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Comparison of Prairie and Eroded Agricultural Lands on Soil Organic Carbon Retention (South Dakota)

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Abstract

The primary objective of this research was to predict changes in soil organic carbon (SOC) and total soil nitrogen (TSN) stocks as a result of land use change from prairie to agricultural land if the mesic-frigid temperature line moved north in the US and the former frigid soils were cultivated. The conversion of prairie to agricultural use, as a result of climate shift, would release SOC to atmosphere and enhance greenhouse gas emissions. The SOC and TSN differences between the prairie site and agricultural land were compared in South Dakota. The agricultural land had 18% less SOC and 16% less TSN or only half of the expected loss from prairie levels. An attempt was made to document the land use history of the prairie site to understand why SOC and TSN losses were less than anticipated. The fly ash concentration levels on prairie side slopes suggested that the prairie was historically disturbed and eroded. Intensive grazing and burning contributed to the disturbance. The SOC and TSN stock losses appear to represent the minimal change that would occur in the next 100-year time period if a prairie was shifted to agricultural use as a result of climate shift and the mesic-frigid temperature line in US was to move north.

Keywords

Soil Organic Carbon, Fly Ash, Erosion, Prairie, Cultivation, Grazing

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1. Introduction

Conversion of prairie to agricultural use would reduce carbon stored in the soil and an increase in CO_2 released to the atmosphere. This change would result in reduced carbon inputs to the soil and the accelerated decomposition SOC [1] [2]. Erosion removes SOC from the original site of formation and increases its burial in depositional soil environments. The net release of carbon to atmosphere from the soil is affected by: 1) replacement of SOC at eroding sites as a result of plant inputs; 2) decrease in SOC available for decomposition at the less productive eroding site [3]; 3) deep placement of carbon and inhibited decomposition especially if conditions are anaerobic [3], and [4] enhanced decomposition of SOC as a result of physical and chemical breakdown of soil during detachment and transport [5].

Gregorich *et al*. [5] found most soils undergo about a 20% to 30% loss of soil organic carbon (SOC) by mineralization and decomposition when they are brought under dryland cultivation. In addition, even greater SOC losses and gains may occur as a result of wind and water erosion, transport and deposition. Vanden Bygaart *et al*. [6] suggested that past erosion, transport and deposition have resulted in redistribution of SOC in the landscape and have yet to be fully considered in the study of SOC dynamics and the potential for C sequestration in agricultural soils. Janzen *et al*. [7] monitored the change in SOC stock over time and found soil management practices to be critical to understanding sequestration of C from atmosphere in agricultural soils. In southern Ontario, VandenBygaart *et al*. [8] measured the changes in SOC after 15 years of NT and found when the entire soil profile was considered there was more loss of SOC stocks than gains. Vanden Bygaart *et al*. [8] found that climate, management history, and soil type and soil landscape process affected the SOC dynamics under NT.

The SOC stock dynamics are affected by land use, tillage, no-tillage, soil erosion, transport and depositional processes [9] [10]. Shukla and Lal [11] showed that erosion decreased soil organic carbon stock of Ohio soils. In Canadian prairie studied by Tiessen *et al*. [12], McGill *et al*. [13], Janzen *et al*. [7] and Bowman *et al*. [14] they found that soils have lost 30% to 35% or more of their C due to farming. Malhi *et al*. [15] reported that soil under permanent grass or hayland cover contained substantially higher SOC stocks than that when soil was tilled for annual grain crops.

Grassland and forest soils tended to lose 20% to 50% of the original SOC stock in the tilled layer (15 - 20 cm) within the first 40 to 50 years of cultivation [12] [16]-[22]. Oxidation of SOC stock and emission of CO_2 to the atmosphere occurred as a result of plowing. Aeration as a result of land drainage of poorly drained and nearly level soils and erosion of well drained sloping soils often resulted in greater rates of oxidation of SOC and increased emission of CO_2 to the atmosphere. Kern [23] estimated the historical SOC stock losses in the surface 30 cm after cultivation for major field crops in the contiguous U.S. to be 16% primarily as a result of the plowing which caused oxidation of SOC and emissions of CO_2 to the atmosphere.

Soil erosion rates can be determined by landscape segment once the landscape, historical soil management, and land use are known. Lal *et al*. [24] estimated the SOC stock of the sediment displaced by cropland erosion would result in 70% of SOC being re-deposited on lower landscape positions, 20% of SOC in sediment being emitted to atmosphere as CO_2 and 10% of SOC being transported to ocean and other aquatic ecosystems. Van Oost *et al*. [3] examined the fate of the SOC exported from eroded watersheds. They found that 53% to 95% of the eroded carbon was retained and re-deposited within the watershed land unit.

Growing concern about greenhouse gas emission and potential to impact climate has resulted in many attempts to reduce greenhouse gas emission by storing in the forest or prairie. Carbon can be sequestered in trees, below ground roots, in wood products and in the soil humus or soil organic matter as SOC and TSN. If the CO_2 and N_2O gases are removed from the atmosphere by trees or prairie plants and stored in the soil humus, it is referred to as SOC and TSN sequestration.

Agricultural, prairie, range, pasture and forest soils are some of the largest SOC storage reservoirs. Efforts should focus on increasing SOC stocks in these areas [25]. The Kyoto Protocol recognized that net emissions of greenhouse gases, such as CO_2, N_2O and CH_4, can be decreased either by reducing emissions and/or increasing the rate of C sequestration in soil.

Water and wind erosion can impact the soil which serves as a source or sink of CO_2, N_2O, CH_4, and other greenhouse gases, depending on soil productivity and the predominant pedospheric processes [4] [14] [26]. Erosion can deplete on-site SOC, transporting dissolved organic C (DOC) in runoff water and particulate organic carbon (POC) in eroded sediments to receive environments. However, the processes involved are not well documented. Globally, C loss from erosion is estimated to be 150 to 1500 million tons per year [4] [5] [26].

Depending on the landscape position, water eroded soil particles move down-slope and may be stored in lower sections of the same field or watershed for long periods of time. The sediment redistribution increased spatial variability of soil properties across landscapes, including SOC and TSN [27] [28]. Some of the eroded soil particles are transported into aquatic ecosystems and bottomland depressions where SOC stock may be retained. Annual atmospheric emission of C caused by wind and water erosion is estimated to be as much as 15 TgC/y in the U.S. and 1 PgC/y in the world [4]. Although erosion is likely to reduce crop productivity, other estimations suggest that soil erosion could contribute to a net sink for C [4]. However, the authors point out that the effects of climate change on the long term stability of buried sediments are unknown and could change simulation results. Land cover and use changes, such as conversion of wetlands into farmland, are examples of climate shift effects that could oxidize relic soil carbon stored in eroded landscapes.

In the Northern Great Plains, soil productivity and SOC stocks are substantially lower than what they are when the original prairie sod was first cultivated [29]. Soil properties in cultivated fields have been modified significantly by a combination of accelerated erosion processes, including tillage, water, and wind erosion events [30] [31]. This has resulted in less than ideal growing conditions at almost all topographic positions in a rolling landscape (crests, shoulders and backslope positions) and substantial losses in SOC [27]. In some cases, the severe erosion has caused the topsoil in deposition zones to reflect the original subsoil of the upper slope [32].

Fly-ash has been used as a time marker in both upland erosion and bottomland depositional studies [33]-[37]. The distribution of fly-ash incidence in soil columns [9] [33] [36]-[38] has been shown to provide useful information regarding pedoturbation of subsurface horizons since settlement.

Olson *et al.* [38] determined the cropland landscape retained 52 percent of the total SOC of the woodland on a mass basis after 150 years of agricultural use. The causes of the 48 percent reduction in SOC included land use change, tillage, mixing, fertilization, and soil erosion. The amounts of SOC retained on both landscapes were significantly different. The agricultural land had significantly lower SOC levels in both the surface and subsurface layers.

Olson *et al.* [39] determined the soil erosion rates in cropland of west central Illinois using a magnetic tracer (fly ash) and radio-cesium (cesium-137). The cesium-137 and fly ash data suggest that cropland lost significant sediment, fly ash and cesium-137 to erosion process especially from the upper and lower backslopes and footslope. The fly ash and cesium-137 determined erosion amounts and annual soil erosion rate for cropland landscapes positions were the highest for the upper and lower backslopes. Past backslope annual erosion rates for three different time periods were 51 Mt ha^{-1} yr^{-1} or less and above the tolerable soil loss rate of 11 Mt ha^{-1} yr^{-1} for Hickory soils.

The primary objectives of this research were: 1) determine the land use from 1851 to present on the Sioux Prairie transect area; 2) verify that the prairie was never cultivated; 3) determine the effects of land use conversion from prairie to eroded row cropland on the SOC and TSN sequestration, net storage, retention and loss from the tilled layer and subsoil; and 4) predict changes in SOC and TSN stocks of uncultivated prairie soils if the former frigid soils were cultivated.

2. Methodology and Activities

2.1. Local Geology, Soils and Vegetation

The Sioux Prairie is located at the southern end of a rolling highland called Prairie Coteau. This massive flatiron shaped plateau includes Sioux Prairie which is located about 16 km (10 mi) west of the Big Sioux River. The coteau west of the Big Sioux River drains into many lakes and potholes. The surficial features of the Sioux Prairie are typical of the rolling potholed coteau. End moraines running approximately north-south direction characterize most of the Sioux Prairie topography [40]. Most of the drainage is directed towards the southern and southeastern portions of the prairie where a wide horseshoe shaped wetland occurs. In addition, a number of small potholes collect runoff in the northern one-half and western edge of the Sioux Prairie including the transect site area. Surficial deposits on the Sioux Prairie consist primarily of glacial till and composed of heterogeneous materials ranging in size from clay particles to boulders with clay being the predominant particle size. This glacial till was deposited during the Wisconsin glacier stage, some 13,000 to 14,000 years ago.

The Sioux Prairie Conservancy (Longitude 96 degrees, 47.326 minutes west; Latitude 44 degrees, 01.793 minutes north) established in 1983 and the EcoSun Center (Longitude 96 degrees, 50.642 minutes west; Latitude 44 degrees, 01.466 minutes north) located near Colman, South Dakota was selected for soil sampling. The soils

are now considered to be in temperature regime mesic and in the past they were frigid temperature. Before 1983, the soils at Sioux Prairie and EcoSun were mapped and classified as Vienna (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls) and Parnell (Fine, smectitic, frigid Vertic Argiaquolls) soils. These soils were reclassified as Wentworth (Fine-silty, mixed, superactive, mesic Udic Haplustolls) and Whitewood (Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) (**Figure 1**).

Approximately 200 species of plants adorn Sioux Prairie in the springtime including the Pasque flower (Pulsatilla vulgaris), prairie smoke (Geum triforum) and gold flower of blue-eyed grass bespangle (Sisyrinchium bellum). The black-eyed Susans dot (Thunbergia alata) the prairie in summer. Autumn brings yellow goldenrods (Solidago genus), sunflowers (Helianthus annuus) and purple flowered asters (Aster tripolium) and ironweed (Vernonia altissima).

The Sioux Prairie and EcoSun sites were used to quantify the amount of SOC (Mg C ha^{-1}) and TSN (Mg N ha^{-1}) in humus or soil organic matter. This prairie area was not cultivated during the last 130 years but was pastured from 1945 to 1971 and burned periodically to control invasive plants. The nearby EcoSun site was used for agriculture including row crops for the previous 130 years. Transects were made of prairie landscapes with soils sampled by landscape position (interfluve, shoulder, backslope, footslope and toeslope), weighted by width of landscape position and determined for the entire landscape at the prairie and cropland sites. Soil erosion rates were determined for the prairie by measuring fly ash concentration levels within each landscape position. The bulk density of each soil layer and at each landscape position were determined, the SOC and TSN and the fly ash concentration of each layer was measured and expressed by volume. When past soil erosion and subsequent deposition occurred, the SOC and TSN rich sediment would changed the SOC, TSN and fly ash contents of each landscape position within a landscape limited the effect on the landscape SOC and TSN stocks since lower landscape positions collected most of the transported and deposited sediment.

2.2. Field Sampling Procedures

Soil samples will be collected from two transect observations (replications) spaced 10 m apart at each of the prairie and cropland landscape positions. The prairie and cropland transects were subdivided by landscape position resulting in samples being collected for each of the following landscape positions (interfluve, shoulder,
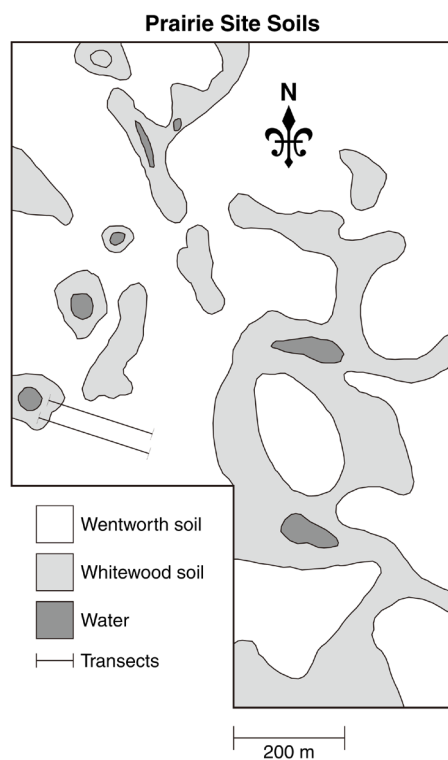

Figure 1. Soil map of prairie.

backslope, footslope and toeslope) (**Figure 2**). Three 3.2-cm-diameter soil cores that were sampled 10 m apart at each transect point using hand soil push probe to a depth of 0.5 m. The prairie soil cores were cut into three segments (0 - 0.15, 0.15 - 0.30 and 0.30 - 0.50 m) for the laboratory determinations. The EcoSun agricultural soil cores were separated into four segments (0 - 0.15, 0.15 - 0.30 and 0.30 - 0.50 m) for the laboratory analysis. Samples were analyzed separately by transect (2), depth (3), landscape position (5) and land use (2). Samples were dried at room temperature, sieved to pass a 2-mm sieve, and subsequently the SOC and TSN stocks were measured for 70 soil samples from both land uses at the two sites.

2.3. Laboratory Procedures

After removal of plant residue, SOC and TSN stocks were measured using the modified acid-dichromate organic carbon procedure number 6A1 [41]. Field moist core bulk density will be determined [41] using a Model 200 soil core sampler (5.6 cm diameter and 6 cm high) manufactured by Soil Moisture Equipment Corp (Goleta, California, USA). The bulk density values for each layer were used to convert the SOC on a concentration basis to a volumetric basis. The replicated SOC stock values were determined for each depth, landscape position and land use. The agricultural land SOC stock values from the 2 separate transects at both the prairie and cropland land use sites were determined and then compared for the same depth and landscape position at each site.

The magnetic minerals and fly-ash content were determined using procedures developed by Jones and Olson [42] and revised in Olson *et al*. [9] [10]. Fly-ash content was determined in the ferrimagnetic fraction of the sample. Sub-samples of fine-earth samples previous passed through a 2-mm sieve were ground to <250 μm in a mortar and pestle to pass a 0.250 mm sieve. Magnetic susceptibility was subsequently determined with a modified Gouy balance (model MK I # 6632, Johnson Matthey Wayne, PA, USA).
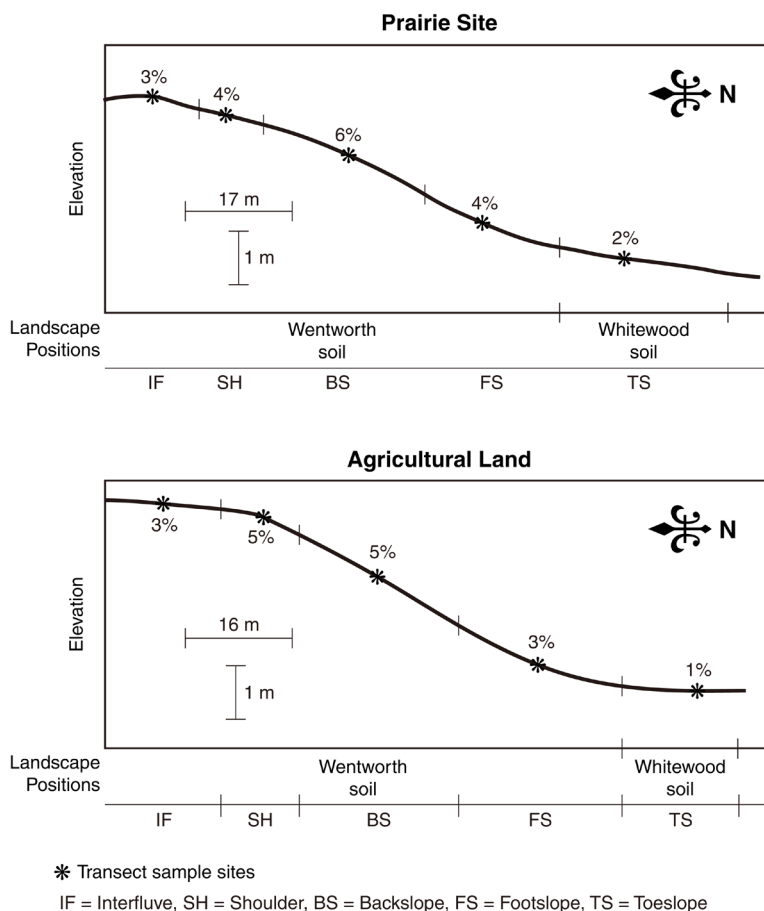

Figure 2. Cross section of prairie and agricultural land transects showing landscape positions, sampling sites, slope gradients and soils.

The fly ash interfluve mean content for prairie was used as baseline to calculate erosion from prairie landscapes. The fly ash interfluve mean for cropland was used as baseline to calculate erosion from cropland landscape positions. The cropland toeslope continued to receive fly-ash rich sediment and fly ash was present to 0.50 m depth. When the cropland toeslope was sampled and totaled to 0.5 m the profile had more fly ash than the prairie 0 - 30 cm layer which clearly showed deposition of fly ash rich sediment. All two cropland transects were tested separately so that a mean and SD by cropland landscape positions could be determined. The cropland landscape position fly ash mean and SD and also provided an indication of the natural variability in the fly-ash data.

The fly ash deposition time started in 1910 and stopped in 1960s but still remained as a time marker in the soils in 2011. This soil marker could be used to determine the amount of soil erosion and the rate for the last 100 years. Initially, the fly-ash method assessed the soil stability, soil erosion and sediment deposition situation during the last 100 years (based on time of coal fired locomotives).

2.4. Statistical Methods

Statistical analyses were performed using Statistical Analysis System (SAS) computer software [43]. A Least Significant Difference (LSD) procedure performed at the P = 0.05 level will be used to determine if there were significant SOC, TSN and fly ash concentration and stock differences between the prairie and agricultural land uses for the same landscape position and layer depth interval.

3. Results and Discussion

Determination Land Use History of the Prairie site

In 1851, the prairie site was part of the eastern South Dakota lands signed over to USA. The first European settlement in the area was in 1857 but was abandoned in 1858 due to an attack from Yankton Sioux. European settlement began again in 1872. In 1873 Moody County was organized. The first railroad to enter South Dakota was in 1872 at Yankton at the Southeast border of South Dakota and Nebraska. Colman (the nearest town to prairie) was founded in 1880 with post office starting in 1881. Based on biographical information from early settlers in Moody County it looks like most arrived in the late 1870s and early 1880s. South Dakota became a state in 1889. The state was surveyed and sections 16 and 36 were used for schools and other public purposes. Sioux Prairie is in section 36. These areas were known as common school lands. The prairie site was legally in the public lands and school lands, protected from private settlement from 1889 to 1945.

The 80 ha (200 ac) of Sioux Prairie land was sold in 1945 to Irving H. Kenison on October 24, 1945 by the state of South Dakota. On November 2, 1971 the prairie land was transferred to the Nature Conservancy. Between 1945 and 1970, the land was private holdings, and the entire area was managed as rangeland under both grazing and haying. During this time period, 8 ha (20 ac) in the northwest corner (**Figure 3**) was plowed and now support an almost pure stand of smooth brome (Bromus inermis L.). In the spring of 1975, the 16 ha (40 ac) in the southwest corner (**Figure 3**) including the transect sites were burned resulting in a robust growth of Big bluestem (Andropogon gerardii Vitman) and other tall grasses. Some grazing occurred in 1975 as a result of a fence failure. However, by 1976 smooth brome regained a dominant appearance in the southwest forty. In August of 1978 a management plan for prairie was prepared. The plan written by Clair D. Welbon [44] of USDA, SCS recommended prescribed burning for the southwestern corner of prairie site (including our transect sites). The plan called for the burning each year from 1978 to 1982 and for heavy spring grazing to reduce competition from smooth brome and Kentucky bluegrass.

Table 1 provides the landscape position, land use, soil series and horizons sampled at the EcoSun sites. The soils are on similar slope gradients and on northwest facing slopes. **Table 2** summarizes the SOC by landscape position at the prairie and agricultural land sites. The total SOC stock at each landscape position declined with depth even with the 30 - 50 cm layer being 5 cm thicker than other layers which increased total amount values by 30%. At all 5 landscape positions the prairie site had more SOC stock in 0 - 50 cm layer than the cropland but only the shoulder and toeslope were statistically higher. The prairie interfluve had 12% more SOC, the shoulder had 57% more, the backslope had 11% more SOC, the footslope 13% more SOC and the toeslope 36% more SOC.

The TSN data for the sloping prairie and the adjacent agricultural land is provided in **Table 3**. At all 5 landscape positions the prairie site had more TSN than the cropland but only the shoulder was statistically higher. The prairie interfluve has 14% more TSN, the shoulder had 28% more TSN, the backslope had the same amount
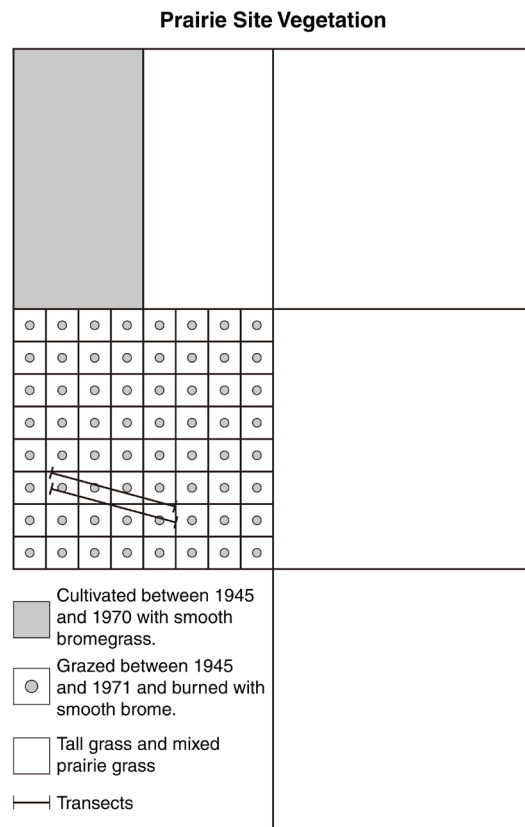
Prairie Site Vegetation

Figure 3. Area cultivated between 1945 and 1971 intensively grazed prairie area with smooth brome grass invading.

Table 1. Landscape position, vegetation, slope gradient, soils and soil horizons at Sioux Prairie and EcoSun, South Dakota sites.

Transect	Landscape segment	Sampled	Slope	Slope	Soil	Vegetation	Cultivation	Soil
	site no.	layer (m)	gradient (%)	shape	series			horizon
	Sioux Prairie							
SP1	Interfluve	0.0 - 0.5	3	linear	Wentworth	prairie	no	A, Bw
SP2	Shoulder	0.0 - 0.5	4	convex	Wentworth	prairie	no	A, Bw
SP3	Backslope	0.0 - 0.5	6	linear	Wentworth	prairie	no	A, Bw
SP4	Footslope	0.0 - 0.5	4	concave	Wentworth	prairie	no	A, Bw
SP5	Toeslope	0.0 - 0.5	2	linear	Whitewood	prairie	no	O
	EcoSun							
ES1	Interfluve	0.0 - 0.5	3	linear	Wentworth	cropland	yes	A, Bw
ES2	Shoulder	0.0 - 0.5	5	linear	Wentworth	cropland	yes	A, Bw
ES3	Backslope	0.0 - 0.5	5	concave	Wentworth	cropland	yes	A, Bw
ES4	Footslope	0.0 - 0.5	3	linear	Wentworth	cropland	yes	A, Bw
ES5	Toeslope	0.0 - 0.5	1	concave	Whitewood	cropland	yes	O

Table 2. Summary of SOC stocks for the sloping prairie and the nearby cultivated cropland. Two pedons were sampled to a 0.5 m depth on each of five landscape positions on each transect.

Depths	SOC (transect means)	SOC (transect means)	SOC difference	Percentage
cm	Mg ha^{-1} layer^{-1}	Mg ha^{-1} layer^{-1}	Mg ha^{-1} layer^{-1}	change
	Interfluve (prairie)	Interfluve (cropland)		
0 - 15	79.10a[*]	53.15b	−25.92	−32%
15 - 30	48.64a	47.43a	−1.21	−2%
30 - 50	27.72a	35.50b	7.78	28%
0 - 50	155.46a	136.09a	−19.37	−12%
	Shoulder (prairie)	Shoulder (cropland)		
0 - 15	78.28a	44.61b	−33.67	−43%
15 - 30	58.86a	33.99b	−24.87	−54%
30 - 50	46.62a	43.59a	−3.03	−6%
0 - 50	183.77a	122.19b	−68.58	−57%
	Backslope (prairie)	Backslope (cropland)		
0 - 15	74.30a	51.09b	−23.21	−61%
15 - 30	51.34a	48.68a	−2.66	−5%
30 - 50	40.85a	47.57a	6.72	16%
0 - 50	166.49a	147.34a	−19.15	−11%
	Footslope (prairie)	Footslope (cropland)		
0 - 15	65.21a	62.49a	−2.72	−4%
15 - 30	56.82a	49.10a	−7.72	−13%
30 - 50	45.78a	39.76a	−6.02	−13%
0 - 50	167.80a	151.3a	−16.45	−13%
	Toeslope (prairie)	Toesleope (cropland)		
0 - 15	86.41a	41.06b	−45.35	−52%
15 - 30	43.92a	34.17b	−9.75	−22%
30 - 50	42.56a	35.15a	−7.41	−17%
0 - 50	172.89a	110.38b	−62.51	−36%

[*]Transect means for different land uses with the same letter and for the same landscape position and depth layer are not significantly different at the 0.05 probability level.

of TSN, the footslope 17% more TSN and the toeslope 15% more TSN. The TSN changes were a little smaller than the SOC differences between the prairie and the cropland.

Table 4 weights the SOC by the landscape segment width. The prairie had 160.6 Mg C ha^{-1} and the agricultural land and had 29.0 Mg C ha^{-1} or 18 less SOC. The SOC loss was thought to be caused by cultivation, tillage disturbance, and soil erosion. The 18% loss is more than expected for a prairie site so it was clearly intensively pastured and periodically burned from 1978 to 1983. Consequently and land use change from prairie to cropland would result in SOC loss from storage and more greenhouse gas emissions. If only the eroding landscapes are included (interfluve, shoulder, backslope and footslope positions) the cropland would have lost 11% instead of 18% of SOC stock.

Table 3. Summary of TSN stocks for the sloping prairie and the nearby cultivated cropland. Two pedons were sampled to a 0.5 m depth on each of five landscape positions on each transect.

Depths	TSN (transect means)	TSN (transect means)	TSN difference	Percentage
cm	Mg ha^{-1} layer^{-1}	Mg ha^{-1} layer^{-1}	Mg ha^{-1} layer^{-1}	
	Interfluve (prairie)	Interfluve (cropland)		
0 - 15	5.80a[*]	4.27b	−1.53	−26%
15 - 30	4.78a	3.95a	−0.83	−17%
30 - 50	2.40a	2.97b	0.57	24%
0 - 50	12.99a	11.18a	−1.81	−14%
	Shoulder (prairie)	Shoulder (cropland)		
0 - 15	5.54a	3.59b	−1.95	−35%
15 - 30	4.76a	2.55b	−2.21	−46%
30 - 50	3.24a	3.54a	0.3	9%
0 - 50	13.53a	9.68b	−3.85	−28%
	Backslope (prairie)	Backslope (cropland)		
0 - 15	5.37a	4.26b	−1.11	−21%
15 - 30	3.81a	4.18a	0.37	10%
30 - 50	3.35a	4.08b	0.73	22%
0 - 50	12.53a	12.52a	−0.01	0%
	Footslope (prairie)	Footslope (cropland)		
0 - 15	6.16a	5.19a	−0.97	−16%
15 - 30	4.90a	4.13a	−0.77	−16%
30 - 50	3.90a	3.14a	−0.76	−19%
0 - 50	14.96a	12.48a	−2.48	−17%
	Toeslope (prairie)	Toesleope (cropland)		
0 - 15	3.71a	3.40a	−0.31	−8%
15 - 30	3.44a	2.75b	−0.69	−20%
30 - 50	3.86a	2.82b	−1.04	−27%
0 - 50	11.01a	8.97a	−2.04	−15%

[*]Transect means for different land uses with the same letter and for the same landscape position and depth layer are not significantly different at the 0.05 probability level.

The weight of TSN by the landscape segment width is shown (distance between tick marks in **Figure 2**) in **Table 5**. The prairie had 12.9 Mg·N·ha^{-1} and the agricultural and had 10.8 Mg N ha^{-1} or 2.1 Mg N ha^{-1} or 19% less TSN. The prairie site may have been pastured and later burned, but not cultivated (**Figure 3**), between 1945 and 1971 when in private use. The loss was most likely a result of intensive grazing, the disturbance as a result of fire and subsequent soil erosion. The C:N ratio for all landscape positions at prairie is 12.4 to 1 and for the cropland the C:N ratio was 12.2 to 1. If only the eroding landscapes are included the cropland would have lost 12% instead of 16% of TSN stock. Apparently more TSN is retained on the toeslope than SOC.

Table 6 provides the fly ash content in g·m^{-2}·layer^{-1} for the 0 - 15, 15 - 30, 30 - 50, and 0 - 50 cm layers. The mean fly ash content for the interfluve was used as a baceline to calculate erosion from cropland landscape positions. **Table 6** shows the backslope and footslope had the highest soil erosion rate (17 Mt ha^{-1} yr^{-1}) for the prai-

Table 4. Prairie and agricultural land SOC for 0.5 m layer and by landscape position and represent the mean of two transects.

Position	Landscape segment width (m)	Landscape fractional segment width as decimal	SOC stock landscape Mg C ha^{-1}	Loss of SOC stock Mg C ha^{-1}	Percentage change
Prairie					
Interfluve	23.7a*	0.205a	31.8a		
Shoulder	20.0a	0.173a	31.8a		
Backlslope	23.9a	0.206a	26.0a		
Footslope	20.9a	0.180a	30.3a		
Toeslope	27.3a	0.236a	40.8a		
Total	115.8a	1.000a	160.6a		
Total without toeslope			119.8a		
Cultivated agricultural land					
Interfluve	22.5a	0.237a	32.3a		
Shoulder	14.6b	0.153a	18.7b		
Backlslope	15.6b	0.164b	24.2a		
Footslope	16.9b	0.178a	26.9a		
Toeslope	25.4a	0.267a	29.5b		
Total	95.0b	1.000a	131.6a	29.0	18%
Total without toeslope			102.1a	17.7	11%

*Transect means for different land uses with the same letter and for the same landscape position and depth layer are not significantly different at the 0.05 probability level.

Table 5. Prairie and agricultural land TSN for 0.5 m layer and by landscape position and represent the mean of two transects.

Position	Landscape segment width (m)	Landscape fractional segment width as decimal	TSN stock in landscape Mg N ha^{-1}	Loss of TSN stock Mg N ha^{-1}	Percentage
Prairie					
Interfluve	23.7a*	0.205a	2.66a		
Shoulder	20.0a	0.173a	2.44a		
Backlslope	23.9a	0.206a	2.03a		
Footslope	20.9a	0.180a	2.70a		
Toeslope	27.3a	0.236a	3.20a		
Total	115.8a	1.000a	13.03a		
Total without toeslope			9.83a		
Cultivated agricultural land					
Interfluve	22.5a	0.237a	2.64a		
Shoulder	14.6b	0.153a	1.49b		
Backlslope	15.6b	0.164b	2.06a		
Footslope	16.9b	0.178a	2.22b		
Toeslope	25.4a	0.267a	2.39b		
Total	95.0b	1.000a	10.80b	2.23	17%
Total without toeslope			8.41b	1.42	14%

*Transect means for different land uses with the same letter and for the same landscape position and depth layer are not significantly different at the 0.05 probability level.

Table 6. Fly ash content summary of data for the sloping prairie and the adjacent cultivated cropland. Representative pedons were sampled to 0.5 m depth on each landscape position and transect.

Depths	Fly ash	Fly ash loss	Bulk density	Soil loss	Average rate of sol loss
	landscape positions				for last 100 years
cm	$g \cdot m^{-2} \cdot layer^{-1}$	%	$g \cdot cm^{-3}$	$Mg\ ha^{-1}\ yr^{-1}$	Percentage
Prairie	Interfluve and Shoulder		Mineral soil		
0 - 15	1.6a	0	1.09a		
15 - 30	1.3a	0	1.09a		
30 - 50	1.3a	0	1.05a		
0 - 50	4.2a	0	1.07a	0	0
Prairie	Backslope and Footslope		Mineral soil		
0 - 15	0.7b	−56	1.07a		
15 - 30	1.0a	−23	1.09a		
30 - 50	0.8b	−38	1.07a		
0 - 50	2.6b	−38	1.07a	2.12×10^3	−17
Cropland	Interfluve and Shoulder		Mineral soil		
0 - 15	2.8a	0	1.31a		
15 - 30	1.8a	0	1.39a		
30 - 50	1.3a	0	1.42a		
0 - 50	6.0a	0	1.39a	0	0
Cropland	Backslope and Footslope		Mineral soil		
0 - 15	2.4a	−14	1.31a		
15 - 30	1.0b	−44	1.39a		
30 - 50	2.3b	28	1.42a		
0 - 50	5.2a	−13	1.39a	1.40×10^3	−11
Representative depositional site	Prairie Toeslope		Organic soil		
0 - 15	0.5	0	0.75a		
15 - 30	0.2	0	0.85a		
30 - 50	0.1	0	0.95a		
0 - 50	0.8	0	0.86a	0	0
Representative depositional site	Cropland Toeslope		Organic soil		
0 - 15	0.6	20	0.75a		
15 - 30	0.4	100	0.85a		
30 - 50	1.0	1000	0.95a		
0 - 50	2.0	150	0.86a	3.27×10^3	25

[*]Transect means for different land uses with the same letter and for the same landscape position and depth layer are not significantly different at the 0.05 probability level.

rie based on fly ash content. These backslope and footslope erosion rates would not have occurred if the prairie had not been intensively pastured and periodically burned. The erosion rate on the cropland was higher as expected. However, as a result of high concentrations of fly ash in the agricultural land backslope soil the erosion rate as only 11 Mg ha^{-1} yr^{-1} versus the prairie backslope rate of 21 Mg ha^{-1} yr^{-1}. It appears that even with a slope of 6% there was 30 cm of deposition on top of the original soil surface which was unexpected. The backslope original surface soil was covered with sediment in the last 130 years. The SOC data for the 30 - 50 cm (**Table 1**) layer of the cropland backslope supports the hypotheses that sediment buried the original horizon surface soil. The SOC stock is 16% above the prairie backslope and a similar comparison of the shoulder and footslope had the more typical 6% to 13% less SOC levels. The interfluve at agricultural land site also appears to have an increase in SOC stocks in the 30 - 50 cm layer which also suggests the original surface was buried by deposition and that could explain why the 30 - 50 cm layer had more fly ash than anticipated for the interfluve and compared to prairie shoulder, backslope and footslope. Fly ash data (**Table 6**) for a representative prairie and cropland depositional toeslope was included to determine if sediment deposition was occurring in the cropland but not in the prairie. As a result of deposition the fly ash content of the cropland toeslope was 1.2 g·m^{-2} higher than prairie toeslope for the 50 cm thick layer.

4. Discussion

As a result of the prairie being in the public lands section the native prairie area was protected from cultivation for all but 26 years. During those 26 years, 1945 to 1971, in private ownership the transect area was subjected to intensive grazing but was never cultivated. After 1978 the transect area was periodically burned until 1983 in an attempt to control invasive plant species. This prairie study results was used to determine baseline SOC and TSN storage for prairie landscapes in South Dakota and can be used to evaluate the effects of any future land use changes, as a result of climate change, on SOC and TSN storage and retention. There was a lack of reliable SOC and TSN data baseline data for current prairie lands and if future land use changes were to occur there is a need for such baseline data to determine the effects of land use change and erosion on SOC and TSN stocks and future greenhouse gas emissions.

Assuming the mesic-frigid temperature line in the US moved north as a result of climate shift, previously South Dakota prairie would be cultivated. If cultivation happened during the next 100 years, as a result of the longer growing season and greater temperatures or growing degree days, then this land use change would result in CO_2 and N_2O transferred to atmosphere (or leached in case of N) from the current soil storage as a result of the farming, transported eroded soil as sediment to lower landscape positions, the water, or the atmosphere or leached in the case of N. If in the future the prairie lands were converted to cropland use the decomposition caused by cultivation will result in at least a 18% to 16% loss of C and N, respectively, to atmosphere as CO_2 and N or N_2O. During the next 130 years of cultivation it appears that approximately 30% of the SOC and TSN in transported sediment will be lost to atmosphere and water. Since up to 70% of the eroded soil mass with attached SOC and TSN stock would be retained on the lower segments of the landscape the SOC and TSN should be retained on the lower landscape segments for many more years. This projected land use conversion from prairie to cropland as a result of climate shift would result in greater greenhouse gas emissions as a result of reduced SOC and TSN stocks in the landscape than if the area stayed as prairie. Spatial and temporal climate change is likely to result in land cover and use shifts depending on temperature and precipitation patterns. Crop production may decline in some areas and expand in others. Examples of these areas include the prairie pothole region of the northern plains.

In the northern US prairie pothole region, cropland acres are likely to increase as wetlands diminish and temperatures increase. This region includes the division between the North American mesic-frigid soil temperature regimes. As a result, prairie and prairie pothole lands currently in the frigid temperature regime may be converted to cropland, pasture and grazing land. Row crop production may expand northward to meet demands for corn, wheat and forage production. Expansions of corn, wheat and forage production have currently been observed in the frigid temperature regime of North and South Dakota.

Temporal and spatial changes in precipitation and temperature patterns can alter the soil carbon and nitrogen dynamics, which has a significant impact on carbon sequestration, storage, retention and loss as well as greenhouse gas release. This in turn affects management techniques because practices that have been used to maximize efficiency may no longer deliver similar results.

5. Conclusion

At the prairie site more past soil erosion as a result of 26 years of intensive grazing and 5 years of periodic burning to control invasive plant species, occurred more than expected based on fly ash concentration on the shoulder, backslope and footslope. The prairie was pastured for 26 years but never cultivated, and it was subjected to periodic burning and subsequent soil erosion. The erosion rates at the backslope and footslope of the prairie site were 17 Mt ha^{-1} yr^{-1} which should not have occurred if it had remained in prairie during the last 100 years. The erosion rates at the cropland backslope and footslope were 11 Mt ha^{-1} yr^{-1} which was slower than the similar landscape positions on the prairie. The SOC and TSN stocks of the agricultural land had 29.0 Mg C ha^{-1} less (18%) SOC and 1.31 Mg C ha^{-1} less (16%) TSN in 2011. These differences represent a predictor of the SOC and TSN loss that would occur if the prairie was cultivated for the next 100 years as a result of climate shift and the mesic-frigid line moving north.

Acknowledgements

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