 ± 5.8	254 ± 6.0
2007	182 ± 4.6	250 ± 4.8	181 ± 4.1	254 ± 5.1
2008	224 ± 4.8	282 ± 7.0	232 ± 5.3	299 ± 6.7
2009	213 ± 4.4	256 ± 7.5	222 ± 5.9	265 ± 8.4

Degree of Herbage Disappearance

A moderate level of grazing at 40 to 60 % herbage disappearance rate was the desired target level on each SL replicate. Cattle preferred to graze the sandy and loamy overflow ecological sites throughout the study, with the exception of forb utilization on sandy and shallow sites in 2007 (Fig. 1). Herbage disappearance throughout the study was within the desired 40-60% range when averaged across all three ecological sites, except for 2006, which was slightly below the desired objective (Table 7). The final clip to determine disappearance did not occur in 2008 due to early heavy snows. Early heavy snows also occurred in 2009, limiting the final clip to five of the six Fitch plots. The Clement site was unable to be clipped in 2009.

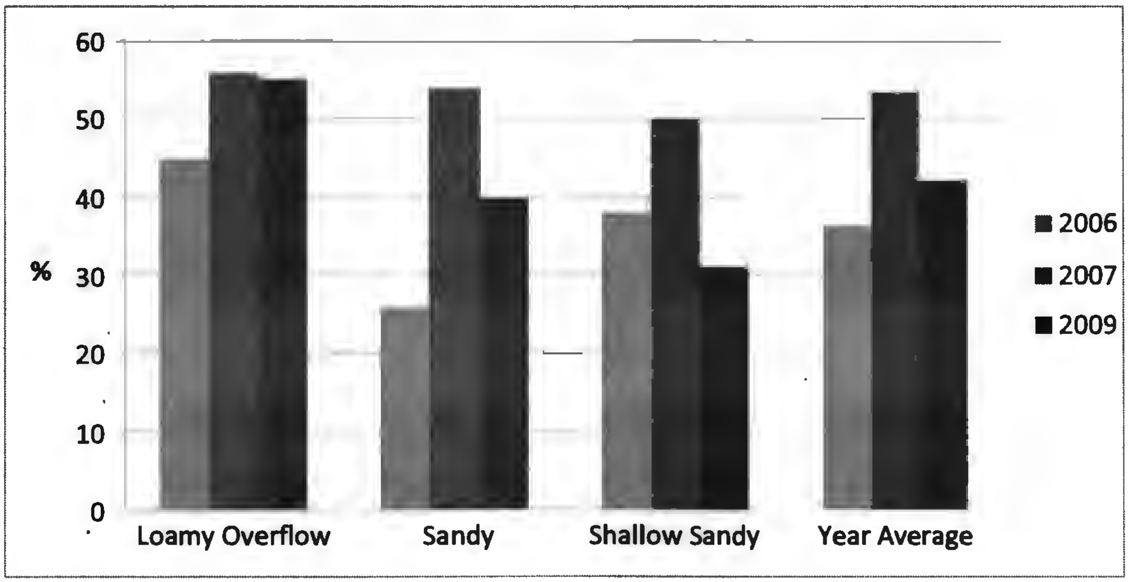

Figure 1. Combined degree of herbage disappearance (%) for grass and forb production on the season long grazing treatment for sandy, loamy overflow, and shallow sandy ecological sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009. The desired range of herbage disappearance was 40-60%. Post-production clips could not be obtained for both study sites in 2008 and one of the study sites in 2009.

Table 7. Degree of herbage disappearance (%; ± SE) on the season long grazing treatment for the sandy, loamy overflow, and shallow sandy ecological sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

	Clipping Sites						
	Sandy		Loamy Overflow		Shallow		WA[4]
Year	Grass	Forb	Grass	Forb	Grass	Forb	
2006	45.2 ± 10.4	32.4 ± 7.6	53.7 ± 1.6	21.2 ± 0	27.5 ± 15.0	39.8 ± 10.6	36.3
2007	28.0 ± 6.8	70.0 ± 10.0	44.2 ± 8.8	50.0 ± 0	31.3 ± 8.5	80.0 ± 10.0	53.3
2008[1]	–[1]	–[1]	–[1]	–[1]	–[1]	–[1]	–[1]
2009[23]	40.1 ± 22.0	97.6 ± 82.1	55.3 ± 15.0	0.0	27.7 ± 9.2	62.3 ± 55.5	42.0

[1]--, the final clip for both Clement and Fitch could not be obtained for 2008.
[2]The final clip for Clement could not be obtained for 2009.
[3]Only one overflow site was clipped at the Fitch site for 2009.
[4] WA represents the weighted average for all ecological sites and vegetation types for each year.

Basal Cover and Species Composition

Although bareground did not differ ($P > 0.05$) between treatments, levels were different ($P \leq 0.05$) between years, with 2006 (7.3%; Table 8) showing an 8.3% reduction compared to 2008 (15.6%; $P = 0.02$). Although no interaction ($P > 0.05$) with treatment and year occurred with bareground, the SL 2006 (3.8%; $P = 0.06$) compared to SL 2009 (13.2%) and HAY 2006 (6.9%; $P = 0.09$) compared to HAY 2008 (24.4%) were trending towards increased levels over the study period.

No treatment effects ($P > 0.05$) occurred in litter levels; however, litter was greater in 2008 (76.4%; Table 9) compared to 2006 (67.3%; $P = 0.02$) and 2009 (66.4%; $P = 0.002$). There was an interaction between year and treatment, with lower litter levels in the CTRL 2006 (63%; $P = 0.03$) than 2008 (82.5%), and lower levels in the SL in 2009 (65.7%; $P = 0.04$) than 2008 (80.2%).

Table 8. Percent bareground (± SE) by treatment on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	**Control**	**Season Long**	**Hay**	**Year Average**[1]
2006	11.2 ± 4.3	3.8 ± 3.7	6.9 ± 3.0	7.3 a
2007	4.8 ± 3.7	9.6 ± 7.3	15.1 ± 3.9	9.8 ab
2008	8.9 ± 4.8	13.6 ± 3.6	24.4 ± 4.2	15.6 b
2009	5.6 ± 5.4	13.2 ± 3.5	14.5 ± 1.5	11.1 ab

[1]Years with the same letter are not significantly different ($P > 0.05$).

Table 9. Percent litter (± SE) by treatment on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	**Control**[1]	**Season Long**[1]	**Hay**	**Year Average**[2]
2006	63.0 ± 2.2 a	71.0 ± 1.8 mn	68.0 ± 3.1	67.3 y
2007	73.0 ± 3.3 ab	69.0 ± 8.5 mn	63.0 ± 4.9	68.0 yz
2008	82.5 ± 5.8 b	80.2 ± 4.3 n	66.5 ± 4.3	76.4 z
2009	72.2 ± 2.7 ab	65.7 ± 2.9 m	61.4 ± 1.9	66.4 y

[1]Treatment values that are not significantly different share the same letter ($P > 0.05$).
[2]Years with the same letter are not significantly different ($P > 0.05$).

No differences were found between years ($P = 0.22$), treatments ($P = 0.51$), or year X treatment interactions ($P = 0.69$; Table 10) for species richness. Additionally, no differences were found between years ($P = 0.22$), treatments ($P = 0.36$), or year X treatment interactions ($P = 0.75$) for species evenness. Species diversity was not different across years ($P = 0.09$), treatments ($P = 0.88$), or with year X treatment interactions ($P = 0.78$).

Table 10. Species richness, evenness, and diversity (Shannon) for the Clement and Fitch sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

		Clement			**Fitch**		
Year	Treatment	Evenness	Richness	Shannon	Evenness	Richness	Shannon
2006	CTRL[1]	0.772	14	2.037	0.693	20	2.076
	SL	0.712	13	1.826	0.541	24	1.718
	HAY	0.797	13	2.043	0.576	17	1.631
2007	CTRL	0.654	11	1.568	0.614	19	1.809
	SL	0.558	12	1.387	0.698	23	2.190
	HAY	0.647	12	1.609	0.725	20	2.171
2008	CTRL	0.716	14	1.888	0.723	17	2.047
	SL	0.730	16	2.024	0.736	16	2.040
	HAY	0.768	17	2.176	0.779	14	2.055
2009	CTRL	0.749	17	2.029	0.717	19	2.112
	SL	0.588	19	1.731	0.691	22	2.136
	HAY	0.733	16	2.032	0.726	25	2.336

[1]Treatments include: control or non-use (CTRL), season long grazing (SL), and hay (HAY).

The PerMANOVA analysis found that community species composition was different between 2007 and 2008 ($P = 0.02$). All other differences between years were not significantly different ($P \geq 0.08$). No significant differences existed on the treatment level ($P \geq 0.06$); however, trends were showing differences.

Species composition was also analyzed by annual forb, perennial forb, annual grass, and perennial grass. No differences occurred with perennial forbs ($P \geq 0.12$). Differences were observed with annual forbs as an interaction between year X treatment

($P = 0.001$). HAY 2009 (2.41%; Table 11) had higher levels compared to HAY 2007 (0.58%; $P = 0.0002$). SL 2009 (1.18%) was higher than SL 2007 (0.43%; $P = 0.02$), while CTRL 2006 (0.93%) was higher than CTRL 2008 (0.20%; $P = 0.006$), representing the highest and lowest species composition for those particular treatments. HAY and SL differences followed the same trend as the year comparisons. HAY 2009 appears to represent the largest variation of annual forbs. The treatment effect was not different ($P = 0.09$).

Table 11. Total abundance (%) for percent species composition by year and treatment for post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year/Treatment	Annual Forb[1]	Perennial Forb	Annual Grass[2]	Perennial Grass[2]
2006 HAY[3]	0.95 ab	8.06	0.00	16.34
2007 HAY	0.58 a	5.88	0.00	13.20
2008 HAY	0.76 ab	3.94	0.00	4.46
2009 HAY	2.41 b	11.69	0.03	9.91
2006 CTRL	0.93 n	7.55	0.01	17.49
2007 CTRL	0.34 mn	4.01	0.10	15.80
2008 CTRL	0.20 m	2.60	0.00	5.75
2009 CTRL	0.71 mn	9.11	0.00	12.15
2006 SL	0.73 yz	6.33	0.13	17.85
2007 SL	0.43 y	4.53	0.45	14.99
2008 SL	0.59 yz	2.03	0.01	3.60
2009 SL	1.18 z	8.96	0.08	10.68
2006	0.87	7.31	0.05 bc	17.23 z
2007	0.45	4.80	0.18 b	14.66 z
2008	0.52	2.85	0.00 a	4.60 x
2009	1.43	9.92	0.03 ac	10.91 y

[1]Values within treatments with same letter are not different ($P > 0.05$).
[2]Years with the same letters are not different ($P > 0.05$).
[3]Treatments include: control or non-use (CTRL), season long grazing (SL), and hay (HAY).

Annual grasses were different ($P = 0.0002$) between years. Year 2007 (0.18%; Table 11) was higher than 2009 (0.03%; $P = 0.001$) and 2008 (0.00%; $P = 0.0005$), while 2006 (0.05%) was higher than 2008 (0.00%; $P = 0.0007$).

Perennial grass composition was not different between treatments (*P* = 0.36). Only 2006 (17.23%; Table 11) and 2007 (14.66%; *P* = 0.07) were not different among the year comparisons. Year 2008 (4.60%) had the lowest percent of perennial grass composition, followed by 2009 (10.91%).

Since the initial seeding of the CRP lands in this study, three species have invaded the replicates including smooth brome (*Bromus inermus* Leyss.), Japanese brome (*Bromus japonicus* Thunb.), and Kentucky bluegrass (*Poa pratensis* L.). Analysis of the invaders within the HAY, CTRL, and SL treatments found smooth brome levels were not different within treatments (*P* = 0.32); however, differences between years existed with higher levels in 2007 (11.2%; Table 12) compared to 2008 (1.2%; *P* = 0.004) and 2009 (2.7%; *P* = 0.003). Variation in Japanese brome levels were not different at the *P* > 0.05, but were trending towards significant differences within treatments (*P* = 0.08) and by year (*P* = 0.06). Kentucky bluegrass levels were not different; however, levels were trending towards significant differences among treatments (*P* = 0.08) and by year (*P* = 0.06).

Western wheatgrass (*Pascopyron smithii* (Rydb.) Gould) and slender wheatgrass (*Elymus trachycaulus* (Link) Shinners) are both native species that are naturally re-establishing in the replicates. Western wheat grass showed no differences among treatments (*P* = 0.56) or by year (*P* = 0.18). Slender wheatgrass showed no differences within treatments (*P* = 0.41) or by year (*P* = 0.17).

The originally seeded grasses included intermediate wheatgrass and crested wheatgrass. Intermediate wheatgrass levels were not different among treatments (*P* = 0.08), although differences existed between years with higher levels in 2006 (18.8%; *P* =

0.0009; Table 12) compared to 2008 (4.3%). No differences among treatments ($P = 0.66$) or by year ($P = 0.09$) existed for crested wheatgrass.

Alfalfa levels were not different among treatments ($P = 0.29$), but differences existed between years with higher levels in 2009 (11.8%; Table 12) compared to 2006 (6.8%; $P = 0.007$), 2007 (5.4%; $P = 0.0002$), and 2008 (3.6%; $P = 0.0006$). Alfalfa levels in 2006 were higher than 2008 ($P = 0.03$). Yellow sweetclover levels were not different among treatments ($P = 0.3470$), although differences existed between years with lower levels in 2007 (0.2%; Table 12) compared to 2009 (1.9%; $P = 0.0023$).

Table 12. Total abundance (%) of key plant species on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Vegetation	2006	2007	2008	2009
Crested wheatgrass[1]	3.3	4.9	0.9	2.7
Smooth brome	5.5 ab	11.2 b	1.2 a	2.7 a
Japanese brome	0.1	0.4	0.0	0.1
Intermediate wheatgrass	18.8 b	8.6 ab	4.3 a	10.0 ab
Western wheatgrass	0.0	2.2	0.1	0.8
Slender wheatgrass	2.6	0.1	0.6	0.1
Kentucky bluegrass	4.2	2.4	2.0	5.4
Alfalfa	6.8 b	5.4 ab	3.6 a	11.8 c
Yellow sweetclover	1.1 ab	0.2 a	1.0 ab	1.9 b

[1]Species with same letters indicate no differences between years ($P > 0.05$).

Relative abundance

Original seeding of the Clement SL treatment and entire Fitch site included intermediate wheatgrass, alfalfa and yellow sweetclover, while the remainder of the Clement site had crested wheatgrass seeded in the perennial cover mix. The overall seeding rate was 40% forbs and 60% cool season grasses. The overall relative abundance of forb and grass composition remained constant throughout the study (Fig. 2). Appendix B contains a complete listing of all species identified at the Fitch and Clement sites.

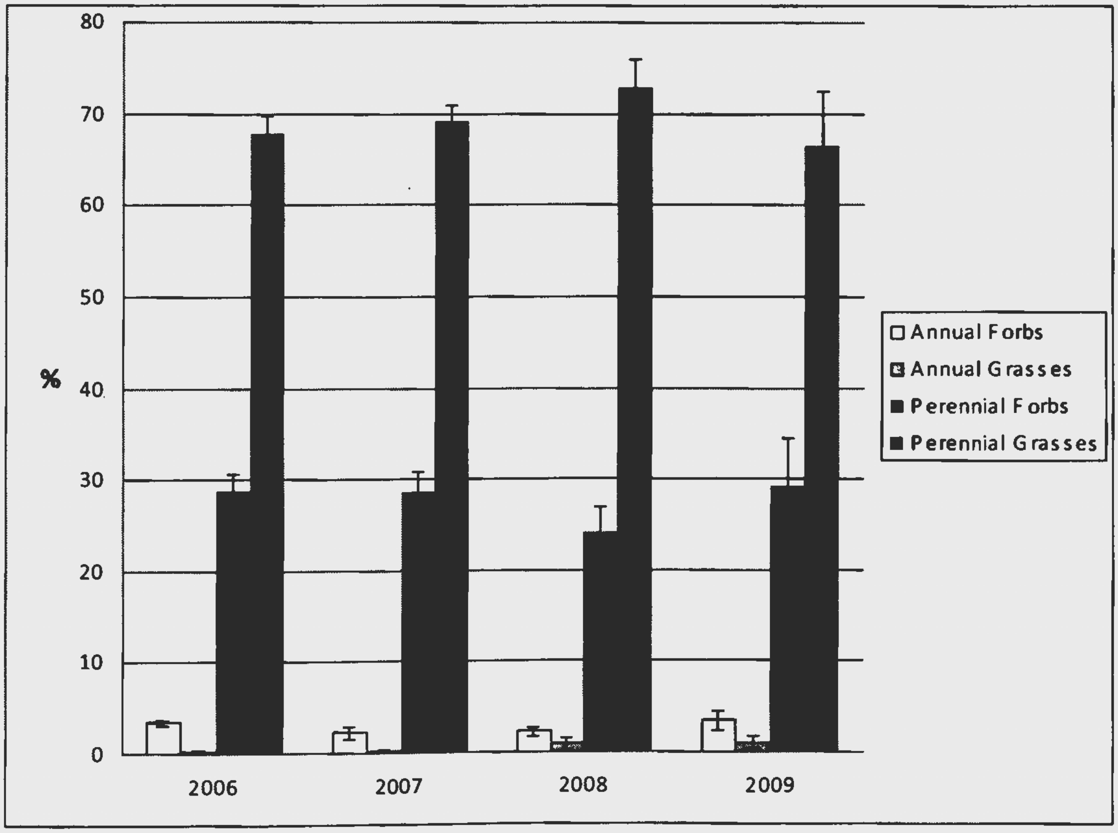

Figure 2. Forb and grass relative abundance (%; ± SE) for both study areas on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

The relative abundance of grass invaders have varied throughout the study, with smooth brome (27.2%) and Japanese brome (0.9%) abundance highest in 2008 (Table 13). Slender wheatgrass abundance was highest in 2006 at 5.5%. Kentucky bluegrass abundance was highest in 2009 at 12.4%, steadily increasing from 3.9% in 2006. Crested wheatgrass was present in all treatments prior to the start of the study, even though it had originally been seeded only in the Clement HAY and CTRL treatment sites. Crested wheatgrass abundance was highest in 2007 (12.4%) and 2008 (13.1%). Alfalfa abundance was relatively constant during the first three years of the study, increasing to 18.0% in 2009. Yellow sweetclover abundance was highest in 2009 at 3.1%.

Table 13. Relative abundance (%) of key plant species on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year and Treatment	CW[1]	SB	JB	IW	WW	SW	KB	A	SC
2006 HAY[2]	8.6	7.7	0.0	38.8	0.0	4.8	4.4	14.6	2.7
2007 HAY	15.1	10.9	0.0	40.6	0.0	0.0	1.4	14.5	1.0
2008 HAY	15.5	25.9	0.0	15.5	7.4	0.0	3.5	14.3	1.3
2009 HAY	4.0	18.4	0.0	9.5	7.4	1.6	11.5	21.2	5.6
2006 CTRL	8.2	17.4	0.0	26.9	0.0	1.2	14.2	10.0	2.9
2007 CTRL	17.6	23.9	0.0	22.6	0.0	0.0	6.6	11.5	0.6
2008 CTRL	18.0	34.5	0.4	12.0	3.5	0.0	10.0	12.3	0.2
2009 CTRL	7.5	27.8	0.4	14.7	3.5	0.4	18.2	16.9	1.7
2006 SL	3.2	6.9	0.5	45.0	0.0	10.4	5.9	16.1	1.2
2007 SL	4.5	7.8	0.6	56.2	0.0	0.3	3.6	14.8	1.0
2008 SL	5.8	21.3	2.2	38.1	4.4	0.6	2.7	13.7	0.3
2009 SL	4.4	16.9	1.7	25.7	5.6	8.3	7.4	15.9	2.2
2006 Average	6.7	10.7	0.2	36.9	0.0	5.5	8.2	13.5	2.3
2007 Average	12.4	14.2	0.2	39.8	0.0	0.1	3.9	13.6	0.8
2008 Average	13.1	27.2	0.9	21.9	5.1	0.2	5.4	13.4	0.6
2009 Average	5.3	21.0	0.7	16.6	5.5	3.4	12.4	18.0	3.1

[1]Key plant species include: crested wheatgrass (CW), smooth brome (SB), Japanese brome (JB), intermediate wheatgrass (IW), western wheatgrass (WW), slender wheatgrass (SW), Kentucky bluegrass (KB), alfalfa (A), and yellow sweetclover (SC).
[2]Treatments include: control or non-use (CTRL), season long grazing (SL), and hay (HAY).

Peak Standing Crop

There was no difference ($P > 0.05$) on the treatment or year level in peak standing crop production for the loamy overflow site for either forb or grass production and on the sandy site for forb production. Differences did occur ($P \leq 0.05$) on the sandy sites for grass production, as well as the shallow sandy sites for both forb and grass production.

Shallow sandy ecological sites had higher levels of grass production in 2009 (4689 kg/ha; Table 14) compared to 2006 (1513 kg/ha; $P = 0.002$), 2007 (1932 kg/ha; $P = 0.01$), and 2008 (2867 kg/ha; $P = 0.02$). A year X treatment interaction in grass production occurred, with higher production in HAY 2009 (6225 kg/ha; Table 15) than HAY 2006 (1530 kg/ha; $P = 0.009$) and HAY 2007 (2183kg/ha; $P = 0.03$).

Forb standing crop production on shallow sandy ecological sites differed by year ($P = 0.01$; Table 14) and with year X treatment interactions ($P = 0.01$; Table 15). Forb production in 2009 (638 kg/ha) was higher than 2006 (326 kg/ha; $P = 0.04$) and 2007 (188 kg/ha; $P = 0.01$). Higher production occurred with HAY 2009 (672 kg/ha) compared to HAY 2006 (197 kg/ha; $P = 0.03$) and HAY 2007 (130 kg/ha; $P = 0.05$).

Grass standing crop production on the sandy ecological site was different ($P = 0.04$; Table 15) between the CTRL and SL treatments. Grass production for the CTRL on the sandy site averaged 1958 kg/ha compared to SL at 5681 kg/ha.

Table 14. Averaged peak standing crop (kg/ha) of grass and forbs for each ecological site on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Clipping Site	Grass Production	Forb Production
2006[1]	Sandy	2115	305
	Loamy Overflow	2823	615
	Shallow Sandy	1513 a	326 y
	Year Averaged Total	2150	415
2007	Sandy	2652	286
	Loamy Overflow	3261	208
	Shallow Sandy	1932 a	188 y
	Year Averaged Total	2615	227
2008	Sandy	4139	403
	Loamy Overflow	4463	466
	Shallow Sandy	2867 a	440 yz
	Year Averaged Total	3823	437
2009	Sandy	4473	907
	Loamy Overflow	4997	551
	Shallow Sandy	4689 b	624 z
	Year Averaged Total	4720	694

[1]Same vegetation types for ecological sites with the same letter are not statistically different between years ($P > 0.05$).

Table 15. Peak standing crop (kg/ha; ±SE) by treatment for grass and forbs on the sandy, loamy overflow, and shallow sandy ecological sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Clipping Sites	Control Grass[1]	Control Forb	Season long Grass[1]	Season long Forb	Hay Grass	Hay Forb
2006	Sandy	1,801 ± 246	346 ± 177	2,451 ± 98	379 ± 95	2,094 ± 518	189 ± 91
	Loamy Overflow	2,600 ± 318	346 ± 46	2,380 ± 660	901 ± 826	3,490 ± 611	598 ± 255
	Shallow Sandy[2]	1,737 ± 530	206 ± 77	1,273 ± 38	574 ± 336	1,530 ± 202 a	197 ± 183 a
2007	Sandy	1,726 ± 284	190 ± 87	3,636 ± 286	445 ± 159	2,594 ± 247	224 ± 6
	Loamy Overflow	3,027 ± 830	296 ± 168	4,179 ± 1,087	228 ± 192	2,577 ± 212	100 ± 58
	Shallow Sandy	1,956 ± 54	225 ± 22	1,657 ± 471	209 ± 6	2,183 ± 313 ab	130 ± 39 a
2008	Sandy	2,172 ±731	321 ± 18	8,383 ± 853	555 ± 155	1,862 ± 528	333 ± 3
	Loamy Overflow	2,914 ± 1212	174 ±66	8,100 ± 242	404 ± 0	2,374 ± 242	820 ± 758
	Shallow Sandy	1,434 ± 71	443 ± 17	5,541 ± 193	282 ± 21	1,626 ± 102 a	597 ± 242 ab
2009	Sandy	2,132 ± 524	886 ± 627	8,254 ± 755	492 ± 200	3,034 ± 4	1,342 ± 1238
	Loamy Overflow	3,856 ± 668	425 ± 326	8,241 ± 35	499 ± 49	2,894 ± 1192	728 ± 487
	Shallow Sandy	1,884 ±316	733 ± 82	5,958 ± 227	466 ± 344	6,225 ±541 b	672 ± 254 a

[1]Grass production on sandy sites in SL was significantly higher than CTRL sandy sites ($P < 0.05$).
[2]Same vegetation types for ecological sites with the same letter are not statistically different between years ($P > 0.05$).

Corn production varied across years from 6528 kg/ha at the Fitch site in 2008 to 45,324 kg/ha at the Clement site in 2009 (Table 16). The CC was not harvested throughout the trial and left as standing crop for cattle consumption during winter months. Barley production varied each year. The highest rate of production was at the Clement site in 2009 (6637 kg/ha). Barley crops were destroyed by weather, prior to harvest at the Clement site in 2006 and at the Fitch site in 2009.

Table 16. Peak standing crop for corn (kg/ha; ± SE) and barley (kg/ha; ± SE) on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Site	**Clement**		**Fitch**	
Year	Corn	Barley	Corn	Barley
2006	16,620 ± 2,631	--[1]	16,620 ± 2,631	639 ± 9
2007	33,376 ± 54.4	2,683 ± 119	33,376 ± 54.4	2,217 ± 103
2008	15,709 ± 2372	4,262 ± 852	6,528 ± 860	4,495 ± 411
2009	45,324 ± 6422	6,637 ± 831	22,674 ± 5160	2,831 ± 626[2]

[1] --, the Clement study site was not harvested in 2006.
[2] The Fitch study site was clipped, but not harvested in 2009.

Soil Carbon

Soil carbon levels were different ($P \leq 0.05$) between years for both total carbon and organic carbon at both the 0-15 and 15-30 cm layers; however, they were not different ($P > 0.05$) between treatments or among years (Tables 17; Table 18). Inorganic carbon showed no difference among years or treatments ($P > 0.05$) at either depth.

Total carbon at the 0-15 cm layer was greatest in 2009 (1.99%; Table 19) compared with 2006 (1.75%; $P = 0.03$), 2007 (1.77%; $P = 0.03$), and 2008 (1.68%; $P = 0.01$). Total carbon at the 15-30 cm layer was greatest in 2006 (1.73%; Table 20) compared to 2008 (1.50%; $P = 0.008$), and 2008 (1.50%) was less than 2009 (1.71%; $P = 0.04$). Total carbon was lowest in 2008 for both the 0-15 and 15-30 cm soil depths.

Organic carbon was higher at the 0-15 cm layer in 2009 (1.51%; Table 19) compared to 2006 (1.30%; $P = 0.01$), 2007 (1.26%; $P = 0.003$), and 2008 (1.26%; $P = 0.005$). Organic carbon at the 15-30 cm layer was lower in 2008 (0.82%) compared with 2009 (1.01%; $P = 0.009$; Table 20). Organic carbon levels followed a similar trend as total carbon in the upper and lower layers, indicating inorganic carbon was not changing in the soil profile.

Table 17. Total, inorganic, and organic carbon (%; ± SE) by treatment at a depth of 0-15 cm for post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Treatment	Total Carbon	Inorganic Carbon	Organic Carbon
	Barley	1.73 ± 0.17	0.27 ± 0.11	1.46 ± 0.22
	Corn	1.62 ± 0.24	0.42 ± 0.21	1.20 ± 0.23
2006	Hay	1.77 ± 0.27	0.58 ± 0.20	1.19 ± 0.18
	Control	2.00 ± 0.22	0.45 ± 0.24	1.43 ± 0.15
	Season long	1.63 ± 0.22	0.39 ± 0.19	1.24 ± 0.14
	Barley	1.71 ± 0.18	0.24 ± 0.11	1.47 ± 0.22
	Corn	1.58 ± 0.19	0.38 ± 0.17	1.20 ± 0.19
2007	Hay	1.93 ± 0.34	0.89 ± 0.36	1.04 ± 0.13
	Control	1.95 ± 0.20	0.58 ± 0.24	1.38 ± 0.16
	Season long	1.66 ± 0.22	0.44 ± 0.20	1.22 ± 0.12
	Barley	1.72 ± 0.13	0.25 ± 0.11	1.47 ± 0.28
	Corn	1.54 ± 0.18	0.30 ± 0.16	1.23 ± 0.16
2008	Hay	1.67 ± 0.20	0.56 ± 0.23	1.12 ± 0.12
	Control	1.90 ± 0.14	0.53 ± 0.22	1.37 ± 0.27
	Season long	1.55 ± 0.17	0.43 ± 0.19	1.13 ± 0.06
	Barley	1.88 ± 0.11	0.24 ± 0.12	1.64 ± 0.28
	Corn	1.77 ± 0.22	0.41 ± 0.22	1.36 ± 0.25
2009	Hay	2.00 ± 0.28	0.61 ± 0.23	1.39 ± 0.13
	Control	2.39 ± 0.29	0.64 ± 0.27	1.72 ± 0.15
	Season long	1.90 ± 0.26	0.44 ± 0.18	1.46 ± 0.19

Table 18. Total, inorganic, and organic carbon (%; ± SE) by treatment at a depth of 15-30 cm for post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Treatment	Total Carbon	Inorganic Carbon	Organic Carbon
	Barley	1.35 ± 0.18	0.29 ± 0.09	1.07 ± 0.24
	Corn	1.74 ± 0.18	0.89 ± 0.32	0.85 ± 0.23
2006	Hay	1.80 ± 0.39	0.98 ± 0.41	0.82 ± 0.13
	Control	1.95 ± 0.31	0.86 ± 0.37	1.10 ± 0.18
	Season long	1.82 ± 0.31	1.06 ± 0.36	0.76 ± 0.16
	Barley	1.42 ± 0.17	0.31 ± 0.12	1.11 ± 0.22
	Corn	1.78 ± 0.37	0.95 ± 0.42	0.83 ± 0.36
2007	Hay	1.76 ± 0.32	0.95 ± 0.32	0.80 ± 0.20
	Control	1.85 ± 0.27	0.85 ± 0.32	1.00 ± 0.18
	Season long	1.53 ± 0.29	0.77 ± 0.29	0.76 ± 0.09
	Barley	1.33 ± 0.12	0.35 ± 0.15	0.98 ± 0.23
	Corn	1.42 ± 0.25	0.72 ± 0.26	0.70 ± 0.14
2008	Hay	1.40 ± 0.23	0.66 ± 0.26	0.74 ± 0.14
	Control	1.90 ± 0.22	0.80 ± 0.30	1.10 ± 0.26
	Season long	1.47 ± 0.23	0.87 ± 0.29	0.60 ± 0.13
	Barley	1.38 ± 0.13	0.27 ± 0.12	1.11 ± 0.21
	Corn	1.74 ± 0.40	0.91 ± 0.47	0.83 ± 0.25
2009	Hay	1.72 ± 0.35	0.82 ± 0.32	0.91 ± 0.11
	Control	2.04 ± 0.27	0.79 ± 0.31	1.25 ± 0.18
	Season long	1.68 ± 0.30	0.74 ± 0.24	0.94 ± 0.21

Table 19. Total, inorganic, and organic carbon (%) at a depth of 0-15 cm on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Total Carbon[1]	Inorganic Carbon	Organic Carbon[1]
2006	1.75 a	0.42	1.30 y
2007	1.77 a	0.51	1.26 y
2008	1.68 a	0.41	1.26 y
2009	1.99 b	0.47	1.51 z

[1]Carbon values with the same letter are not significantly different ($P > 0.05$).

Table 20. Total, inorganic, and organic carbon (%) at a depth of 15-30 cm on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Total Carbon[1]	Inorganic Carbon	Organic Carbon[1]
2006	1.73 a	0.82	0.92 yz
2007	1.67 ab	0.77	0.90 yz
2008	1.50 b	0.68	0.82 y
2009	1.71 a	0.71	1.01 z

[1]Carbon values with the same letter are not significantly different ($P > 0.05$).

DISCUSSION

Bareground increased across years from an average 7.3% in 2006 to 15.6% in 2008, dropping to 11.1% in 2009. Hendrickson (2003) noted warm temperatures influence decomposition rates, which may account for higher levels of bareground. Temperatures for July 2006 were higher than normal, so higher levels of decomposition may have occurred, depleting litter levels that normally overwintered. Increased temperatures for July also occurred in 2007, potentially increasing decomposition rates along with bareground. Temperatures in 2008 were near normal, so decomposition rates would have maintained typical levels allowing an increase in litter accumulation in 2009.

Griffiths and Birch (1961) determined that dry periods followed by a wet period increased decomposition rates. Both June and July 2006 had below normal precipitation, followed by three months of near normal precipitation. Most production months during 2007 and 2008 received near normal precipitation, allowing normal decomposition processes to occur. Fuhlendorf et al. (2001) found plant basal cover was directly correlated to precipitation levels.

The CTRL treatment had the lowest bareground among treatments at 7.6% and highest litter at 72.4% when averaging the four years. The CTRL was not harvested, so all biomass produced remained at the site and accumulated as litter. Hay plots had the highest level of bareground overall with an average of 15.2% across all four years and highest in 2008 (24.4%). The HAY treatments had the lowest average level of litter at 64.7%. Removal of biomass through haying reduces available material that produces litter. Guo et al. (2000) determined peak biomass production occurs in May and decreases throughout the remainder of the season, indicating most biomass is removed during first cut haying.

The SL treatment averaged 71.5% litter across all four years, which was slightly lower than the CTRL (72.4%) and higher than HAY treatment (64.5%). Willms et al. (2002) noted grazing cattle breakdown litter through hoof action, accelerating decomposition rates. Biondini et al. (1998) determined litter decomposition increased in all grazing treatments compared to non-grazed. Among the levels of grazing used by Biondini et al. (1998), moderate grazing created the highest level of litter decomposition.

Knapp and Seastedt (1986) found litter improves water interception and infiltration into the soil. Willms et al. (1993) determined litter improved production by maintaining soil moisture and reducing evaporation during low moisture conditions, thus positively influencing productivity levels. Loss of litter negatively impacted plant development and productivity in three of the four years of this study (Willms et al. 1993). Dormaar et al. (1997) found plant species development and growth patterns could be affected either negatively or positively by high levels of litter, depending on the species. Although the CTRL in this study had higher levels of litter, it did not have the highest level of productivity.

Species evenness, or the distribution and abundance of a species within a community (Guo et al. 2006; Gurevitch et al. 2006), was not different between years or treatments in the study. Species richness, or number of species in a community (Guo et al. 2006; Gurevitch et al. 2006), did not vary in the study. Species diversity was determined using the Shannon –Weiner index that measures biodiversity and is highly responsive to rare species (Gurevitch et al. 2006). Species diversity did not differ among treatments.

Analysis suggested that changes in species composition within grasses may be occurring as invaders moved into the sites. Assessment of dynamics within the plant communities was analyzed with no succession or directional changes occurring within treatments. Environmental conditions appear to be influencing shifts in vegetation levels between years.

Milchunas and Lauenroth (1993) found species composition changes were influenced by precipitation, temperature, and herbivory. Hooper and Vitousek (1998) determined dominant species can monopolize available resources, influencing species composition within plant communities. Increased plant diversity aided in maximizing resource use within plant communities. Forb and grass composition remained consistent throughout the study.

Across all four years of the study, shallow sandy sites had the highest levels of grass production in 2009. Precipitation levels for 2009 were above normal during the 2008-2009 winter months and at near normal levels throughout the growing season, so moisture was not a limiting factor for plant productivity. Peak production values for grass at shallow sandy sites was lower compared to sandy and loamy overflow sites for most years of the study. Grass production on the shallow sandy sites for HAY was more productive than CTRL and SL treatments in 2009. Forb production at shallow sandy sites followed a similar trend with higher levels of production in 2009 compared to other years.

Upland sites tend to have well-drained soils (Brady and Weil 2008) susceptible to wind and water erosion. A North Dakota study conducted by Aguilar and Heil (1988) determined that soil nutrient levels are lowest on hilltops or knolls and increase moving downslope. Consequently, landscape position can influence plant productivity due to nutrient availability.

Sandy site grass production levels were higher in SL treatments (5681 kg/ha) compared to CTRL (1958 kg/ha). The HAY sandy site grass production averaged 2396 kg/ha. Loamy overflow sites produced an average of 3099 kg/ha of grass on the CTRL, 5725 kg/ha on SL, and 2834 kg/ha on HAY. Nutrient loss from upland soils is frequently captured and held in low-lying or overflow sites (Aguilar and Heil 1988). As nutrients are removed from a site, plant productivity decreases (Bauer and Black 1994). Due to nutrient gains and higher levels of soil moisture, loamy overflow areas tend to have higher levels of productivity (Aguilar and Heil 1988) compared to other landscape positions. Salo et al. (1997) reported higher productivity in loamy overflow (4068 kg/ha) compared to silty sites (2952 kg/ha) on native rangelands sites.

Cattle consistently selected for sandy and loamy overflow sites throughout the study. These sites were the most productive and tend to stay green longer when moisture is available. Willms et al. (2002) found grazing decreased herbage production on semi-arid mixed prairie rangelands. In contrast, our study showed higher productivity on moderately grazed SL treatments compared to the CTRL (non-grazed).

During the first three years of this study, total organic carbon levels were not different between years or treatments for the upper 0-15 centimeters of soil. The total carbon level for 2009 (1.99%) was higher in the upper 0-15 centimeters when compared to the three previous years. Total carbon levels in the 15-30 centimeter portion of soil showed differences between 2006 (1.73%) and 2008 (1.50%), and differences between 2008 (1.50%) and 2009 (1.71%).

Burke et al. (1989) suggested soil carbon levels were a result of primary productivity coupled with decomposition rates. Whalen et al. (2003) found perennial plantings of grasses and legumes influenced carbon levels, and in some cases slowed or reversed carbon losses. Whalen et al. (2003) also found carbon levels were most directly influenced by vegetative inputs and climate (temperature and precipitation). Schuman et al. (1999) noted belowground carbon accumulation occurs within the rooting zone (0-30 centimeters) through inputs by root biomass.

Holland and Dettling (1990) suggested above ground carbon inputs are decreased when grazing occurs, causing lower levels of root biomass production. In contrast, Schuman et al. (1999) found total carbon levels were lower in non-grazed plots. Milchunas and Lauenroth (1993) found grazing did not impair below ground root production, while Manley et al. (1995) noted grazing reduced litter and dead standing biomass. Henderson et al. (2004) suggested grazing impacts on soil carbon levels varies depending on climate and vegetation inputs.

Malo et al. (2005) found total carbon levels were deeper in cultivated soils compared to uncultivated soils due to soil churning. Reeder et al. (1998) determined total carbon levels decreased in cropped fields starting six years after tillage begins. Additionally, they found litter accumulation aided in higher soil organic matter levels, which can then be broken down to release carbon. The quality of litter also influences soil carbon levels (Wright and Hons 2005).

Total carbon levels within this study did increase in 2009 within the upper 30 cm compared to the previous three years, which may be affected by the increased production levels and available soil moisture from the 2009 season. The decrease in the 15-30 cm total carbon value in 2008 may reflect lower litter levels available for decomposition into soil carbon.

Organic carbon was different across all four years with 2009 (1.51%) having the highest value in the upper 0-15 cm of soil. Only 2009 (1.01%) was different than 2008 (0.82%) in the 15-30 cm range. Organic carbon levels showed patterns similar to the total carbon levels.

Post and Kwon (2000) determined that soil organic carbon is influenced by three components; vegetative inputs, disturbance, and soil conditions, which creates a continual feedback system. When vegetative inputs are greater, a higher level of carbon is contributed to the soil. Increasing plant diversity can positively influence carbon levels (Fornara and Tilman 2008). Disturbance, such as soil tillage, can negatively influence inputs by increasing exposure of carbon within the soil-atmosphere interface accelerating soil carbon conversion to a gaseous CO_2 (Dao et al. 2002). Soil conditions, which may include soil moisture and microbes involved in decomposition, can decrease or increase decomposition rates (Bolinder et al. 2007) holding or releasing carbon into the soil and atmosphere (Dao et al. 2002). Gilley and Doran (1997) noted a significant drop in soil organic carbon nine months after the cropping treatment began compared to non-use. Potter et al. (1999) found cropped plots have the lowest organic carbon levels, yet a uniform distribution within the upper 10 cm of soil. VandeBygaart et al. (2002) found organic carbon levels decreased regardless as to the type of plowing used and that land use practices had more impact on organic carbon levels.

Based on our study, total, inorganic, and organic carbon levels in the upper 30 cm of soil are not adversely affected by moderately stocked, season-long grazing, no-till cropping, or one-cut haying systems within the first four years of implementing a multiple use agricultural system. In addition, total and organic carbon levels within the upper 30 cm can be maintained and increased after land has been released from CRP.

SUMMARY AND CONCLUSIONS

The two main objectives of this study were to determine if plant species composition changed due to livestock grazing, one-cut haying, or non-use; and determine if cropping, haying, and grazing influenced soil carbon levels. After four-years of study, species richness, evenness, and diversity did not change in the SL, CTRL, or HAY treatments. Soil total, inorganic, and organic carbon levels were not adversely impacted by any of the treatments, and increased in the fourth year using a sustainable livestock grazing program.

If properly managed, soil is a renewable resource. CRP restores soil quality through increased organic matter inputs, reduced soil erosion, and improved soil structure. Lands set aside in CRP are considered HEL, which require special considerations in some land use situations. When released from CRP, these lands can be degraded, maintained, or improved. Implementing the proper land management techniques is critical to maintain or improve soil quality gained during the CRP contract period.

This study has initially shown land management techniques including moderate grazing, no-till cropping, and a one-cut haying system can be beneficial in maintaining species composition and soil carbon levels. We recommend the project continuation for a minimum of six years to determine if species composition and soil carbon levels continue their current trends on post-contract CRP lands in a semi-arid region.

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APPENDIX A. INITIAL WEIGHTS (KG) FOR COWS ON THE CLEMENT AND FITCH SITES FROM 2006-2009

Table 21. Cow weights (± SE) by replicate on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

	Years			
Site	2006	2007	2008	2009
Clement	507 ± 10	565 ± 14	627 ± 11	--[1]
Fitch	508 ± 13	563 ± 14	620 ± 13	--[1]

[1] --, data not available.

APPENDIX B. TOTAL ABUNDANCE OF PLANT SPECIES ON THE CLEMENT AND FITCH SITES FROM 2006-2009

Table 22. Total abundance (%) of plant species for individual treatments at Clement and Fitch sites on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Year	Site	Treatment	Annual Forbs	Perennial Forbs	Annual Grasses	Perennial Grasses
2006	Clement	HAY[1]	1.4	6.0	0.0	18.1
		CTRL	1.4	4.8	0.0	17.7
		SL	0.5	5.5	0.3	16.9
	Fitch	HAY	0.5	10.2	0.0	14.6
		CTRL	0.4	10.4	0.0	17.3
		SL	1.0	7.1	0.0	18.8
2007	Clement	HAY	0.4	3.6	0.0	14.5
		CTRL	0.2	3.4	0.0	14.1
		SL	0.6	4.2	0.3	15.2
	Fitch	HAY	0.8	8.2	0.0	11.9
		CTRL	0.5	4.7	0.2	17.5
		SL	0.3	4.9	0.7	14.8
2008	Clement	HAY	0.9	3.8	0.0	4.6
		CTRL	0.3	2.7	0.0	6.5
		SL	0.3	1.9	0.0	4.7
	Fitch	HAY	0.6	4.1	0.0	4.4
		CTRL	0.1	2.5	0.0	5.0
		SL	0.9	2.1	0.0	2.5
2009	Clement	HAY	2.4	7.3	0.0	10.7
		CTRL	0.7	5.7	0.0	12.9
		SL	1.4	8.9	0.1	11.2
	Fitch	HAY	2.4	16.1	0.1	9.1
		CTRL	0.8	12.5	0.0	11.4
		SL	1.0	9.0	0.0	10.2

[1]Treatments include: control or non-use (CTRL), season long grazing (SL), and hay (HAY).

APPENDIX C. PLANT SPECIES LIST FOR THE CLEMENT SITE FROM 2006-2009.

Table 23. Plant species found on the Clement replicate on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Scientific Name	Common Name
Agropyron cristatum (L). Gaertn.	Crested wheatgrass
Androsace occidentalis Pursh.	Fairy candelabra
Antennaria microphylla	Littleleaf pussytoes
Artemesia absinthium L.	Absinth wormwood
Artemisia frigida Willd.	Fringed sagewort
Asclepias pumila (A. Gray) Vail	Plains milkweed
Aster ericoides L.	Heath aster
Bromus inermis Leyss.	Smooth brome
Bromus japonicus Thunb.	Japanese bromegrass
Calamovilfa longifolia (Hook) Scribn.	Prairie sandreed
Camelina microcarpa Andrz.	Small-seeded false flax
Carex filifolia Nutt.	Threadleaf sedge
Chenopodium album L.	Lamb's quarter
Chrysopsis villosa (Pursh) Nutt.	Hairy gold aster
Cirsium flodmanii (Rydb.) Arthur.	Flodman's thistle
Convolvulus arvensis L.	Field bindweed
Descurainia sophia (L.) Webb.	Flixsweed
Elymus caninus (L.) L.	Bearded wheatgrass
Elymus hispidus (P. Opiz) Melderis	Intermediate wheatgrass
Elymus repens L. Gould	Quackgrass
Elymus trachycaulus (Link) Shinners	Slender wheatgrass
Erigeron strigosus Muhl.	Daisy fleabane
Erysimum aspera (Nutt.) DC.	Western wallflower
Hedeoma hispida Pursh	Rough pennyroyal
Koeleria macrantha (Ledeb.) J.A. Schultes	Prairie junegrass
Lactuca oblongifolia Nutt.	Blue lettuce

APPENDIX C. (Continued)

Scientific Name	Common Name
Lepidium densiflorum Schrad.	Peppergrass
Liatris punctata var. *nebraskana* Gaiser	Nebraska blazing star
Lotus purshianus Clem.& Clem.	Golden pea
Medicago sativa L.	Alfalfa
Melilotus officinalis (L.) Lam.	Yellow sweet clover
Pascopyron smithii (Rydb.) Gould	Western wheatgrass
Poa pratensis L.	Kentucky bluegrass
Salsola iberica Sennen & Pau	Russian thistle
Selaginella densa Rydb.	Small clubmoss
Solidago rigida L.	Stiff goldenrod
Solidago ptarmicoides (Nees) B. Boivin	Prairie goldenrod
Taraxacum officinale Weber.	Common dandelion
Tragopogon dubius Scop.	Goatsbeard
Vicia americana Muhl.	American vetch

APPENDIX D. PLANT SPECIES LIST FOR THE FITCH SITE FROM 2006-2009.

Table 24. Plant species found on the Fitch replicate on post-contract Conservation Reserve Program lands in southwestern North Dakota from 2006-2009.

Scientific Name	Common Name
Achillea millefolium L.	Western yarrow
Agropyron cristatum (L). Gaertn.	Crested wheatgrass
Agropyon subsecundum (Link) Hitchc.	Bearded wheatgrass
Androsace occidentalis Pursh.	Fairy candelabra
Antennaria microphylla	Littleleaf pussytoes
Antennaria neglecta Greene.	Field pussytoes
Artemisia frigida Willd.	Fringed sagewort
Asclepias pumila (A. Gray) Vail	Plains milkweed
Aster ericoides L.	Heath aster
Berteroa incana (L.) DC.	Hoary alyssium
Bromus inermis Leyss.	Smooth brome
Bromus japonicus Thunb.	Japanese bromegrass
Calamovilfa longifolia (Hook) Scribn.	Prairie sandreed
Camelina microcarpa Andrz.	Small-seeded false flax
Chenopodium album L.	Lamb's quarter
Chrysopsis villosa (Pursh) Nutt.	Hairy gold aster
Cirsium arvense (L.) Scop.	Canada thistle
Cirsium flodmanii	Flodman's thistle
Cirsium undulatum (Nutt.) Spreng var. *undulatum*	Wavyleaf thistle
Collomia linearis Nutt.	Tiny trumpet
Convolvulus arvensis L.	Field bindweed
Coryphantha vivipara (Nutt.) Britt.& Rose var.	Ball cactus
Descurainia sophia (L.) Webb.	Flixsweed
Echinacea angustifolia DC.	Black Sampson
Elymus caninus (L.) L.	Bearded wheatgrass

Scientific Name	Common Name
Elymus hispidus (P. Opiz) Melderis	Intermediate wheatgrass
Elymus trachycaulus (Link) Shinners	Slender wheatgrass
Erigeron strigosus Muhl.	Daisy fleabane
Erysmium aspera (Nutt.) DC.	Western wallflower
Erysmium inconspicuum (S. Watson) MacMill.	Shy wallflower
Grindelia squarrosa (Pursh) Dunal.	Curlycup gumweed
Hedeoma hispida Pursh	Rough pennyroyal
Koeleria macrantha (Ledeb.) J.A. Schultes	Prairie junegrass
Lactuca oblongifolia Nutt.	Blue lettuce
Lepidium densiflorum Schrad.	Peppergrass
Lotus purshianus Clem.& Clem.	Golden pea
Medicago sativa L.	Alfalfa
Melilotus officinalis (L.) Lam.	Yellow sweet clover
Oxytropis campestris	Slender crazyweed
Pascopyron smithii (Rydb.) Gould	Western wheatgrass
Penstemon glaber Pursh.	Smooth beardtongue
Physaria brassicoides Rydb.	Double twinpod
Plantago patagonica Jacq.	Woolly plantain
Potentilla recta L.	Sulphur cinquefoil
Poa pratensis L.	Kentucky bluegrass
Ratibida columnifera (Nutt.) Wooton & Standl.	Prairie coneflower
Salsola iberica Sennen & Pau	Russian thistle
Selaginella densa Rydb.	Small clubmoss
Solidago mollis Bartl.	Soft goldenrod
Solidago ptarmicoides (Nees) B. Boivin	Prairie goldenrod
Solidago rigida L.	Stiff goldenrod
Sphaeralcea coccinea (Nutt.) Rydb.	Scarlet globemallow
Taraxacum officinale Weber.	Common dandelion
Tragopogon dubius Scop.	Goatsbeard

APPENDIX D. (Continued)

Scientific Name	Common Name
Vicia americana Muhl.	American vetch

APPENDIX E. REPLICATE AND TREATMENT SOIL TRANSECT INFORMATION

Table 25. Soil, ecological site, and land capability classes for Clement and Fitch transect locations on post-contract Conservation Reserve Program lands in southwestern North Dakota.

Replicate	Treatment	Transect	Soil Type	Slope	Ecological Site	Land Capability
Clement	Control	1	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Control	2	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Control	3	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Control	4	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	1	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	2	Vebar-Parshall	0-6	Sandy	3e
Clement	Crop	3	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	4	Arnegard	0-2	Loamy	2c
Clement	Crop	1	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	2	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	3	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Crop	4	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Fitch	Season Long	1	Vebar-Parshall	0-6	Sandy	3e
Fitch	Season Long	2	Vebar-Parshall	0-6	Sandy	3e
Fitch	Season Long	3	Vebar-Parshall	0-6	Sandy	3e

APPENDIX E. (Continued)

Replicate	Treatment	Transect	Soil Type	Slope	Ecological Site	Land Capability
Fitch	Season Long	4	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	1	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	2	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	3	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	4	Vebar-Parshall	0-6	Sandy	3e
Fitch	Control	1	Vebar-Parshall	0-6	Sandy	3e
Fitch	Control	2	Vebar-Parshall	0-6	Sandy	3e
Fitch	Control	3	Vebar-Parshall	0-6	Sandy	3e
Fitch	Control	4	Belfield-Savage-Daglum	0-2	Clayey-Clay pan	2s,4s,2c
Fitch	Crop	1	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	2	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	3	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	4	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	1	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	2	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	3	Vebar-Parshall	0-6	Sandy	3e
Fitch	Crop	4	Vebar-Parshall	0-6	Sandy	3e

APPENDIX F: REPLICATE AND TREATMENT CLIPPING SITE INFORMATION

Table 26. Soil, ecological site, and land capability classes for clipping sites at Clement and Fitch for the season long, control, and hay treatments on post-contract Conservation Reserve Program lands in southwestern North Dakota.

Replicate	Treatment	Clip Site	Soil Type	Slope	Ecological Site	Land capability
Clement	Season long	Shallow sandy	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Season long	Shallow sandy	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Season long	Sandy	Shambo	0-2	Loamy	2c
Clement	Season long	Sandy	Vebar-Flasher	3-9	Sandy-Shallow sandy	4e, 6e
Clement	Season long	Loamy overflow	Harriet Loam	0-2	Saline lowland	6s
Clement	Season long	Loamy overflow	Vebar-Parshall	0-6	Sandy	3e
Clement	Hay	Shallow sandy	Vebar-Parshall	0-6	Sandy	3e
Clement	Hay	Sandy	Vebar-Parshall	0-6	Sandy	3e
Clement	Hay	Loamy overflow	Harriet Loam	0-2	Saline lowland	6s
Clement	Control	Shallow sandy	Vebar-Parshall	0-6	Sandy	3e
Clement	Control	Sandy	Vebar-Parshall	0-6	Sandy	3e
Clement	Control	Loamy overflow	Harriet Loam	0-2	Saline lowland	6s
Fitch	Season long	Shallow sandy	Vebar-Parshall	0-6	Sandy	3e
Fitch	Season long	Shallow sandy	Vebar-Parshall	0-6	Sandy	3e

APPENDIX F. (Continued)

Replicate	Treatment	Clip Site	Soil Type	Slope	Ecological Site	Land capability
Fitch	Season long	Sandy	Vebar-Parshall	0-6	Sandy	3e
Fitch	Season long	Sandy	Vebar-Parshall	0-6	Sandy	3e
Fitch	Season long	Loamy overflow	Harriet Loam	0-2	Saline lowland	6s
Fitch	Season long	Loamy overflow	Harriet Loam	0-2	Saline lowland	6s
Fitch	Hay	Shallow sandy	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	Sandy	Vebar-Parshall	0-6	Sandy	3e
Fitch	Hay	Loamy overflow	Belfield-Savage-Daglum	0-2	Clayey-Clay pan	2s, 4s, 2c
Fitch	Control	Shallow sandy	Belfield-Savage-Daglum	0-2	Clayey-Clay pan	2s, 4s, 2c
Fitch	Control	Sandy	Belfield-Savage-Daglum	0-2	Clayey-Clay pan	2s, 4s, 2c
Fitch	Control	Loamy overflow	Belfield-Savage-Daglum	0-2	Clayey-Clay pan	2s, 4s, 2c