The Influence of Land Use on Carbon and Nitrogen Accumulation in Prairie Soils within the Cheyenne River Watershed, Custer and Pennington Counties, South Dakota

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Abstract:

Due to the impact of land use change on carbon and nitrogen accumulation in soils and the increasing loss of both, this study examines the effects of variable land use on soil carbon and nitrogen in order to determine how the use of land as range for farming and grazing purposes effects soil dynamics as compared with undisturbed land. My primary objective was to determine if ungrazed portions of rangeland differ from those grazed with non-native species, namely beef cattle. I also hypothesized that there might be implications for larger-scale ecosystem effects, namely increased losses of soil nutrients, depending on how soils in this particular region of the North American Great Plains are protected or exploited.

Based on an analysis of variance, results show that total measured soil carbon and nitrogen levels at varying depth increments were not statistically significant for the size of this study. Bulk density measurements for soils also produced statistically insignificant results. It is clear that an expansion of the size of the study area and an increase in sampling replications would benefit this research in order to derive a clear conclusion about the effects of land use change on soil-nutrient dynamics. While this study did not produce statistically significant results, a clear correlation between my own data and that cited in other literature shows potential for further research.

Keywords: bulk density, carbon cycle, nitrogen cycle, prairies, soils, South Dakota

Table of Contents:

Introduction:

Over the last two centuries, land use has caused a significant change in soil dynamics on the North American Great Plains (NAGP) (Burke et al, 1995; Franzluebbers et al, 2002; Parton et al, 1987; Potter et al, 1999). Agricultural activity and land development have degraded soils, causing them to become net sources of atmospheric greenhouse gases (GHGs) (Schlesinger and Andrews, 2000; Six et al, 2001). With GHG emissions presently increasing, current proposals call for geologic and biologic methods of reduction and stabilization (Jackson and Schlesinger, 2004). Some evidence may show that soil could be used to store excess nutrients that, if released to the atmosphere, would otherwise cause increased GHG emissions, and in effect, global warming (Houghton and Hackler, 1999; Hungate et al, 1997; Riedo et al, 2000; Schlesinger and Andrews, 2000; Trumbore, 1997).

At the global scale, about 1500Pg (1 Pg = 10^{15}g) of carbon and 3.5 Pg of nitrogen are contained in soil (Schlesinger, 1997; Trumbore, 1997). Carbon and nitrogen cycle regularly through soil in the form of soil organic matter (SOM), supplied to soils through plant biomass and detritus and animal waste because of plant-soil interactions (Figures 1 and 2). These natural cycles maintain the soil fertility of a given ecosystem. Environmental controls over biota and ecosystem functioning as well as anthropogenic forcing (i.e. ranching and farming practices) can determine accumulation of both nitrogen and carbon in grassland soils. When nutrients are sequestered or lost, vast regions of Earth's surface play the role of either sources or sinks (Post et al, 2001). Soil nutrients are released to the atmosphere naturally through mineralization and oxidation as well as erosion of soil caused by wind and water (Hunt, 1972; Jenny, 1941; Reeder, 1998; Ritter, 1978; Nielsen, 1996). However, other processes that allow for nutrient loss from soils include human influences on land through farming and agriculture, deforestation and the combustion of fossil fuels. When soil is exposed to air as a result of tillage, decomposition increases and soil aggregates are broken up more quickly. Increased nitrogen additions in the form of fertilizer can further aggravate the loss of soil nutrients, because too much input can quickly degrade soils.

Nitrogen is a limiting nutrient in grassland ecosystems, because it influences biological productivity. Soils may represent a large and effectively stable sink for nitrogen (Barrett and Burke, 2002; Collins et al, 1998; Glimskär and Erickson, 1999; Kaye et al, 2002; Parton et al, 1988). Surface soils, namely the O and A horizons (Figure 3), serve as the primary sink for nitrogen, both as fertilizer additions and as a naturally occurring nutrient. In soils, nitrogen can be found in a number of different forms (Figure 2). The pool of nitrates is more prone to losses from soil than that of ammonium so environmental changes are evident when changes in nitrates occur (Watson and Poland, 1999). Nitrates are released from soil in the form of nitrous oxide (N_2O) and nitrogen gas (N_2), through denitrification (Figure 2). Köchy and Wilson (1997) found that atmospheric nitrogen from industrial processes can become a potential nitrogen source for accumulation in soils (giving soils the potential for becoming a nitrogen sink), even in remote areas, like that chosen for this particular study. On the other hand, they also suggest that on a local scale, nitrogen dynamics in soil are affected more by litter quality than by habitat or degrading sunlight. Many studies speculate that as modern agriculture, urbanization and fossil fuel use continues to increase, nitrogen losses from soil and in effect, the amplification of N_2O release from soil, will continue to intensify (Barrett and

Burke, 2000; Ruddiman, 2001; Schlesinger, 1997; Vitousek et al, 1997) because of subsequent soil disruption.

Like nitrogen, soil carbon can also be an indicator of the fitness or disturbance of ecosystems. Olsson and Ardö (2002) found that the loss of carbon from soil due to land use change has raised atmospheric CO_2 influx rates as high as 3.5 Gt/yr (1Gt = 10^9 tons). According to Averett et al (2004), the loss of soil carbon after conversion from prairie to agricultural fields is as high as 75%. Tiessen et al (1994) establish that under cultivation, carbon losses from soil happen twice as quickly as carbon mineralization associated with the turnover of organic matter in natural ecosystems. A loss of this magnitude could take up to 200 years to reverse. A growing body of information shows that the conversion from croplands back to pasture causes significant re-accumulation of carbon and nitrogen that may have been lost from the soil due to cultivation (Manies et al, 2001; Paustian et al, 2000; Reeder et al, 1998; Smith et al, 2000). Other studies show that soil organic carbon (SOC) loss was between 30% and 43% after agricultural practices were implemented (Potter, 1999; Kucharik et al, 2001) and that it could take about a century to regain such losses.

SOC and SOM depend on Net Primary Production (NPP) (Schlesinger, 1999), which can provide a good estimate of the size of the soil carbon and nitrogen pools. The NPP of grasslands is unique because of the massive amount of belowground biomass present. Although grasslands are only marginally productive compared with other ecosystems, they still maintain high levels of SOC and other various nutrients like nitrogen, because of their extensive root systems (Frank and Dugas, 2001; Frank et al, 2002; Gill et al, 1999). In effect, belowground biomass often plays a more important role in determining nutrient fluxes because the belowground primary production (BPP) rates in grassland vegetation is often much higher. Over time, these nutrients may accumulate in the top 300 cm of soil at rate of up to 110 g C m^2/y (Post and Kwon, 2000) (Figure 1). The largest carbon fluxes in grassland ecosystems are caused by soil respiration due to root functioning and microbial decomposition (McCulley et al, 2005). Alterations to the rates of inputs and outputs of nutrients to soil can change the nutrient pools. If additions of carbon and nitrogen to soil are too small to match the chemical, physical and biological processes that cause losses, accumulation does not occur. Therefore nutrient sequestration is highly dependent on current and future climatic conditions and human land use effects on the carbon and nitrogen cycles (McCulley et al, 2005; Post and Kwon, 2000).

Much like SOC levels, grassland soils typically have large SOM stores because of limited water availability and therefore, low microbial decomposition rates (Schlesinger, 1997). A large portion of nitrogen in terrestrial soils is often found in the form of SOM, which can be mineralized both biotically and abiotically. Microbial immobilization of nitrogen seems to be the most significant cycling process for nitrogen retention in soils (Barrett and Burke, 2002). Higher levels of immobilized nitrogen are found in soils with high SOM and a wide C:N ratio. When there is a higher carbon content in soil, there is less nitrogen turnover because more carbon is mineralized decreasing the potential for microbial metabolic stimulation (Barrett and Burke, 2000). Generally, C:N ratios are about 10:1 because as microbial respiration takes place in soil, CO_2 is released and nitrogen is immobilized (Gill et al, 1999; McCulley et al, 2005). This correlation between carbon content and nitrogen immobilization in grassland soils appears to take place on both small and large regional scales (Barrett et al, 2002). Therefore, discontinuous plant cover and animal waste distribution make knowledge of past management history at specific locations important because on the larger regional scale, this information can be used as a guide for determining carbon and nitrogen content and the extent of environmental losses (Watson and Poland, 1999).

Soils are the locale for nutrient accumulation because of their very distinct physical characteristics like particle size, particle surface area and texture. Soil formation factors like water availability, moisture and topography influence nutrient accumulation and retention (Willms et al, 2002). Therefore, it is important to understand the interactions between biological and physical nutrient cycling within soil. The USDA defines soil texture in terms of sand, silt and clay particles and content of each. The rapid percolation of water through sandy soils results in lower carbon and nitrogen values. Clayey soils have the highest potential for nutrient sequestration because clay particles have the highest surface area and water percolates more slowly through clay soils. Clays also have a high cation exchange capacity, meaning that due to the negative charge of clay soil particles, they attract more positively charged cation nutrients (Schlesinger, 1997). Silty soils, which reside mainly on floodplains, have medium sized particles and are the intermediate source or sink of nutrients in terms of soil characteristics (Hunt, 1972; Jenny, 1941; Kohnke and Franzmeier, 1996; Singer and Munns, 1996). Sandy soils display higher nutrient loss rates. When soils are exploited through land use, through tillage and heavy grazing, they can be compacted so that water permeability decreases. Furthermore, when soils are overturned, weathering rates increase due to increased exposure. In effect, soils become a source for the loss of carbon and nitrogen to the atmosphere in the form of N_2O and CO_2 (GHGs) (Figures 1 and 2).

The manipulation of land for farming and grazing not only causes a heightened release of nutrients from soil, but it also causes an interruption of naturally occurring disturbance regimes such as fires, which has changed the diversity and health of grassland ecosystems (Briggs et al, 2002). For example, fire limits the spread of woody plant species, which are less effective at storing carbon in soils than native perennial grasses (Post and Kwon, 2000). Rocky Mountain Juniper (*Juniperus scopolorum*) is a hearty woodland plant that has begun to relocate to deeper soils in the region of this study, because fire has been almost completely suppressed here (Gartner and Sieg, 1996; O'Brien, 2005; BGNG (USFS), 2005). In many areas of the NAGP, the suppression of fire has caused an increase in the permanent establishment of woody plant species. Smith and Knapp (1999) found that generally, total exotic plant species cover was higher in long-term unburned prairie. In addition to excluding invasive plant species, fire can help increases the productivity of the region through the removal of excess litter accumulation. Some studies speculate that fire could further limit nutrient availability in grassland ecosystems, but there is little evidence for the negative effects of fire because of the resulting long-term rejuvenation of above ground biomass that comes from the disturbance (Brye et al, 2002).

When combined with fire disturbances, the presence of ungulate grazers also has an effect on carbon and other nutrient losses from the grassland ecosystem. Briggs et al, (2002) found that fire-grazing interactions may affect the grassland matrix and subsequent nutrient availability, but they could not conclude if it was the presence of grazing or the lack of fire that had the most impact. Moreover, fires do have an indirect effect on soils, mainly because of the changes to the overlying vegetation and organic matter lost during burning. The increase in temperature of soils during and after fires, can cause a rise in decomposition, and thus a release of carbon and nitrogen into the atmosphere. Furthermore, runoff can cause soil erosion, resulting in increased nutrient loss from soils. However, DeBano et al (1998) argue that natural fires are akin to an extremely rapid decomposition process within soils and thus claim that soil nutrients increase the viability of the ecosystem because essentially, more nutrients are cycled through the soil at a higher rate. Furthermore, as the post-fire ecosystem recovers, soil-water interactions also improve, causing erosional processes to diminish (Wondzell and King, 2003). In effect, nutrient cycling processes within soils return to an equilibrium state over time.

Due to the impact of land use on carbon and nitrogen accumulation in soils, this study considers the grazing of American bison (*Bison bison*) and cattle (*Bos taurus*), because a vast proportion of the NAGP is utilized as primary rangeland for the beef cattle industry and in the past, served as the primary habitat for bison. Overall, grazing may enhance vegetative species diversity and soil fertility (Polley and Detling, 1990). Furthermore, species richness in terms of vegetation may not be affected nearly as much as abundance of vegetation when grazing occurs. Soil compaction and bulk density increase with intensified grazing. But, increasing litter and vegetation cover due to grazing exclusion also changes the soil, because decomposition of aboveground litter increases. In effect, this decreases SOC (Henderson et al, 2004; Naeth et al, 1990). Bremer et al (2001) found also that cattle may have a direct effect on soil by removing significant amounts of aboveground biomass thus altering the surface and deeper soil horizon interactions. Therefore, it is important to analyze the nature of grazing habits rather than simply whether rangelands are used as such.

The grazing habits of cattle and bison differ in a number of ways that can directly affect carbon and nitrogen storage in soils. Bison tend to selectively graze on graminoids over forbs thus inadvertently affecting the ungrazed plant community. Fahnestock and Knapp (1994) hypothesized that bison herbivory may indirectly cause an increase in water and light availability and therefore forb productivity. This directly affects nutrient dynamics in the ecosystem. Their conclusion is that selective herbivory does indeed enhance carbon gains and also increases biomass and potential fitness of the ecosystem. Furthermore, the cloven shape of bison hooves is different from cattle hooves and tends to aerate the soil more so than compacting it (Allen, 2005 and Lott, 2000), increasing the potential for nutrient accumulation. Bison also tend to cover more area while grazing as opposed to cattle, which will remain in one location until it is thoroughly cleared of its edible vegetation. In areas where decline in vegetation was caused by burning, the negative effects seem to have been reversed by the presence of bison (Collins et al, 1998). It is assumed that the reintroduction of native grazing species in stressed grassland ecosystems may enhance biodiversity and ecosystem health (Allen, 2005; Collins et al, 1998; Fahnestock and Knapp, 1994; Milchunas and Lauenroth, 1993; O'Brien, 2005).

Objectives:

This research examines the effects of variable land use on soil carbon and nitrogen in order to discover how the use of land as range for farming and grazing purposes effects soil dynamics as compared with native and undisturbed land. My primary objective is to determine if ungrazed portions of rangeland differ in nutrient content from areas grazed with non-native species, namely beef cattle. I hypothesize that soil carbon and nitrogen accumulation will be greater in areas where the impact of grazing is lighter or where undisturbed native prairie remnants exist. A supporting objective is to observe whether the replacement of non-native cattle with native American bison has a significant effect on soil dynamics after only four years. Because the grazing habits of bison appear to have a lesser effect on the landscape I hypothesize that the presence of this native species could decrease the loss of carbon and nitrogen from the soil. The long-term goal of this research aims to determine whether this particular region of the NAGP plays the role of a possible sink for GHG-forming nutrients. From this, I also hypothesize that there might be implications for larger-scale ecosystem effects depending on how the soil in this particular region of the NAGP is protected or exploited.

Setting:

The research area lies across the border of Pennington and Custer counties, along the Cheyenne River in South Dakota (Figure 4a, b, c). The Cheyenne River is 475 km long, flows from northeast Wyoming and drains into the Missouri river in central South Dakota. The Cheyenne River is one of the major drainage-ways for what the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) determines as the prairie section of Pennington and Custer Counties. This study is limited to the Cheyenne River watershed, between Indian Creek and Little Corral Draws on the east side of the river. The study also incorporates land on the west side of the river, across Phiney Flat and along the southern border of Spring Creek. The northern-most sampling site lies at N43°47′ N, 102°42′ W and the southern-most sampling site lies at 43°44′ N, 102°46′ W (Figure 4a). Elevations range from 770 m to 920 m. The land studied is made up of both privately owned ranch lands and publicly owned range maintained by the United States Forest Service.

The study area is located within the semi-arid region of the NAGP. Aside from the Cheyenne River and its tributaries, water is scarce in this area, especially within the Indian Creek draw. Because of the spatial variance of water availability here, this area is described as a combination short and mixed-grass prairie. Long-term temperatures and precipitation in this region of South Dakota range from –4 °C and approximately 330 mm in winter to 32 °C and approximately 50 mm during the summer.

Despite the scarcity of water, there are at least 47 grass species. Nearly all of these are perennial. The most common native grass species is Western Wheat (*Agropyron smithii*). Less dominant native grass species include Green Needlegrass (*Stipa viridula*), and Buffalograss (*Buchloe dactyloides*). Blue Gramma (*Bouteloua gracilis*) is also a native grass species, however it is less dominant. Of the grass species found here, about 20% are non-native. These include Downy Brome, or Cheatgrass (*Bromus tectorum*), which is probably the most common on the Great Plains. Kentucky Bluegrass (*Poa pratensis*) and Leafy Spurge (*Euphorbia esula L.*) are non-native, invasive species also present in the area. Vegetation is generally scattered and plant cover and litter are irregular here. Other regularly occurring vegetation include yucca (*Yucca glauca*), various cacti species (*Opuntia spp.*) and an array of dryland sedges (*Caves spp.*) (Gartner and Sieg, 1996; O'Brien, 2005; Nielsen, 1996; BGNG (USFS), 2005; USFS, 1995) The most predominant tree species in this area is the Cottonwood (*Populus deltoids*), which dominates the Cheyenne River floodplain. Areas with large amounts of vegetation usually occur in small draws and valleys fed by natural springs, near livestock watering areas, if these are not over-utilized, and along the Cheyenne River and its tributaries.

Ranching and farming are extensive and make up the principal uses for land in the study area (Nielsen, 1996). Most of the land in this study is or has been grazed by cattle since settlement. Cattle ranching has been a dominant way of life in the region since the United States Government established the Homestead Act in 1862 and bison ranching is only a recent phenomenon. The small bison ranching operation I chose to include in this study is run without supplementary feeding processes and utilizes the grasses already on the land without extra plantings. This particular ranch runs approximately 350 bison. Bison have been grazing this land for close to four years. Both bison and cattle graze the surrounding public lands based on grazing permits obtained from the United States Forest Service for grazing purposes. Summer grazing takes place between April 15 and October 15, while winter grazing takes place between October 15 and April 15. Because bison and cattle are not legally permitted to graze together, bison are run on the public land through the winter and the cattle are run here during the summer grazing season.

Because the focus of this study is to determine the effects of land use variability on soil dynamics, I chose four different land treatments for soil sampling and testing. Agricultural fields used in this study are planted with wheat or general hay species. Cattle fields were the most abundant sites located for this study, because the land in this area is used predominantly as rangeland for the beef industry. Bison-grazed sites have only been grazed by the species for four years. There is no other land within this area that has been grazed naturally by bison within the last 150 years, despite the fact that they are native to nearly all of the NAGP. Cattle graze the land surrounding the bison fields for most of the year. Moreover, ungrazed native prairie is nearly nonexistent in the area. The native prairie that was located, was done so using historical records. However even in these areas, there were still signs that this land was being used as cattle range and in one site, pasture for horses (for descriptions of sites sampled, see Tables A2 through A5, Appendix 1).

The geologic history of soil parent material originates from the Cretaceous and Tertiary (Figure 4a, b). Illuvial deposits along the Cheyenne River floodplain are from the Holocene. Topographically, the area is a combination of the Pierre Hills and the Tertiary Tablelands. The Pierre Hills, west of the Missouri River, are rolling hills with parent material that consist of the Fox Hills Formation and the Pierre Shale formations. Soils here are formed from clayey and silty uplands (Gartner and Sieg, 1996). To the south, the Tertiary Tablelands are comprised of the Brule and Chadron formations and includes areas of badland, level and loamy terraces and gently sloping alluvial deposits (Nielsen, 1996). This area varies in geomorphology and topography from deeply entrenched drainage-ways and steeply sloping hills and buttes to nearly level tabletops and floodplains. Underlying material is comprised of sand- and siltstones and shale. Soils are therefore variably loamy, sandy and clayey in texture. In the area of this research, the soils are a combination of mollisols, entisols, aridisols and vertisols (University of Idaho, 2005; Nielsen, 1996).

In terms of texture and physical composition, the soils sampled for this research, comprise at least five soil associations (Figure 5). These associations are further broken down into no less than 12 soils series. Agricultural fields sampled, consist of Satanta soils. In this area of the NAGP, this is the primary soil used for cultivated croplands (Nielsen, 1996; USDA-NRCS, 2005). Samsil and Nunn loams represent the soils found along the Cheyenne River Floodplain. Samsil, Pierre and Kyle clays occur most frequently at cattle and bison sites sampled. Native prairie sites display the most variable soils. Badland soils occur at native sites 2 and 3 (for a comprehensive description of site-specific soil characteristics, see Table A1, Appendix 1 and for soil association and series descriptions see Appendix 2).

As opposed to tallgrass prairie, where SOM is very high and soils are close to black in color, the short and mixed-grass plant regime in the area does not produce as much SOM and displays a shallower root system (Figure 6). These are soils with dark-brown to brown organic layers 20 - 25 cm in thickness and a SOM content measured at about 5% (USDA-NRCS, 2005). Because of the aridity of this region, $CaCO_3$ precipitation is common. Although signs of carbonate accumulation are visible in the area (Figure 7), this usually occurs in soil layers lower than 15 cm (Hunt, 1972), which is not shallow enough to pose a problem for this study.

Methods:

Field Sampling

Field sampling for this study took place within the same Cheyenne River watershed so as to decrease the variability in soil and land use type characteristics. All sampling sites were chosen randomly and are distributed on both sides of the Cheyenne River, at varying elevations and within varying soil series (Figure 8).

No known prairie restoration projects have taken place in this particular area of South Dakota. Therefore, I used information about the locations of deeded and homesteaded land obtained from the Pennington County Courthouse in Rapid City in order to determine where land was affected the least by grazing. Based on government records and land-sale documentation, I looked for land that was settled for a short time or never purchased from the government, or had not been utilized as primary grazing pasture for cattle. From this information, I was able to determine where native prairie remnants may still exist. Where native prairie was not easily distinguishable, I sampled at higher elevations in order to insure the inaccessibility of roaming cattle or bison.

Soil sampling was done using an Oakfield Auger (Oakfield Apparatus Co., Oakfield, WI) with a 2 cm diameter. After clearing away visible plant detritus, each sample site was cored to two depths: the upper soil was cored from 0-5 cm and lower soil core samples were taken from 5-15 cm below the soil surface (Figure 9). From a total of 31 sampled fields, five are used for agricultural purposes, nine are grazed by beef cattle, nine are grazed by American bison, and eight have been identified as native prairie remnants. From all four land us types, I randomly chose three sample locations within each field. From these three locations I radiated out about one meter in three different directions and sampled from these sites again (Figure 9). In order to avoid pseudo-replication, I increased the number of treatment sites and remained consistent in the number of samples I took from each site. On agricultural sites 3, 4 and 5, cattle and bison sites 7, 8 and 9 and all native prairie sites, accessibility constraints and inclement weather allowed for the selection of only two initial sample soil cores sites, from which I again radiated out one meter and sampled three more times, for a total of eight samples. At each coring site, all 0-5 cm samples and all 5-15 cm samples were combined in a plastic bag to create composite samples defined by depth increment. Therefore, I had a total of either two or three composite samples at each depth increment for each site. Ultimately, I took a total of 152 samples for carbon and nitrogen analyses during the fieldwork portion of this study. Using a Garmin GPS 72 Personal Navigator (Garmin Ltd., 2002, Olathe, Kansas), I was able to locate the exact location of my initial testing sites to within a few meters.

In order to calculate the total carbon and nitrogen in a unit of soil per unit area, bulk density measurements are required. Therefore, I also took three sub-samples from each of the fields where I took samples for carbon and nitrogen analysis. Strong winds and inclement weather called for sub-sampling of soils for bulk density so that accuracy was not compromised. Although the original soil sample volumes could not be calculated, the use of GPS information from original sampling sites helped to decrease the variability and inaccuracy.

Lab Analysis

To prepare the soil for analyses, each sample was oven dried in a paper bag at a temperature no lower than 50 °C for at least 24 hours. After hand removal of visible plant materials (i.e. roots, leaves and stems), the soil was passed through a 2 mm sieve. Rocks and other non-soil materials were removed. Using a Ball Mill (Spex Certiprep, Metuchan, NJ) each sample was ground for eight minutes. To quantify the carbon and nitrogen content in each sample, I packed 50 mg of each sample into tin cups to be run in an Element Analyzer (Costech Inc., Valencia, CA). Following analysis, the various land use types were then compared according to carbon and nitrogen content.

Bulk Density sub-samples were also dried in an oven at 50 °C for no less than 24 hours. Next, these samples were weighed with a Mettler AJ 100L scale (Mettler

Instrument Corp., Hightstown, NJ). Rocks and other non-soil matter were removed using a 2 mm sieve and placed in a 25 mL graduated cylinder. The cylinder was then filled with water to 5 mL in order to determine the volumetric displacement this matter may have caused within the soil samples. After the volume of displacing material was subtracted from the total volume of the soil, bulk density calculations were done using the following equation:

$$\text{Bulk Density} = \text{weight of soil (g) / volume of soil fraction smaller than 2 mm}$$

The bulk density measurements were then used to convert the percent carbon and percent nitrogen measurements obtained from the Costech Element Analyzer to grams of carbon and nitrogen per cm^2 for each field. To calculate the total grams of carbon and nitrogen / area of soil, I used the following equation:

$$\text{Total C or N (g/m}^2\text{)} = \text{concentration C or N (g C or N/g soil) x bulk density (g/cm}^3\text{) x core depth (cm)}$$

This was then converted from units of g C or N/cm^2 to g C or N/m^2.

Statistical Analyses:

Following lab analysis and calculations, a statistical analysis of variance (ANOVA) was carried out in order to determine if site means were significantly different. F and p values obtained from this analysis are reported.

Results:

Calculations from an ANOVA do not reveal any statistical significance for this data. Total carbon values for all samples at 0-5 cm depth ($F = 0.88$, $p = 0.46$) and 0-15 cm depth ($F = 0.83$, $p = 0.49$) did not vary significantly between land treatments or within different sampling sites. Total nitrogen values at the 0-5 cm depth increment ($F = 1.20$, $p = 0.33$) and at the 5-15 cm depth increment ($F = 0.47$, $p = 0.71$) also showed no signs of statistical significance for both intra- and inter-site classifications.

Carbon and nitrogen values in all agricultural fields appear to be the lowest values measured on average compared with the rest of the land use types sampled and (Table 1 and Figure 10). These fields contain higher levels of nitrogen versus carbon as well (Figure 11). The values measured for soil carbon and nitrogen content in all cattle-grazed fields were on average the highest values measured in this study. Although bison-grazed field values are less than those reported for cattle-grazed fields, they are not significantly lower and they follow the same relative pattern. Measurements for the prairie remnants are lower than cattle or bison-grazed sites. These soils seem to be the most variable as well. The value for native prairie soil nitrogen at 5-15 cm falls lower than that for agricultural fields (Table 1). All total soil carbon and nitrogen content measurements from all fields were consistently lower in surface samples compared with those taken at the 5-15 cm depth increment. (Table 1, Figure 10 and Figure 11). Furthermore, C:N ratios are consistent in remaining close to the expected 10:1 ratio for each depth and at each sampling location (Gill et al, 1999; McCulley et al, 2005).

The average bulk densities of the agricultural sites at both depth increments are the highest. Bulk densities measured for cattle-grazed fields are nearly equal for each depth. Bison-grazed fields demonstrate the lowest values, although they do not differ significantly from the cattle site measurements. Finally, the native prairie field bulk densities coincide with the C:N ratio values in that they prove to be the most variable (Table 1 and Figure 12) as were the fields these sub-samples were taken from. Bulk density measurements for all land use types sampled decrease by depth. However, the standard error reported for this data shows no statistical significance in these differences.

Discussion:

The single most confounding variable for this study involves the fact that this study accounts for only belowground soil carbon and nitrogen pools and the spatial variability of the land in relation to both plant cover and grazing is not thoroughly accounted for. Due to the variations in topography and water availability throughout the landscape, vegetation is not consistent with respect to both coverage and species. Furthermore, the lack of ideally replicated field sites is a major barrier to this type of study (Henderson et al, 2004). No two fields in the area are exactly the same, and it is unreasonable to believe that this would ever occur. Increasing sampling replications may aid in producing more statistically significant results if soils and landscapes within fields were all exactly the same. However, based on the data from this study, a good argument against increasing sample numbers and replications has to do not only with the heterogeneous nature of soils sampled, but also with the low carbon and nitrogen values measured over the entire area. It may be that carbon and nitrogen values in this area are naturally low and multiple sample replications may not reveal statistically significant results. However there is a limited amount of data available for historic soil carbon and nitrogen levels in this region so it is difficult to draw any sort of comprehensive conclusion.

It is important to account for the factors of soil formation like parent material, topography, climate, time and vegetation, in order to develop a clear understanding of what is happening with the soils tested for this particular study (Jenny, 1941).

Topography for example, has played a very influential role in determining soil dynamics in this area. First, at the native prairie sites in particular, it is probable that we see such low carbon and nitrogen values (Table 1) partly because most of these samples were taken at varying elevations and on steep slopes. The existing topographic variability of chosen native prairie sites in particular, poses the question of whether these sites were initially comparable with each other, despite similar land use type classification. It is likely that typical downslope geomorphic processes have caused a decline in carbon and nitrogen values. In order to insure the exclusion of grazers, prairie remnants were sampled that lie in areas that could not be reached by cattle. Cattle and bison are known to travel very far for forage, but they often will not climb steep and precarious slopes due to weak footholds (O'Brien, 2005). Therefore, I chose remnants that had the most potential for remaining ungrazed. Also, prairie soils on average, had less clay content based on information from the USDA-NRCS (1996). This helps to explain why carbon and nitrogen values are lower since high clay content in soils causes greater accumulation of nutrients (Hunt, 1972; Singer and Munns, 1996).

Agricultural field samples were also taken at higher elevations and along a gradient. However, it is more likely that low values occur here because cultivation and tillage practices are known to decrease soil nutrients (Kohnke and Franzmeier, 1995; Stevens and Walker, 1970) This conclusion is backed by the fact that, while elevation for agricultural sites is high, higher elevations occur on level land on top of Phiney Flat (Figure 4), where runoff has less of an effect on the decline of soil nutrients, so that cultivation here clearly has more impact than geomorphology.

Geomorphic processes affect measurements of carbon and nitrogen because downslope movement of soils often results in nitrogen and organic accumulations within depressions and at the foot of slopes and in floodplain deposits (Hunt, 1972; Schimel et al, 1985; Schlesinger, 1997; Stevenson and Cole, 1999). This helps clarify the reasons for soil carbon and nitrogen measurements at cattle and bison sites. These, together have the highest carbon and nitrogen values because a number of these samples were taken from loamy soils along the Cheyenne River Floodplain and in areas that lie at the foot of slopes (see Table A1, A3 and A4, Appendix 1).

Like the native prairie land treatment, site-specific variability also accounts for differences in carbon and nitrogen values on bison sites. At bison 5, on top of Phiney Flat, and bison 6 located at the foot of the slope below Phiney Flat (Figure 4a), large prairie dog towns dominate the landscape. Prairie dogs (*Cynomys ludovicianus*) are known to aerate soil from within. Due to the vast stretch of tunnels and burrows they build, these animals aid in influencing soil nutrient cycling and increasing NPP (Rogers et al, 2001). However, the town at bison 5 has been poisoned and eliminated, while the town at bison 6 thrives, so a comprehensive comparison will not allow for a conclusion about the effects of prairie dogs on soil nutrient dynamics.

Time also confounds the results of this study because bison have only been grazing on this particular land for a little less than four years. Therefore, it is difficult to say whether or not they have had a strong positive or negative influence. In comparison to cattle fields, it seems that the presence of bison may have some influence because both carbon and nitrogen values are slightly higher in surface soils (Table 1). However, because results from ANOVA show no statistical significance, this is not a conclusive argument. Furthermore, because the land, which is now grazed by bison, was grazed by cattle before its conversion and without any lag time before bison reintroduction, we may not see a large difference between the two types of treatments because recovery of land (especially if it is overgrazed) takes much longer than four years (Burke et al, 1995; Reeder et al, 1998).

Grazing itself complicates soil nutrient studies like this, because when grazing is added to the land, the preference of plants ingested by grazers is not consistent. Grazing also leads to large spatial variability in nitrogen and carbon content in soils because of uneven waste distribution (Watson and Poland, 1999) and irregular grazing preferences. This is a situation, where an increased number of sampling replications may help in obtaining more representative results. Furthermore, this study did not account for grazing by other species like Mule deer (*Odocoileus hemionus*) and Pronghorn Antelope (*Antilocapra americana*) and smaller animals like prairie dogs (NPWR, 2005). It is also important to remember that the public lands along Indian Creek are grazed by cattle in summer or bison in winter, based on USFS grazing permits and also by other grazing wildlife. There is not a clear understanding of how land is affected by different species when it is used as rangeland year round without limitation. Also, in consideration of the time it is hypothesized that it takes for carbon and nitrogen to re-accumulate to their natural levels, four years may not be enough time to see any large effect by the reintroduction of native ungulates (Allen, 2005; Burke et al, 1995; Collins et al, 1998; O'Brien, 2005; Paustian et al, 1998; Reeder et al, 1998).

Vegetation plays an influential role in soil dynamics as well, because it has a direct influence on the quality of nutrient cycling within the soil. Available vegetation surveys for this area are limited, so information on the existence and extent of certain species is unattainable as of yet and much of the information used in this study comes from personal communication and observation. There is evidence of the presence of blue gramma after the reintroduction of bison as primary grazers in certain areas (BGNG (USFS), 2005; O'Brien, 2005). Because of its ability to leave higher concentrations of SOC residue within soil, blue gramma may indicate improvement in soil fertility (Henderson et al, 2004), but this cannot yet be proven as neither bison or blue gramma have lived in the region for a long enough time period.

A few social issues also have implications for the results of this study. Due to the location of this study, I was unable to sample more than five agricultural fields for safety and legal reasons. Also, locating definitive native prairie was not possible because of the way land is used mainly as rangeland for cattle and for various hay crops. Firstly, cattle ranchers have used land in this particular area for over 150 years and there are no available or easily identifiable native or restored prairie sites which have not been grazed at some point in time since settlement. Secondly, because of the difficulty in sampling agricultural fields and due to the limited access and lack of communication with farmers, it is impossible to know for sure what has been planted here in the past and whether or not farmers plant different crops from year to year or how often they allow their fields to lay fallow. Also, because of the predominant land use (range and croplands), naturally occurring fires are often suppressed. Therefore, grazing and agriculture are presently the greatest disturbances and it is difficult to ascertain whether the levels of carbon and nitrogen we see, even on the native prairie remnants, are truly naturally occurring because of disturbance, but more importantly, due to the fact that the only current restoration efforts are related to the reintroduction of bison as a native grazing species in this region. However no complete grazing exclusion has been implemented.

One of the main issues in determining the effects of each land treatment on soil nutrient dynamics is that soil characteristics were not clearly defined during field sampling and soil types have been determined only on the basis of information from a soil study carried out by the USDA-NRCS (1996). The soil maps for the Pennington and Custer County, South Dakota are conceptual rather than definitive because, as mentioned before, the factors of soil formation are subject to change caused by geomorphic and natural weathering processes. In effect, definitive soil boundaries can often be obscured and limitation to access of land for survey purposes decreases precision and accuracy of landscape soil series mapping and definition.

In light of all the confounding variables in this study, this information can still provide a general basis for further soil carbon and nitrogen fluctuation monitoring for this are of the NAGP. Conant and Paustian (2002), found in a similar study that the variability of soil carbon data, even without information about causation for such fluctuations (which are factors like soil type and geomorphology in my own study), could still be used to form an efficient grassland soil carbon monitoring system on a larger regional scale. More specifically, a study from similar semiarid grasslands in northeastern Colorado, by Gill, et al (1999), established that C:N ratios follow a general 10:1 pattern and that carbon and nitrogen values also increase as depth from the soil surface increases. This seems to be a recurring trend in a number of different studies accounting for SOC and total nitrogen in soil (Barrett and Burke, 2002; Frank and Dugas, 2001; McCulley et al, 2005). Furthermore, measured bulk densities from the same studies along a mixed to short grass gradient show values as large as 1.17 g/cm^3 and as small as 0.80 g/cm^3 (Gill et al, 1999; McCulley et al, 2005). Bulk density measurements for these studies also decrease in value as depth from the soil surface increases (0.88 g/cm^3 at 0-5 cm and 1.09 g/cm^3 at 5-10 cm, in Gill et al, 1999). Despite the lack of statistical significance found in this study, the results, to a certain extent, are consistent with those reported in other literature.

Conclusions:

Based on the large body of literature used in this study, it is clear that land use change can affect soil-nutrient dynamics. However, I cannot say for sure whether I have found any true degradation or improvement in the fitness of the soils within the Cheyenne River watershed, based on my own data and its lack of statistical significance. Generally, variability of study sites within the same land treatment for all treatments sampled, confounds this study. Simply grouping similar land treatments by inter-site characteristics does not effectively account for intra–site-specific differences. Furthermore, the lack of statistical significance makes the argument for the use of native grazers as a mechanism for the maintenance of the long-term health of a semi-arid, short and mixed-grass prairie inconclusive because a negative effect on the ecosystem due to grazing in general, cannot be determined. Finally, despite the growing body of literature that argues otherwise, it is impossible to tell for sure whether this area of NAGP can provide a sufficient and effective sink for carbon and nitrogen sequestration in lieu of global warming. A longer term study, incorporating a larger area and number of replications in land treatments and soil types could provide better information to support and better address these questions and provide a comprehensive conclusion. While this study did not produce statistically significant results, the correlation between my data and that included in other literature shows potential for further research.

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Glossary:

Aboveground Biomass - the amount of living matter above the soil surface

Aridisol - arid soils with signs of $CaCO_3$ accumulation

Belowground Biomass - the amount of living matter below the soil surface

Belowground Primary Production – the amount of energy produced by living matter below the soil surface

Brown Soil - alkaline rich soil with a thin brown surface layer, under which lies a layer rich in carbonate accumulation; develops under plants in semiarid climates

Bulk Density - a measure of soil compaction based on the weight of soil per unit volume

Cation Exchange Capacity - a value obtained during soil particle analysis, which reports the capacity of the soil to hold cation nutrients

Chernozem - tallgrass prairie soil characterized by a thick, dark, organic-rich layer; ,ore common in tallgrass prairies

Chestnut Soil - shortgrass prairie soil with a dark brown layer at the top; thinner than Chernozem; occurs in subhumid to semiarid climates

Denitrification - the release of ammonia gas (NH_3), and the leaching of NO^-_3 from soil

Entisol - diverse, young soils developed from unconsolidated parent material within steep and rocky landscapes

Mesic - of or pertaining to, a moderately moist habitat

Microbial Immobilization - the accumulation of nitrogen and other nutrients in soil microbes

Mollisol - grassland soils characterized by thick, dark surface horizon organic matter

Net Primary Production – a measure of the combination of above- and belowground energy produced by living matter

Organic Nitrogen - organic nitrogen (N), nitrates (NO^-_3) or ammonium (NH^+_4) added to the soil surface through human influence (fertilization), by animal waste and by the conversion of N_2 gas from the atmosphere

Sink - a soil with the capability to release nutrients from soil through natural processes and as a result of disturbance

Soil Aggregates - large masses of bound sand, silt and/or clay particles within the soil horizon

Soil Organic Matter - organic matter supplied to soils through root respiration, plant biomass and animal waste

Soil Organic Carbon - carbon stored in soils when there is a net balance between carbon inputs and outputs; produced through the decomposition of plant, animal and microbial residues

Source - a soil with the capability of sequestering nutrients after accumulation

Vertisol - soils, which are well mixed due to the crack and swell behavior of clays caused by changes in water availability

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Figure Captions:

Figure 1. The Carbon Cycle in a Terrestrial Grassland Ecosystem. The cycle begins when **(1)** CO_2 is taken up by plants for photosynthesis. Animal waste and dead plant and animal dead biomass **(2)** provide a constant source of organic carbon to the soil O-Horizon. This organic carbon continues to accumulate in both the O- and A- Horizons **(3)**. Microbial decomposition **(4)** breaks down litter and dead biomass, while below ground respiration in plant roots takes place **(5)**. Plants release O_2 **(6)** into the atmosphere as a product of photosynthesis and CO_2 **(7)** as a product of respiration. The cycle continues and plants continue to take up CO_2 **(8)**, an atmospheric input from fossil fuel combustion (Averett et al, 2004; Hungate et al, 1997).

Figure 2. The Nitrogen Cycle in a Terrestrial Grassland Ecosystem. N_2, Organic N and ammonium inputs from animal wastes and human fertilization **(1)** begin the cycle. Microbial decomposition **(2)** causes ammonification. Ammonium is taken up by biological plant processes **(3)**. Through nitrification, Ammonium compounds are oxidized into nitrates **(4)**. At the same time, both nitrates and ammonium are lost to ground water **(5)**. Microbial activity in soil horizons causes denitrification **(6,7)**. After release from the soil, N_2O **(8)** is converted back into N_2 and the cycle continues (Barrett et al, 2002; Singer and Munns, 1996; Vitousek et al, 1997; Watson and Poland, 1999).

Figure 3. **Soil Horizons.** Soil horizons accumulate over of hundreds of years and change considerably along a gradient from tallgrass to shortgrass prairies moving westward across the NAGP. The O-Horizon and A-Horizons (topsoil) are made up predominantly of plant biomass and organic matter ranging from 75 cm deep and 20% organic content to only 20 cm deep and less than 5% organic content. The majority of soil nutrient cycling takes place in the A-Horizon. Loss of silicate clay, iron, aluminum and humus takes place within the E-Horizon, leaving sand and silt particles. Illuvial concentrations are found within the B-Horizon, also known as subsoil. This is light in color and very low in organic matter concentration. Leached materials continue to accumulate here, thus increasing soil density until water can no longer percolate through soil at the water penetration limit. The C-Horizon makes up the substratum and overlies the R-Horizon where bedrock and soil parent material can be found (Hunt, 1972; Singer and Munns, 1996; University of Idaho, 2005).

Figure 4a. Region of Study and Underlying Geologic Topography. The study location for this research lies within the Cheyenne River watershed. The river valley runs diagonally from the southwest to northeast and is surrounded on all sides by deeply entrenched drainageways, Phiney Flat and Hart Table.

Figure 4b. Geologic Explanation Underlying geology of the area is defined by color. It is important to note that Holocene deposits along the Cheyenne River Floodplain are not included on this map (Gartner and Sieg, 1996; King and Raymond, 1971 [Geol. Map]).

Figure 4c. Map Legend. The legend for this map and the map in Figure 5 show region of study within South Dakota, scale, and defines sampling sites by color.

Figure 5. Soil Associations and Series Sampled. (A) The study area is a combination of all of soil associations pictured. Only four of these associations were sampled for this study. Along the flood plain of the Cheyenne River valley, soils are sandy and silty, well drained, fluvial deposits. **(B)** Land along the upper tables, like Phiney Flat and Hart Table, is used mainly for farming. These soils are usually loamy and clayey. In the most remote areas, especially along Indian Creek, where native prairie samples were taken, the soils are clayey and loamy and include badland mudstones. All soil series within each association are labeled with their symbols. See Figure 4b. for the legend to this map. For a comprehensive description of sampling site characteristics see Apendix1 For a description of soil Associations and Series, see Appendix 2 (Nielsen, 1996; USDA-NRCS, 1996).

Figure 6. The Tallgrass to Shortgrass Prairie Ecosystem Gradient. From East to West within the NAGP, climate becomes more arid and tallgrass prairie gives way to shortgrass prairie where above and below ground biomass decreases. At about the 100th meridian, precipitation decreases from 50-65 cm to 40 cm or less. Chernozem soils found in tall grass prairies are more organic-rich than Brown soils, which are more typical in semi-arid and desert ecosystems. Because of limited water availability along the same gradient, and the westward increase in aridity, the NAGP show increased signs of weathering, salt leaching and $CaCO_3$ precipitation in more western regions (Hunt, 1972; Ritter, 1978; Singer and Munns, 1996).

Figure 7. Evidence for $CaCO_3$ Presence and Salt Leaching. (A) This ammonite was found at native prairie site 3. **(B)** Salt leaching was also evident at native prairie site 8. The semiarid nature of this region causes $CaCO_3$ to precipitate at shallow depths within the B-Horizon, however sampling for this study was not deep enough to be significantly affected.

Figure 8. The Influence of Spatial Variability on Sampling. In order to insure random sampling soil samples were taken at various elevations throughout the Cheyenne River valley. Other variables that influenced results include soil type, which are generally influenced by geomorphic processes, where due to erosion and downslope movement of soils and nutrients, the largest concentrations of carbon and nitrogen are normally found at the foot of slopes and along flood plains, as well as on moderately flat tabletops. Based on soil maps from the USDA-NRCS (1996) agricultural fields sampled (1) tend to have a higher clay content, native prairie fields (2) have sandier soils and cattle and bison fields (3,4) occurred mostly within the Cheyenne River floodplain on silty soils. Geomorphology plays a major roll in the extent of mixed soils at the foot of slopes. (Hunt, 1972; Jenny, 1941; Singer and Munns, 1996; USDA-NRCS, 1996) This is a generalized diagram of sampling variations, which does not consider the implications of underlying geology.

Figure 9. Diagram of Sampling Methods. A simplified diagram of soil sampling shows how initial coring sites were selected randomly and then coring sites were further chosen randomly. At each coring site, two cores were taken: one from 0-5 cm from the

surface and the second from 5-15 cm from the surface. Each set of two cores was at least 1 m away from the primary site chosen site. In total, 31 fields from four different land use types were cored in this manner.

Table 1. Data obtained after lab analysis shows total carbon, nitrogen and bulk density values for all sites sampled**.**

Figure 10. Total Soil Carbon. Total carbon values for all soil samples tested did not elicit statistically significant results, although minor differences can be inferred from the data.

Figure 11. Total Soil Nitrogen. Total nitrogen values for all soil samples after analysis are clearly relative to values calculated for total soil carbon, and generally follow the 10:1 pattern measured in C:N ratios.

Figure 12. Soil Bulk Density. Bulk density results show that agricultural soils are clearly the most compacted most likely due to heavy disturbance and tillage. Native prairie soil data displays the most variable results, because this land use has the most intra-site differences. Bison and Cattle results are very similar, bringing into question whether their impact on land is truly different.

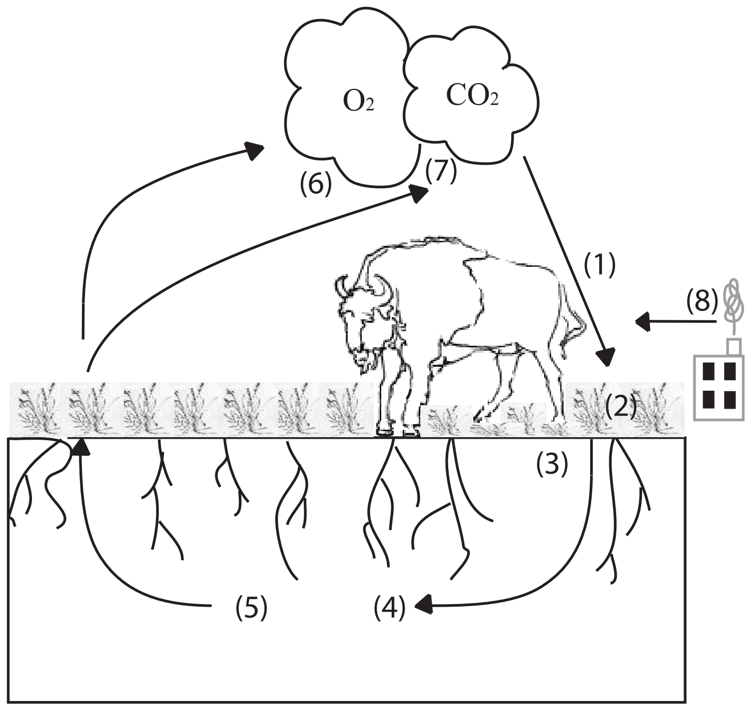


Figure 1.

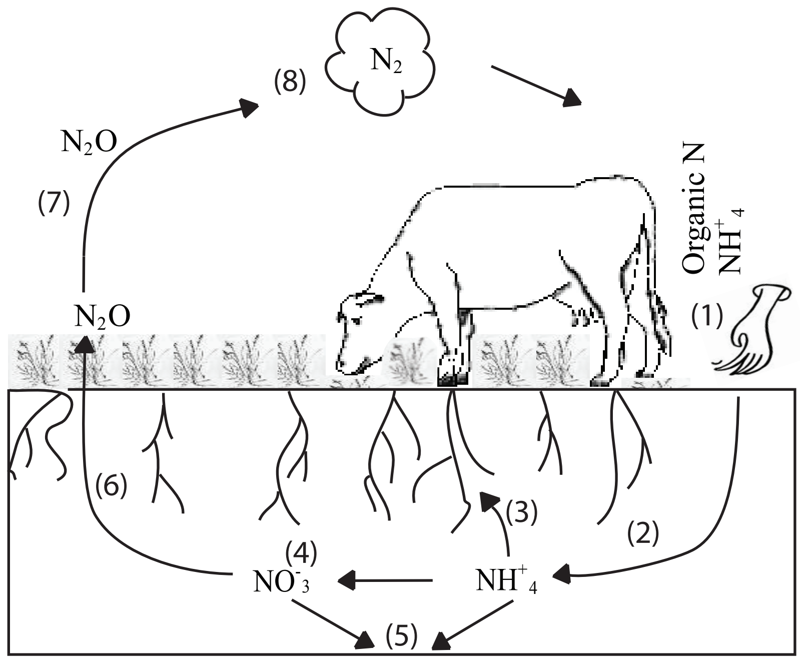


Figure 2.

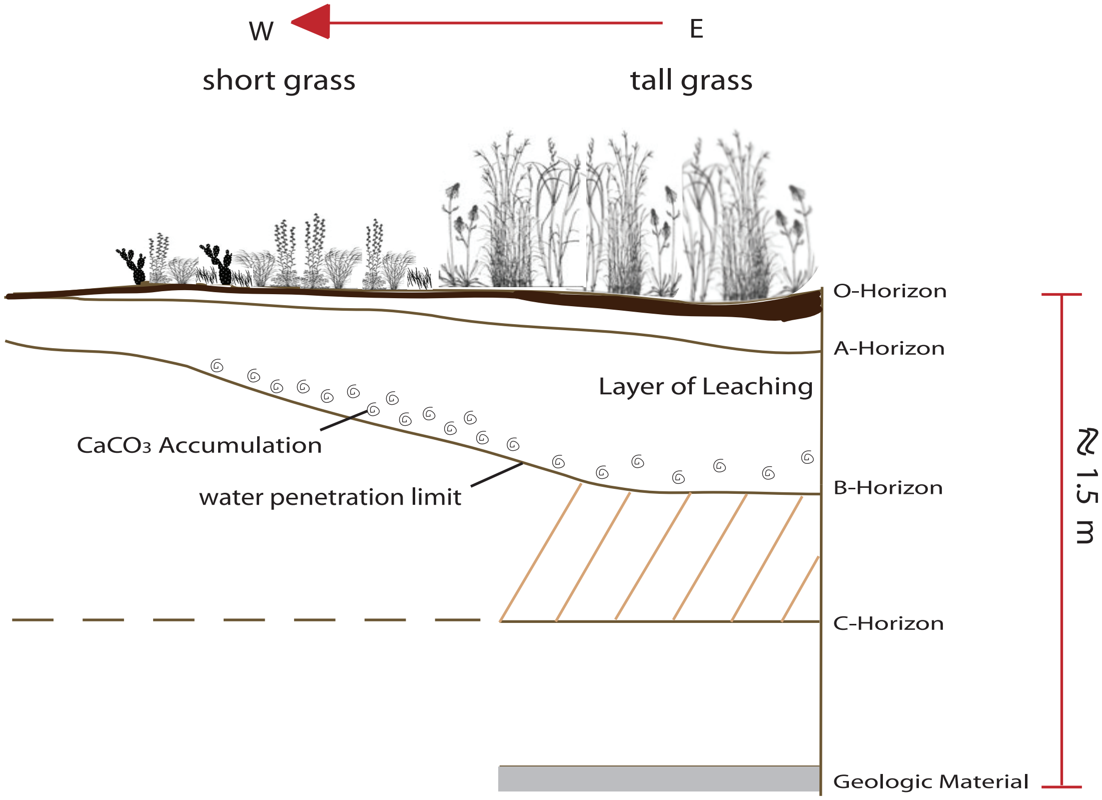
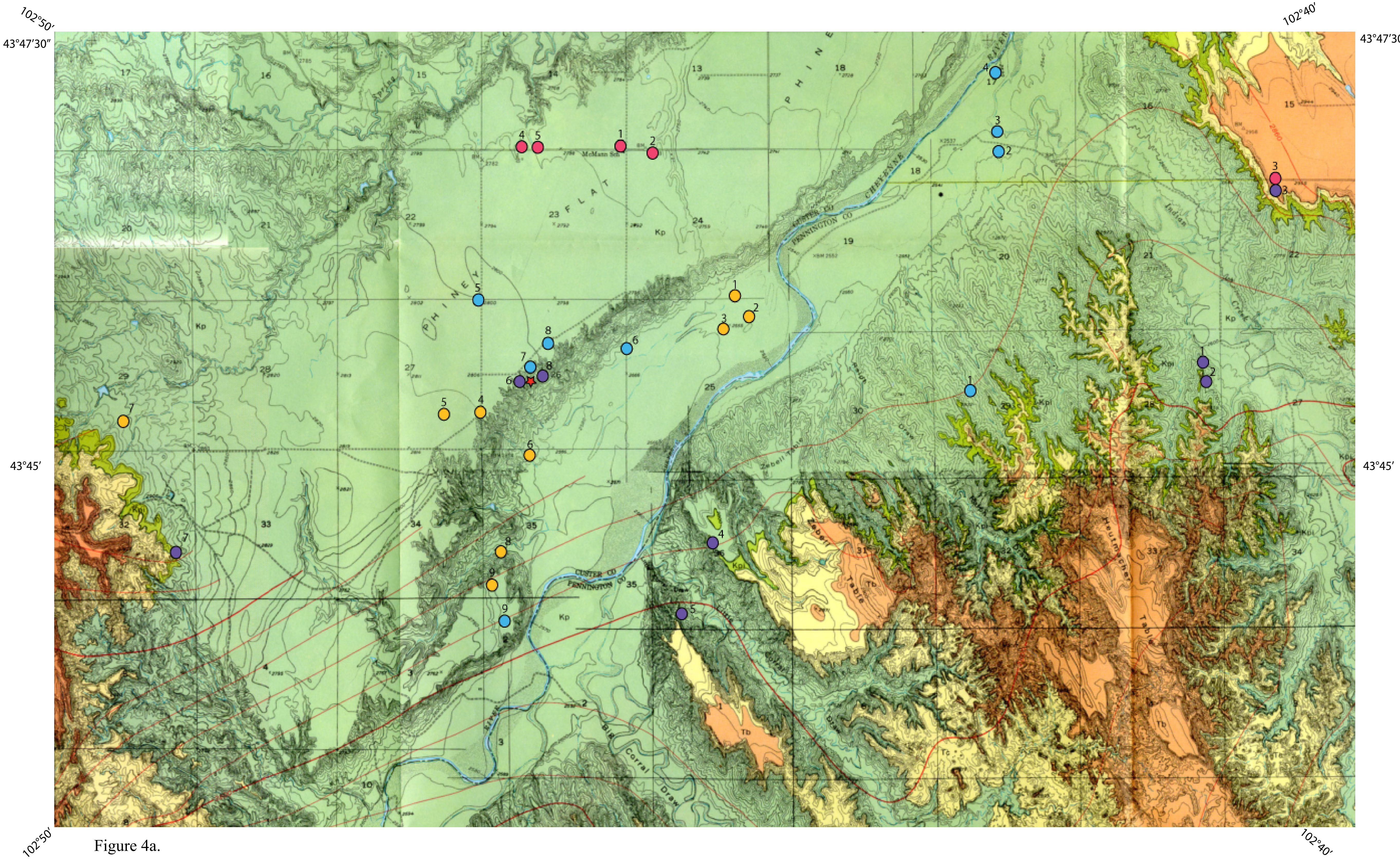

W
E
short grass
tall grass
O-Horizon
A-Horizon
Layer of Leaching
CaCO3 Accumulation
water penetration limit
B-Horizon
C-Horizon
Geologic Material
≈ 1.5 m

Figure 3.



102°50′
43°47′30″
102°40′
43°47′30″
43°45′
43°45′
102°50′
102°40′
McMann Sch
PHINEY FLAT
CUSTER CO
PENNINGTON CO
CHEYENNE
Kp
Kpl
Tb
Zebell Table
Big Corral Draw

Figure 4a.

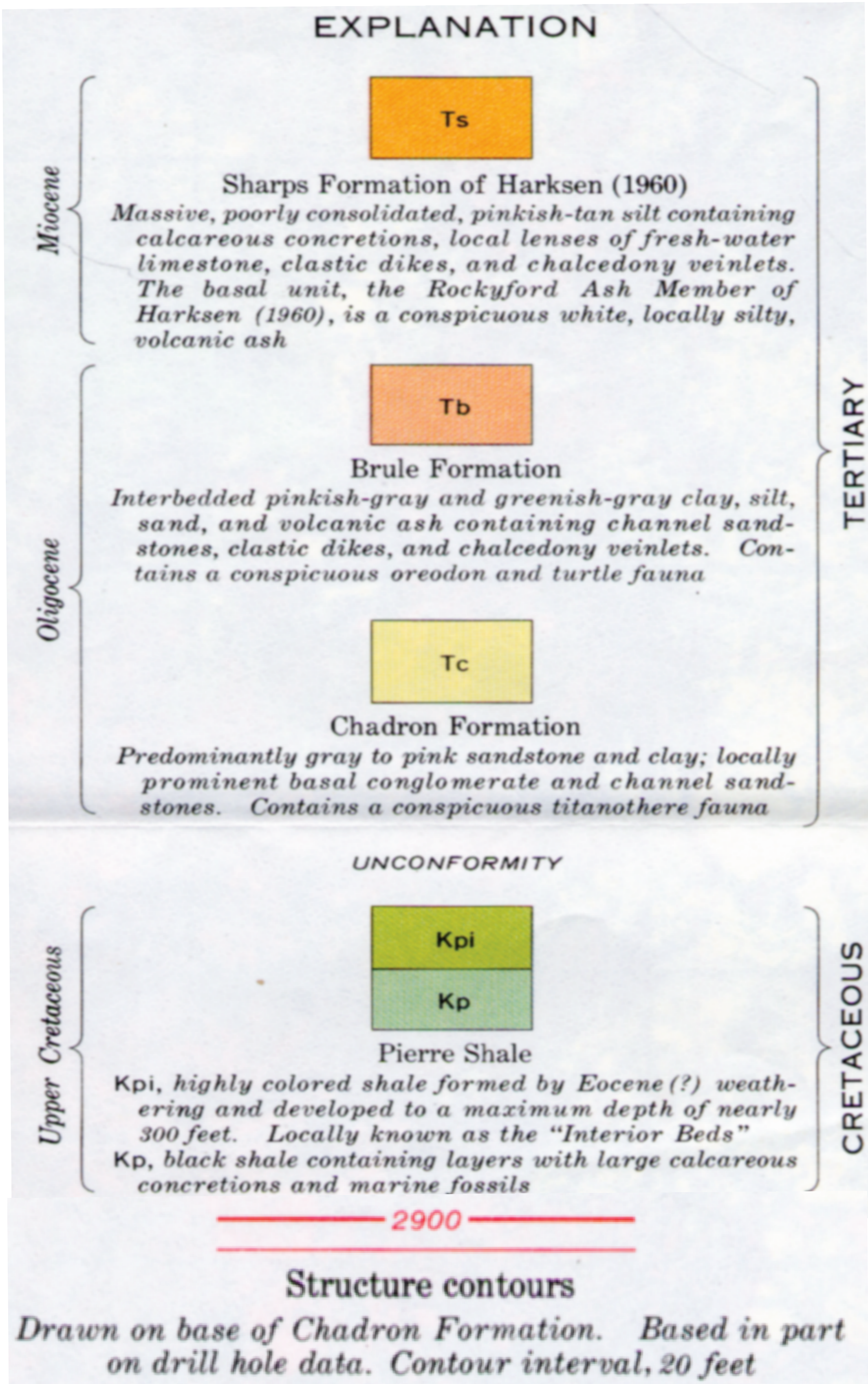

EXPLANATION
Ts
Sharps Formation of Harksen (1960)
Massive, poorly consolidated, pinkish-tan silt containing calcareous concretions, local lenses of fresh-water limestone, clastic dikes, and chalcedony veinlets. The basal unit, the Rockyford Ash Member of Harksen (1960), is a conspicuous white, locally silty, volcanic ash
Miocene
Tb
Brule Formation
Interbedded pinkish-gray and greenish-gray clay, silt, sand, and volcanic ash containing channel sandstones, clastic dikes, and chalcedony veinlets. Contains a conspicuous oreodon and turtle fauna
Tc
Chadron Formation
Predominantly gray to pink sandstone and clay; locally prominent basal conglomerate and channel sandstones. Contains a conspicuous titanothere fauna
Oligocene
TERTIARY
UNCONFORMITY
Kpi
Kp
Pierre Shale
Kpi, highly colored shale formed by Eocene (?) weathering and developed to a maximum depth of nearly 300 feet. Locally known as the "Interior Beds"
Kp, black shale containing layers with large calcareous concretions and marine fossils
Upper Cretaceous
CRETACEOUS
2900
Structure contours
Drawn on base of Chadron Formation. Based in part on drill hole data. Contour interval, 20 feet

Figure 4b.

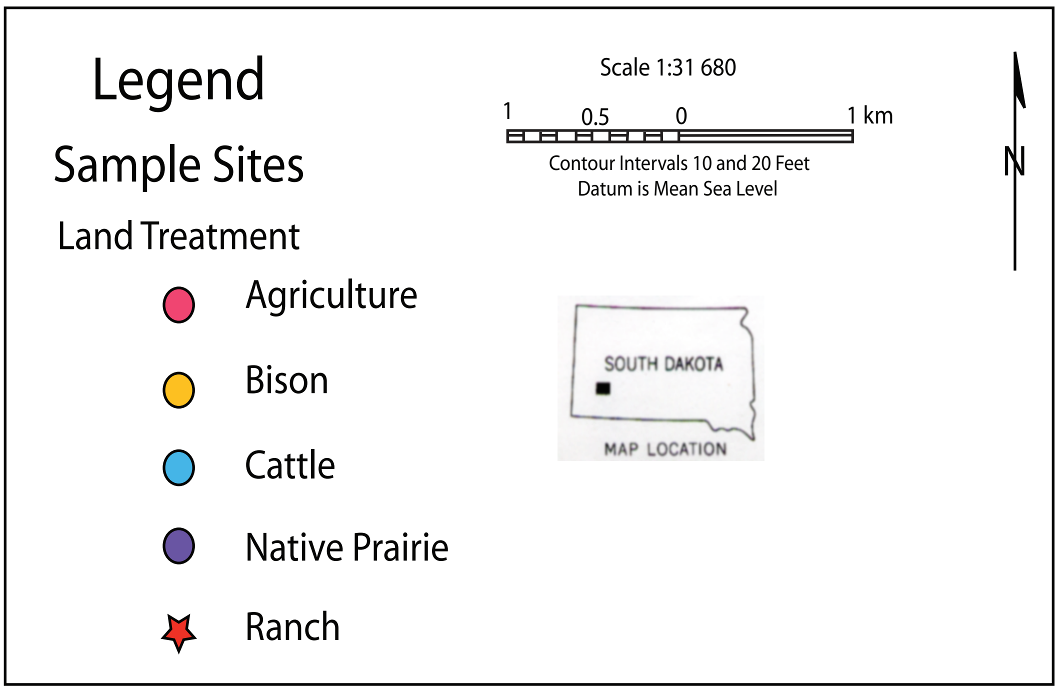

Legend
Sample Sites
Land Treatment
Agriculture
Bison
Cattle
Native Prairie
Ranch
Scale 1:31 680
1
0.5
0
1 km
Contour Intervals 10 and 20 Feet
Datum is Mean Sea Level
SOUTH DAKOTA
MAP LOCATION
N

Figure 4c.

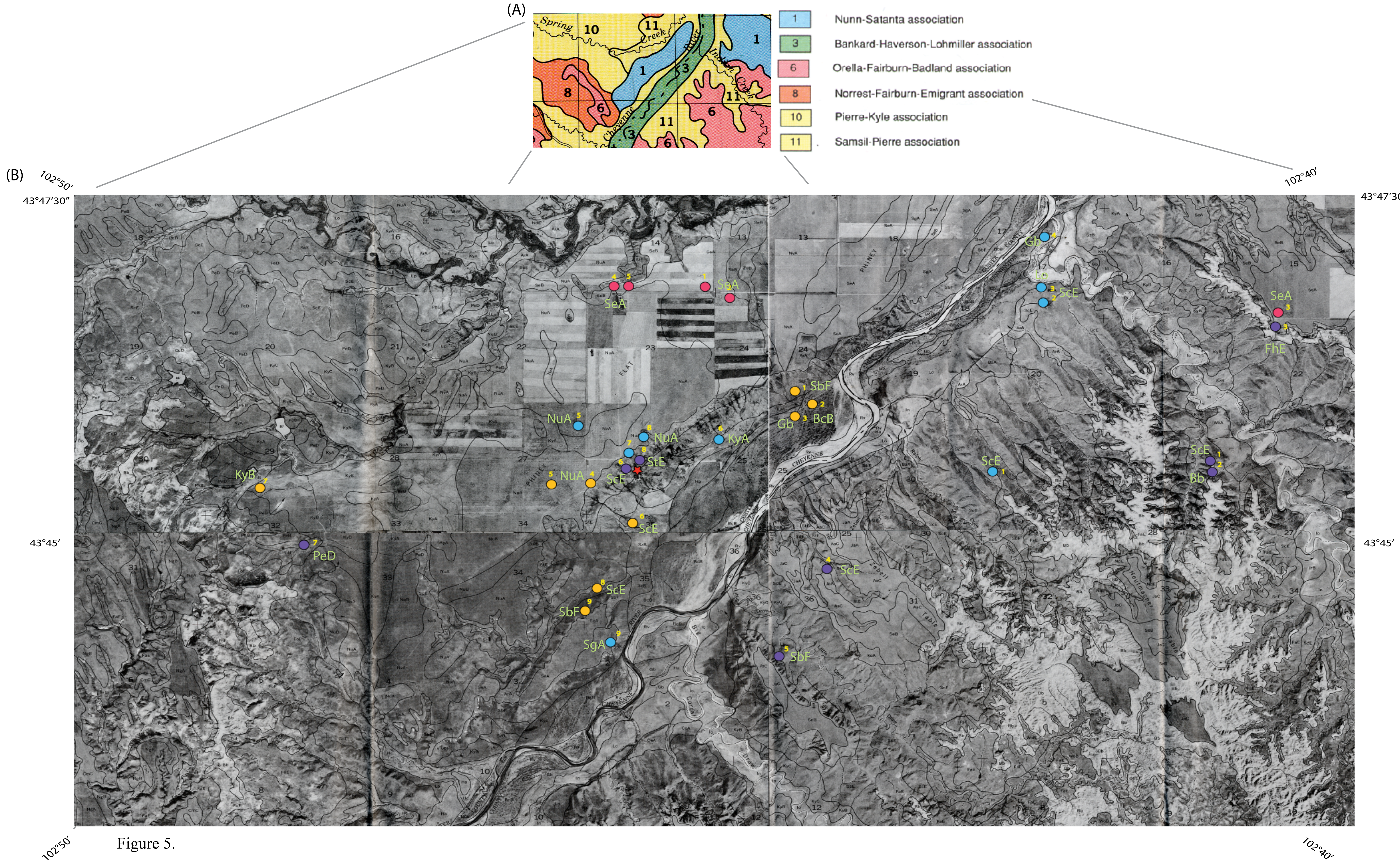

(A)
Nunn-Satanta association
Bankard-Haverson-Lohmiller association
Orella-Fairburn-Badland association
Norrest-Fairburn-Emigrant association
Pierre-Kyle association
Samsil-Pierre association
(B)
102°50′
43°47′30″
102°40′
43°47′30″
43°45′
43°45′
102°50′
102°40′

Figure 5.

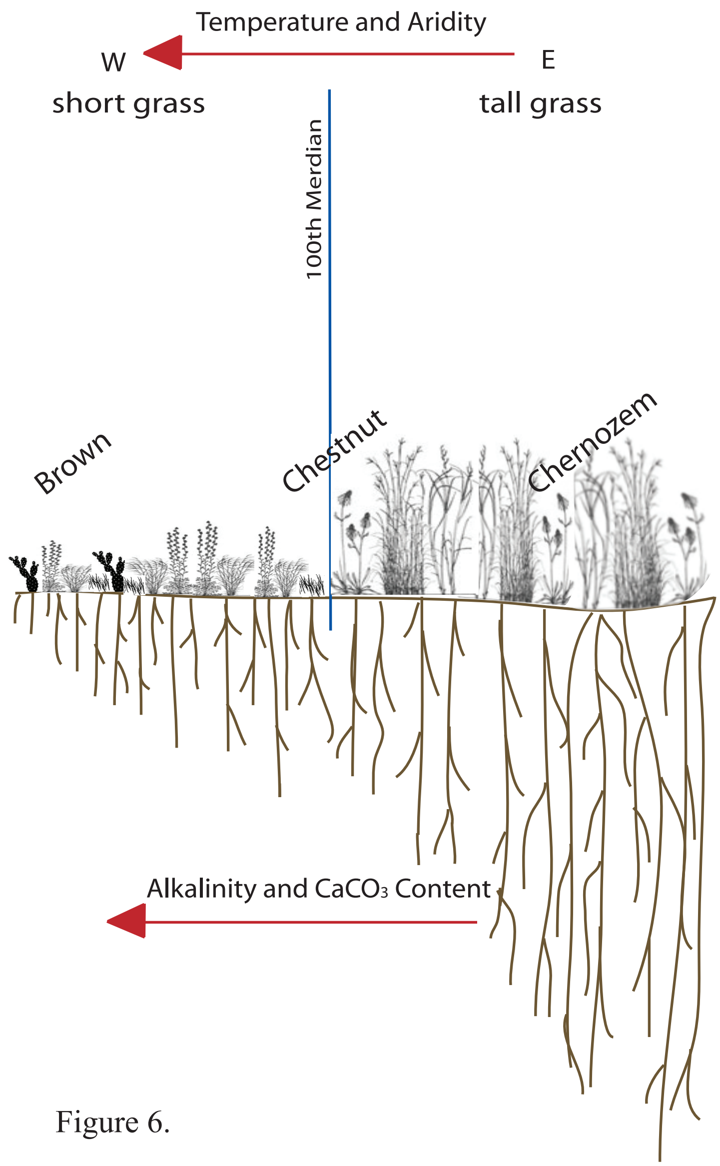
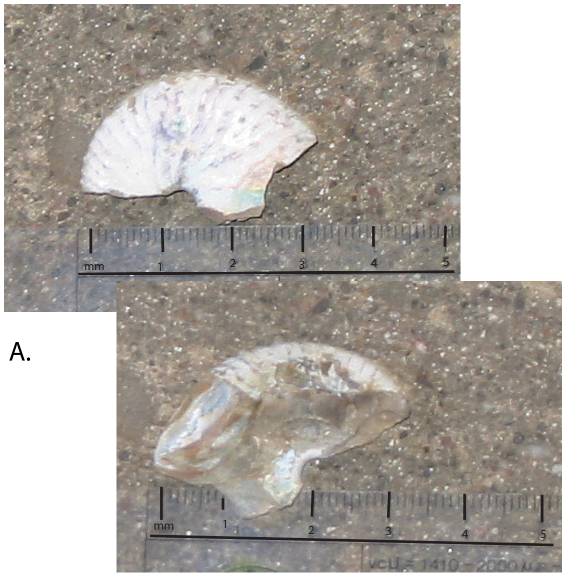

Temperature and Aridity
W
E
short grass
tall grass
100th Merdian
Brown
Chestnut
Chernozem
Alkalinity and $CaCO_3$ Content

Figure 6.

A.



B.

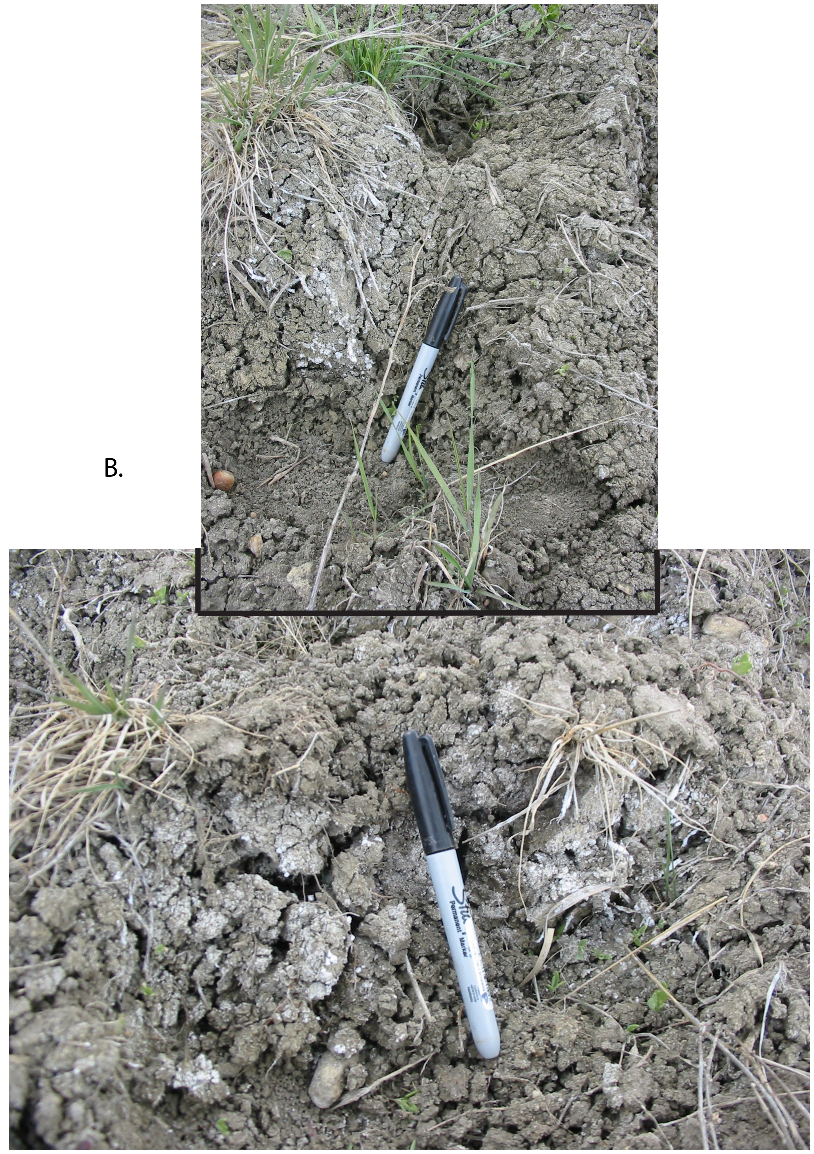


Figure 7.

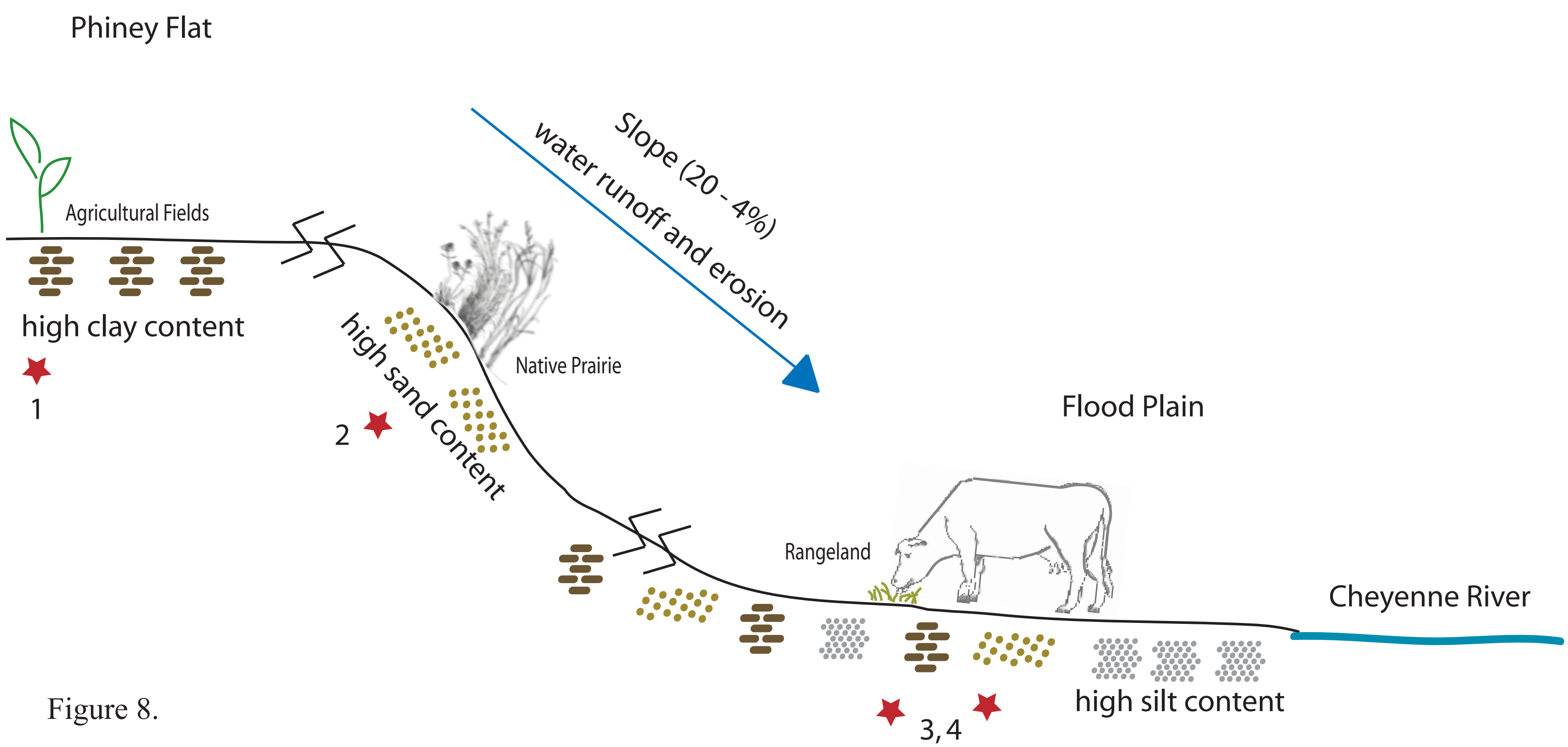

Phiney Flat
Agricultural Fields
high clay content
1
high sand content
2
Native Prairie
Slope (20 - 4%)
water runoff and erosion
Flood Plain
Rangeland
Cheyenne River
3, 4
high silt content

Figure 8.

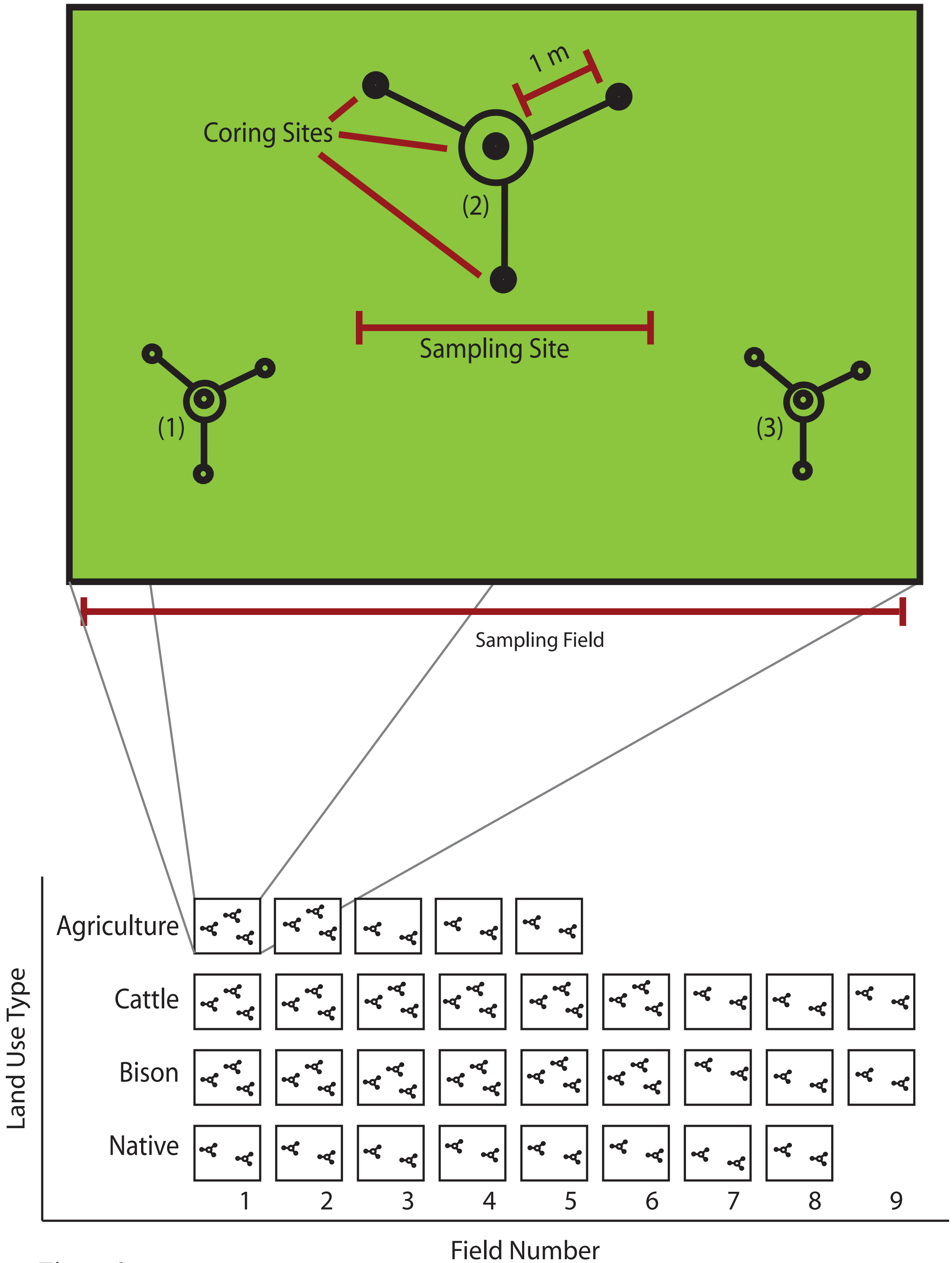

1 m
Coring Sites
(2)
Sampling Site
(1)
(3)
Sampling Field
Agriculture
Cattle
Bison
Native
Land Use Type
1
2
3
4
5
6
7
8
9
Field Number

Figure 9.

Table 1. **Total Soil Nutrients and Bulk Density Measured**

Treatment/Depth(cm)	Average Soil C (g soil/m^2)	Average Soil N (g soil/m^2)	Bulk Density (g soil/cm^3)
Agricultural 0-5	623.93	60.41	1.02
Agricultural 5-15	1570.18	153.37	0.96
Cattle 0-5	872.45	72.82	0.88
Cattle 5-15	2177.51	185.70	0.82
Bison 0-5	879.06	80.50	0.87
Bison 5-15	1880.09	169.03	0.73
Native 0-5	728.80	64.12	0.99
Native 5-15	1621.79	149.91	0.78

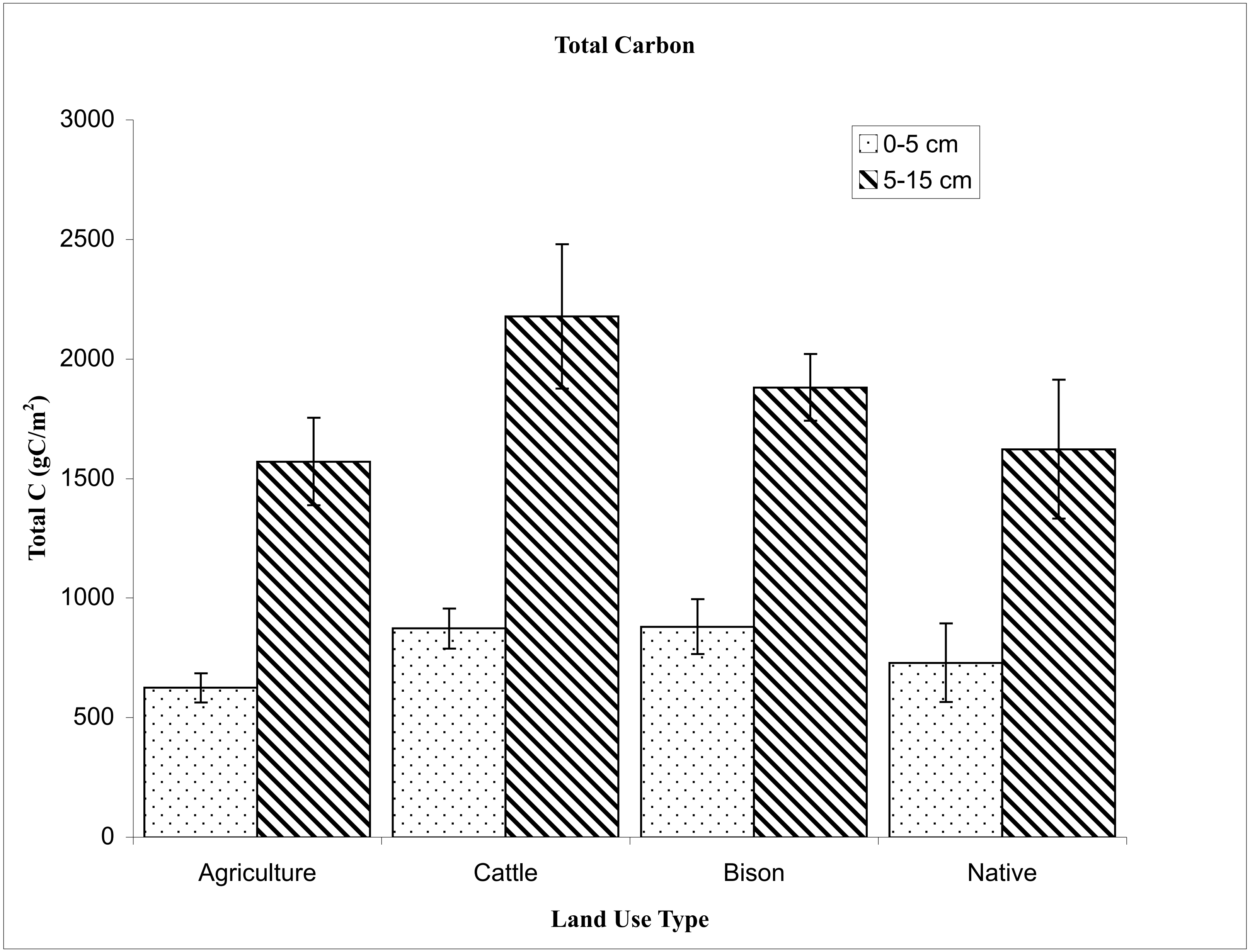

Total Carbon
3000
2500
2000
1500
1000
500
0
Total C (gC/m²)
0-5 cm
5-15 cm
Agriculture
Cattle
Bison
Native
Land Use Type

Figure 10.

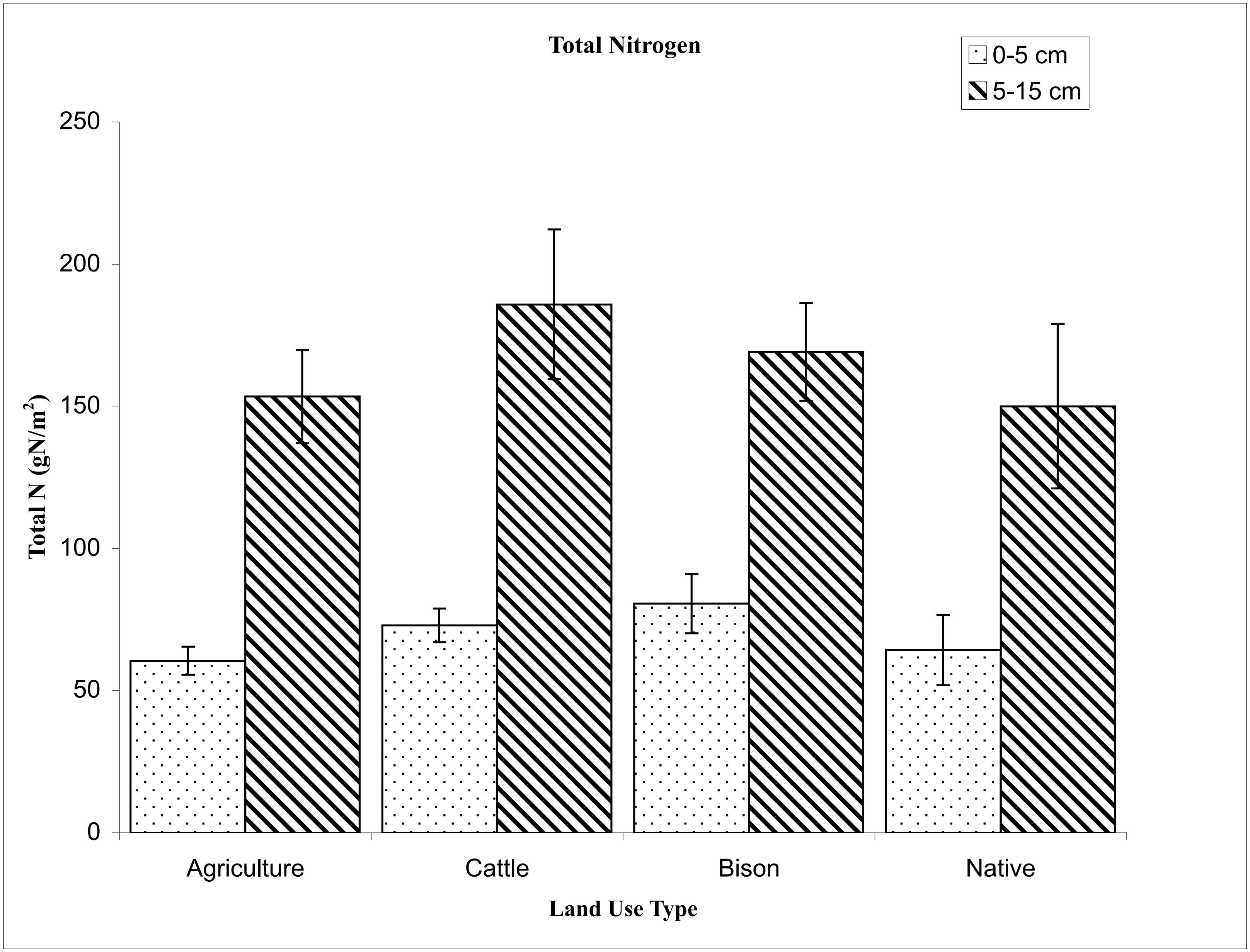
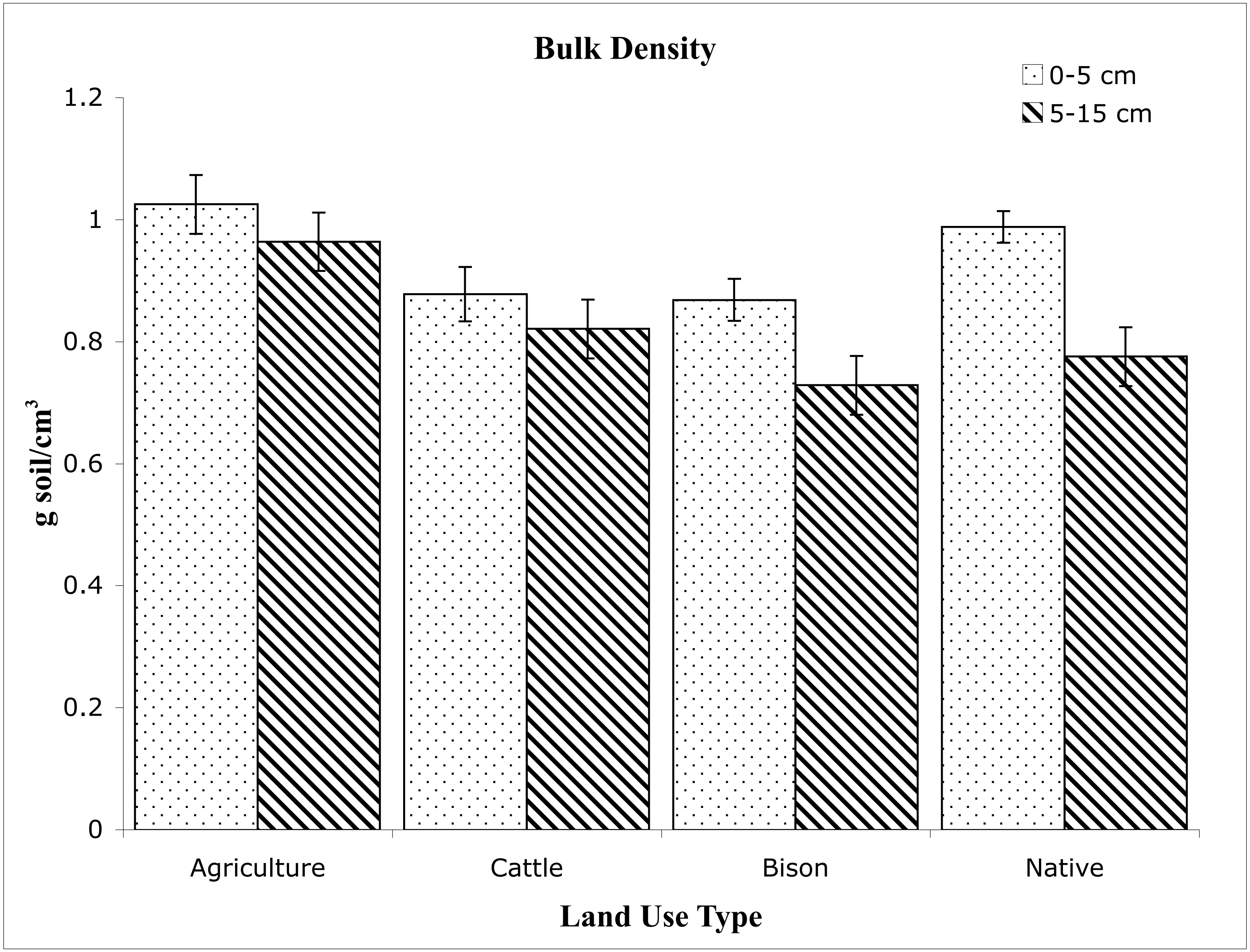

Total Nitrogen
0-5 cm
5-15 cm
Total N (gN/m2)
250
200
150
100
50
0
Agriculture
Cattle
Bison
Native
Land Use Type

Figure 11.



Bulk Density
0-5 cm
5-15 cm
1.2
1
0.8
0.6
0.4
0.2
0
g soil/cm^3
Agriculture
Cattle
Bison
Native
Land Use Type

Figure 12.

Appendix 1

Table A1.

Land Use/ Site	Lat/Long	Elevation (m)	Topography	Soil Series (Symbol)
Agricultural 1	N43°46.877' W102°45.511'	854.8	0-2% slope	Satanta loam (SeA)
Agricultural 2	N43°46.878' W102°45.385'	846	0-2% slope	Satanta loam (SeA)
Agricultural 3	N43°46.691' W102°40.145'	903.8	0-2% slope	Satanta loam (SeA)
Agricultural 4	N43°46.884' W102°46.404'	848.9	2-6% slope	Satanta loam (SeA)
Agricultural 5	N43°46.884' W102°46.404'	848.9	2-6% slope	Satanta loam (SeA)
Cattle 1	N43°45.464' W102°42.671'	776.5	15-25% slope	Samsil-Pierre Clay (ScE)
Cattle 2	N43°46.853' W102°42.411'	780.1	15-25% slope	Samsil-Pierre Clay (ScE)
Cattle 3	N43°46.954' W102°42.439'	778.3		Lohmiller Silty Clay (Lo)
Cattle 4	N43°47.353' W102°42.405'	772.2		Glenberg fine sandy loam (Gb)
Cattle 5	N43°46.004' W102°46.737'	857.5	0-2% slope	Nunn loam (NuA)
Cattle 6	N43°45.658' W102°45.544'	782.9	0-3% slope	Kyle Clay (KyA)
Cattle 7	N43°45.636' W102°46.292'	851.7	0-2% slope	Nunn loam (NuA)
Cattle 8	N43°45.755' W102°46.188'	850.5	0-2% slope	Nunn loam (NuA)
Cattle 9	N43°44.118' W102°46.531'	850	0-3% slope	Satanta-Beckton Complex (SgA)
Bison 1	N43°46.012' W102°44.604'	776.8	25-40%	Samsil clay (SbF)
Bison 2	N43°45.890' W102°44.508'	783.4	0-4%	Bankard loamy fine sand (BcB)
Bison 3	N43°45.847' W102°44.725'	783.2		Glenberg fine sandy loam (Gb)
Bison 4	N43°45.333' W102°46.738'	859.2	0-2% slope	Nunn loam (NuA)
Bison 5	N43°45.318' W102°47.043'	862.7	0-2% slope	Nunn loam (NuA)
Bison 6	N43°45.095' W102°46.298'	795	15-25% slope	Samsil-Pierre Clay (ScE)
Bison 7	N43°45.363' W102°50.022'	890.3	3-6% slope	Kyle Clay (KyB)
Bison 8	N43°44.527' W102°46.703'	805.8	15-25% slope	Samsil-Pierre Clay (ScE)
	N43°44.313'			Samsil Clay

Appendix 1

Native 1	N43°45.585' W102°40.729'	843.8	15-25% slope	Samsil-Pierre Clay (ScE)
Native 2	N43°45.502' W102°40.748'	843.9		Badland (Bb)
Native 3	N43°46.638' W102°40.132'	901.7	9-40% slope	Fairburn-Badland Complex (FhE)
Native 4	N43°44.579' W102°44.825'	852.2	15-25% slope	Samsil-Pierre Clay (ScE)
Native 5	N43°44.145' W102°45.064'	835.2	25-40% slope	Samsil Clay (SbF)
Native 6	N43°45.543' W102°46.390'	812.8	15-25% slope	Samsil-Pierre Clay (ScE)
Native 7	N43°44.650' W102°49.724'	919.7	6-15%	Pierre Clay (PeD
Native 8	N43°45.568' W102°46.217'	845.3	15-40% slope	Samsil Complex (StE)

Table A2.

Land Use/Site	Observations:
Agricultural 1	• located along the western edge of Phiney Flat • tilled, unplanted; fallow for the year, but normally planted with alfalfa hay • soil is rocky and somewhat compacted • gray to brown in color
Agricultural 2	• located along the western edge of Phiney Flat • tilled, unplanted; possibly fallow • soil is rocky and somewhat compacted • tan to brown in color • dry when sampled
Agricultural 3	• located at the western edge of Hart Table leading down into Indian Creek • tilled and planted with wheat • soil is very compacted • grayish in color
Agricultural 4	• lies on top of Phiney flat • tilled and planted with hay harvested in mid-July • soil was loose for the first 5 cm and compacted after the first 10 cm • very light tan to gray color
Agricultural 5	• lies on top of Phiney flat • tilled and planted with hay harvested in late mid-July • soil was loose for the first 5 cm and compacted after the first 10 cm • very light tan to gray color

Table A3.

Land Use/Site	Observations:
Cattle 1	• located along the Cheyenne River floodplain • lies at the foot of a group of rolling hills • soil is tan in color • sticky and moist at the time of sampling • compacted
Cattle 2	• located along the Cheyenne River floodplain • lies at the foot of a group of rolling hills • soil is tan to brown in color • sticky and moist at the time of sampling • compacted
Cattle 3	• located along the Cheyenne River floodplain • soil is tan in color • sticky and moist at the time of sampling
Cattle 4	• located along Cheyenne River floodplain • soil is tan in color • slightly sandy
Cattle 5	• on top of Phiney Flat • water and cattle are brought in by truck here • no animals were present during sampling • soil is brownish gray
Cattle 6	• located at the foot of a long and steep slope • a naturally occurring spring feeds this bottom land • soil is dark in color • private land
Cattle 7	• located within a small depression • land here is very flat with surrounding rolling hills • soil is dark brown • lots of vegetation present • private land
Cattle 8	• sampling was done along the escarpment of the slope on top of Phiney Flat • this area is used frequently by cattle as a path to a watering tank • soil was compacted and gray in color • very little vegetation due to visible overgrazing • private land
Cattle 9	• on top of Phiney Flat • soil is hard and tan to light brown in color • area is very dry

Table A4.

Land Use/Site	**Observations:**
Bison 1	• lies north of a sharp bend in the Cheyenne River along the floodplain • in a small depression • slightly sandy soil • brown in color
Bison 2	• located along the west side of the Cheyenne River floodplain • ground is somewhat compacted • soil is light brown in color • private land
Bison 3	• located along the west side of the Cheyenne River floodplain ground is somewhat compacted • soil is light brown in color • private land
Bison 4	• lies at the edge of the scarp on a very level portion of Phiney Flat • soil is brown in color • vegetation here is very dry
Bison 5	• located on a very flat portion of Phiney Flat • there is a prairie dog town, but most to all rodents have been poisoned • visibly overgrazed • private land
Bison 6	• lies along the bottom half of the slope coming from Phiney Flat an active prairie dog town is located here • vegetation is abundant here • soil is dark brown and wet during sampling
Bison 7	• located along the western edge of Phiney Flat in a small depression • soil is very compacted and somewhat damp • soil is dark in color
Bison 8	• located within a small draw fed by a natural spring running through the bottom • soil is slightly loose and grayish brown in color • salt leaching was noted in the area but not at the sampling site
Bison 9	• overlooking the entire Cheyenne River Valley on top of Phiney Flat • soil is brown • very dry

Table A5.

Land Use/Site	**Observations:**
Native Prairie 1	• lies on a very steep hillside on the south side of Indian Creek • soil is sandy and rocky • tan to light brown in color • cattle waste was noted for this site
Native Prairie 2	• on the peak of a badland butte • soil is sandy and rocky • signs of salt leaching were evident here • very little vegetation
Native Prairie 3	• the presence of fossilized ammonite and other mollusks was found during sampling • soil is very sandy • tan in color
Native Prairie 4	• located on the south slope of Little Corral Draw • soil is dark tan to brown and silty • grayish brown in color • public land often grazed by cattle
Native Prairie 5	• located on the north slope of Little Corral Draw • soil is silty • dark tan to brown • public land often grazed by cattle
Native Prairie 6	• samples were taken on either side of a dividing road along steep slopes • rich in vegetation • very sandy and rocky • light in color
Native Prairie 7	• sampling took place on a very steep slope • soil is silty and rocky • gray to brown in color
Native Prairie 8	• located at the peak of a very high hill • this land is used for horse pasture • soil is extremely sandy

Appendix 2

Table B1.

Soil Association	Description	Soil Series
Nunn-Satanta	Deep, well drained, level to strongly sloping, loamy soils on high terraces	Altvan, Beckton, Haverson, Hoven, Nihill, Nunn, Satanta, Samsil, Zigweid
Bankard-Haverson-Lohmiller	Deep, well-drained, level sloping, sandy, silty and clayey soils on flood plains	Bankard, Haverson, Glenberg, Kyle, Lohmiller, Pierre
Pierre-Kyle	Deep, well drained, level to sloping, clayey soils on plains and fans	Pierre, Kyle, Lohmiller, Nihill, Nunn, Samsil
Samsil-Pierre	Moderately deep and well drained, slightly sloping to steep, clay soils on dissected plains	Kyle, Lohmiller, Pierre Samsil
Orella-Fairburn-Badland	Shallow, well-drained, steeply sloping Badlands	Badland

(Nielsen, 1996. pp.7,9,12-13)

Soil Series Descriptions:

Altvan - moderately deep, gravelly sand, grayish-brown in color and formed in loamy sediments on upland hillslopes. Permeability is moderate in the soil and rapid in underlying material. Usually these soils are found on slopes with less tan 1% grade. These areas are used primarily as cultivated farmland.

Bankard - a floodplain and low terrace residing soil, which is very deep, well to excessively drained and light brown to gray in color. This soil is found on slopes up to 6%. It is a loamy sand, and carbonates are usually found within the upper 20 cm from the surface. SOC is measured from 0.5% to 1.5%.

Beckton - a well to moderately well drained soil formed in loamy alluvium or valley fill from parent sedimentary rocks. These soil are fine and have very slow permeability. Depth to carbonate material ranges from 0-65 cm and soils are slightly acidic and alkaline. The Beckton series is found normally on stream terrace and sloes ranging from 0-9%.

Glenberg - a grayish-brown, sandy-loam formed from thick alluvial sediments containing calcareous material. It is found on food plains and low terraces and on slope with less than 8% grade.

Haverson - soils located on floodplains, and low terraces with slopes of 0-9%. These soils are formed in alluvium. They are fin-loamy, mixed and calcareous, and pale brown in color. Organic carbon ranges from 0-5 to 2.0 % in surface horizons and decrease irregularly as depth increases. These soils are utilized as grazing pasture.

Hoven - a dark gray, moist soil, low in permeability and found on slopes of less than 2%. It is described as a silt loam formed in clayey alluvium and within closed basins.

Kyle - a deep, well drained soil formed within weather clay shale sediments from uplands. Particles are usually very fine and grayish brown. This soil does not typically show signs of carbonate precipitation at depths shallower than 10-15 cm. Dry soil displays 1.5 to 5 cm wide cracks extending down through the surface. Average organic carbon values for the upper 25 cm is 0.6 to 1.7%.

Lohmiller - a deep and well drained, grayish brown soil that exists within alluvium on bottom lands. This soil has low permeability, it is fine and calcareous, and carbonates can be found within the top 25 cm. This soil exists on floodplains and high bottom lands at the foot of slopes that range between 0 and 8 %. This soil forms from calcareous sedimentary rocks and can be used as crop and rangeland.

Nihill - a gravelly alluvium formed from a mix of parent materials. The Nihill is found on late Pleistocene terraces and remnants thereof, with slopes at a maximum of 80%. Calcareous material is found in the upper few inches of this loamy-skeletal, mixed, dark brown soil.

Nunn - a grayish brown, fine, clay loam, which is very deep and well drained. This soil forms in loess and mixed alluvium and found on terraces and/or alluvial fans and in drainageways. It can be found on slopes ranging from 0-25%.A majority of this soil is currently used as land for irrigated crops like alfalfa and winter wheat.

Samsil - an extensive, clayey, calcareous soil, located on gently sloping to very steep hills, ridges and breaks of dissected shale plains. Permeability of this soil is slow. This soil is light brownish in color, shallow, well-drained and formed in alluvium and from weathered shale. This soil is utilized primarily as rangeland.

Satanta - a deep, well-drained , moderately permeable soil, sound on high terraces and tablelands where runoff is low. Permeability is moderate. These soils are formed most from eolian deposits. This soil is fin and loam, dark gray to brown and has a $CaCO_3$ content less than 15%. Most areas with this soil are cultivated with wheat, alfalfa or hay.

Zigweid - a light to dark brownish gray soil formed in alluvium and is deep and well drained. This is a fine, loamy and mixed mesic soil utilized as rangeland. Depth to carbonates ranges anywhere within the upper 8 inches from the surface. This series is usually found in alluvial fans, fan aprons o piedmonts and along ridges and hills with up to a 20% slope.

Reference:
USDA-NRCS (2005). "Official Soil Series Descriptions." http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi

Nielsen, Robert D. (1996). Soil survey of Custer and Pennington Counties, Prairie Parts, South Dakota. USDA-NRCS with the South Dakota Agricultural Experiment Station