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Land Use Change Sustainability and Carbon Turnover Rate in the Northern Great Plains Soil

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LAND USE CHANGE SUSTAINABILITY AND CARBON TURNOVER RATE IN THE NORTHERN GREAT PLAINS SOIL

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Plant Sciences degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

LAND USE CHANGE SUSTAINABILITY AND CARBON TURNOVER RATE IN THE NORTHERN GREAT PLAINS SOIL

DEEPAK R. JOSHI

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Sustainable land management involves the management of land, water, biodiversity and other resources that meet human requirements while maintaining ecosystem services. In the northern Great Plains (NGP), the combined impacts of land-use and climate variability have placed many soils at the tipping point of sustainability. The objectives of this study were to: 1) calculate land-use changes from 2006 to 2012 and from 2012 to 2014 in South Dakota and Nebraska; 2) assess if land use changes had impacted on soil sustainability; 3) calculate variation in total carbon budget and turnover due to seasonal climate variability, biomass quality and soil properties; and 4) determine effect of fire and on the CO_2 emissions, soil temperature and soil moisture. For South Dakota and Nebraska, 43,200 and 38,400 points, respectively were visually classified from high resolution imagery in 2006, 2012, and 2014 into five different categories (cropland, grassland, Habitat, NonAg, and Water). From 2006 to 2014, 910,000 million hectares were converted from grassland to cropland in South Dakota and 360,000 hectares were converted from grassland to cropland in Nebraska. In South Dakota, approximately 92% of the land-use changes occurred on land suitable for crop production (Land Capability Class, LCC ≤4), whereas in Nebraska 80% of the land-use

changes occurred on land considered suitable for cropland (LCC ≤4). In the second study, the impact of season on above ground decomposition kinetics were investigated. This work showed that the winter season exhibit the lowest rate of litter decomposition, followed by spring and summer. The results indicated that the plant biomass C: N ratio and temperature explained 52 and 45%, respectively of the measured changes in biomass decomposition. Sites producing biomass with a low C: N ratio had higher first order rate constants than sites with high C: N ratios. These findings indicate that the winter period cannot be ignored when assessing carbon turnover. In the third study, the impact of annual fire on CO_2-C emissions was investigated. Total carbon lost, soil temperature and moisture contents were higher in fire than control treatment.

Chapter 1

Land Use Change Sustainability and producer responses to climatic and price variability

Abstract

Sustainable land management involves the management of land, water, biodiversity and other resources that meet human requirements while maintaining ecosystem services. In the northern Great Plains (NGP), the combined impacts of land-use and climate variability have placed many soils at the tipping point of sustainability. The objectives of this study were to 1) calculate land-use changes from 2006 to 2012 and from 2012 to 2014 in South Dakota and Nebraska; 2) assess if land use changes were impacted by different land capability classes; and 3) determine the relationship between land uses, rancher preferences, and soil sustainability. South Dakota and Nebraska were selected for this study because they are located in climate transition zone having row cropping in eastern portion of states and grasslands in the west regions. For South Dakota and Nebraska, 43,200 and 38,400 points, respectively, were visually classified from high resolution imagery in 2006, 2012 and 2014 into five different categories (cropland, grassland, Habitat, NonAg and Water). From 2006 to 2014, 910,000 million hectares were converted from grassland to cropland in South Dakota and 360,000 hectares were converted from grassland to cropland in Nebraska. In South Dakota, approximately 92% of the land-use changes occurred on land suitable for crop production (Land Capability Class, LCC ≤4), whereas in Nebraska 80% of the land-use changes occurred on land considered suitable for cropland (LCC ≤4). Out of 210,000 ha of grassland to cropland

changes in South Central South Dakota, 13.5 % of total conversion occurred on soil with a LCC of 6. Different results were observed in the North Nebraska NASS region, which is dominated with Sand Hills, where 61.2% of the 90,000 ha of grasslands that were converted to croplands had LCC of 6. Differences between South Dakota and Nebraska were attributed to the availability of irrigation. In both states, the conversion of grassland to cropland was concentrated in the eastern regions.

Introduction

Providing food for 2 billion more people in 2050 can be accomplished by increasing the amount of land used to produce annual crops, reducing waste, and increasing the productivity on current lands. Land conversion can occur on land suited for crop production and land not suited for crop production. In the northern Great Plains (NGP), the concern is that land conversion will occur on land not suited for crop production and that land conversion can result in wildlife habitat fractionation, increased erosion, and increased greenhouse gas emissions.

The NGP is bordered by the Rocky Mountains to the west and deciduous forest to the east. The NGP contains large portions of the Missouri River reservoirs and hundreds of glacial lakes that supply habitats for water fowl. The soil and climatic properties of the region make it a net exporter of grain, livestock, poultry and dairy products. According to the USDA, in 2015, Nebraska was ranked 1st in dry edible great northern beans, popcorn and red meat production, 2nd in millet production, 3rd in grain corn production and livestock receipts, 4th in soybean and 7th in sunflower production in

US Agriculture. Similarly in 2014, South Dakota was ranked 4th in wheat production, 7th in corn production, 8th in beef calves and calf production.

The NGP are semi-arid and the land is used to produce crops and livestock (Rossum and Lavin, 2000). In 1980, only 5% area of the South and North Dakota had been seeded to corn or soybeans farming area which then tripled between 1980 and 2011 (USDA NASS, 2013). Similarly, Wright and Wimberly (2013) reported more than 530,000 ha of grassland have disappeared from 2006 to 2011 in North Dakota, South Dakota, Nebraska, Iowa and Minnesota alone. However, Reitsma et. al. (2015) had slightly different values and reported that 730,000 ha of grassland was converted to cropland in just South Dakota between 2006 and 2012.

Associated with the conversion of grassland to cropland, are the losses of habitat and biodiversity (Mushet et al., 2014). Between 2008 and 2011, all across the U.S., 23.7 million acres of grassland, shrub and wetland were changed to agricultural land and 3.2 million acres of wild life habitat disappeared in North and South Dakotas alone (Faber et al., 2012). Grasslands are one of the most threatened and least protected ecosystems. Worldwide, the NGP ecoregion in North America is considered one of best remaining opportunities for grassland maintenance (Schrag et. al., 2012). Similarly, other common side effects of land-use change are increased greenhouse gas emissions (Searchinger, 2008; Tilman, 2006), reduced water quality (Moss, 2008), and higher soil erosion (Montgomery, 2007).

Various management practices like the maintenance of soil health along with soil organic carbon, erosion minimization, protection from salt accumulation and consideration of several services provided by various resources are main factors impacting sustainability in South Dakota (Clay et al., 2012, 2014, 2015; Cook et al., 2015; He et al., 2013, 2015). Reitsma et al. (2015) failed to link land-use changes in south Dakota to one specific driving factor and they reported that change most likely resulted from of many factors including recent technological improvements, land ownership structure changes, climate variability, various governmental policies, crop prices, and aging workforce (Reitsma et al., 2015; Clay et al., 2014; Lee et al., 2014; Mamani-Pati et al., 2014).

Technology improvements, such as the development of new planting equipment and the wide scale adoption of transgenic crops have provided the opportunity to seed annual crops in areas that previously were considered unsuitable for crop production (Clay et al., 2014). Moreover, complex interaction of various factors like climatic variability, soil quality, topography and socio-economic factors may influence individual decisions (Rindfuss et al., 2004; Global Land Project, 2005; Turner et al., 2007). In the NGP, higher rainfall and temperatures linked to climate change may be especially important (Hatfield et al., 2011; Schrag, 2011). Land conversion to cropland may can be not be appropriate with the prospective of sustainability if change occurs in unsuitable land (Reitsma et al., 2015). Rashford (2012), found that between 1978 and 2008, 0.4 million hectare of cropland increased and most of this converted land had suitable soil quality (land capability classes 1-4). Similarly, another study estimated that grassland with LCC 1 and 2 have a 30 to 50% greater probability of being converted to cropland than grassland with LCC values of 3 and 4 (Rashford et al., 2010). These findings are in agreement with Lark et al. (2015) who reported that for land-use conversion between 2008 and 2012 occurred primarily on land not suited for crop production.

For individual farms and ranchers, the conversion of grassland to croplands has a potential to increase family income and produce local jobs. However, from a social perspective the conversion of grasslands to croplands will reduce habit for wildlife, reduce water quality and increase emission of greenhouse gasses. Thus, land conversion from grasslands to croplands creates the classical dilemma of balancing economic development with environmental impacts.

In light of tremendous pressure on land and various forces driving land-use change, it is essential to examine the dynamics of land changes. The objectives of this study were to 1) calculate the rate of land-use changes from 2006 to 2012 and from 2012 to 2014 in South Dakota and Nebraska; 2) assess if land-use changes were impacted by different land capability classes; and 3) determining the relationship between land uses, and soil sustainability. This region was selected as a model system because it is located in a climate transition zone which have a humid continental zone in the east making it suitable for crop production, and a semiarid zone in the west, dominated with grasslands or irrigation (Elder, 1969; McKnight, 1996).

Materials and Methods

This study was conducted in South Dakota and Nebraska. The eastern portion of South Dakota is dominated with the glacial drift soils and it considered highly suited for annual crop production. This region receives most of its precipitation in the spring and fall (Clay et. al., 2014). The most common annual crops in South Dakota include corn (Zea mays L.), soybean [(Glycine max (L.) Merr.], and wheat (Triticum aestivum L.). In South Dakota rainfall decreases from east to west and temperatures decrease from South to North. On the western portion of South Dakota, the soils are not glaciated and the dominant land-use is beef production on native grasslands. South Dakota's western and rolling shale plain region has parent materials dominated by marine shale with the exception of the sandy and silty tablelands in Southwest South Dakota. These non-glaciated shale soils have shrink–swell clays and crop production that is often limited by low plant available water, steep slopes, and saline-sodic conditions. Farmers in this region, use crop rotations that include corn, soybean, wheat, sunflower, canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.), lentil (*Lens culinaris* Medik.), flax (*Linum usitatissimum* L.), and pea (*Pisum sativum* L.).

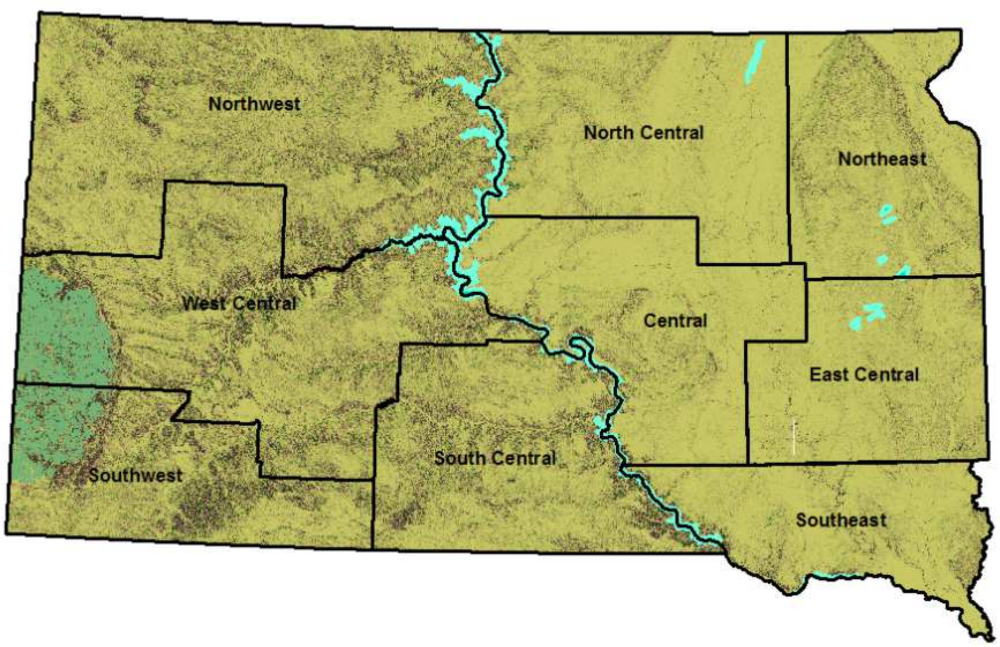

Fig 1. 1. USDA – NASS reporting regions of South Dakota
(Source of Data, USDA – NASS)

Nebraska can be separated into the eastern and western components. Eastern Nebraska has a humid continental climate, whereas the western region has a semiarid climate (Elder 1969; McKnight 1969). Eastern Nebraska which has fertile, moist and warm soil making it well suited for corn and soybean production. It consists of loess and glaciated till soils. The Nebraska Sand hills, are contained almost entirely within the Nebraska North NASS region (Fig 1.2), and it represents one of the most unique and homogenous ecoregions in North America (Omernick, 1987; U.S. Environmental Protection Agency, 1997). The Sand hills are one of the largest areas of semiarid grass stabilized sand dunes in the world (Grassland Foundation, 2005).

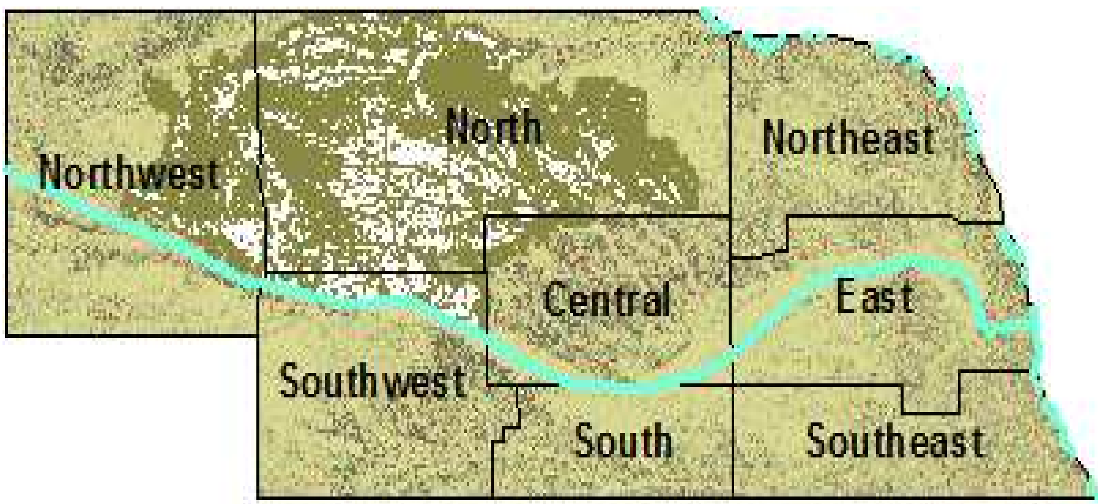

Fig 1. 2. NASS regions in Nebraska
(Source of Data, USDA – NASS)

Assessing Land Use Change

South Dakota has 9 NASS regions (USDA- NASS, 2015) that include the Northeast (NE), South East (SE), North Central (NC), East Central (EC), Central (C), South Central (SC), Northwest (NW), West Central (WC) and South West (SW) (Fig 1.1). Nebraska has 8 NASS regions that include the Northwest (NW) , North (N), Northeast (NE), Central (C), East (E), South west (SW), South (S), South east (SE) (Fig 1.2). Stratified random sampling approach was used for sampling within each of 17 USDA NASS reporting districts of South Dakota and Nebraska. In each NASS region, 1600 points were randomly identified. These points were laid over high resolution imagery, obtained from United States Department of Agriculture (USDA), Farm Service Agency (FSA), National Agricultural Imaging Program (NIAP) (USDA-FSA, 2013). NIAP data is collected during the growing season and information from 3 bands (blue, green, and red) were used to construct a natural color image. The NAIP imagery for 2006 had a 2 m resolution and the 2012 and 2014 imagery had a 1 m resolution. The approximate dimensions for each of the 27,200 points was 8 by 8 m. Based on various crop rows, streams, roads, forest and buildings within each sampling point, dominant land use was classified into five different categories (Cropland, Grassland, Habitat, Non-Ag and Water for 2006, 2012 and 2014 separately. Each point was assessed 3 times (2006, 2012, and 2014). In South Dakota, 43,200 points in total were visually classified (14,400 points each year). Similarly in Nebraska, 38,400 points were classified (12,800 points each year) over same three years. Thus in total 81,600 points were classified for both states. For validation we randomly selected 100 sampling points from 17 different counties of South Dakota following reclassification for each three different years. The reclassification and field observed classification were identical 100% of time.

Assessing changes in soil quality

Land Capability class (LCC) and dominant subclass were obtained from the Soil Survey Geographic (SSURGO) data set by superimposing the sampling points over SSURGO (Soil Survey Staff, 2015). SSURGO is digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS). The LCC classifies soil into 8 different classes on the basis of their capabilities for use and limitations in each class become progressively greater from class 1 to 8. Class 1 to 4 are considered suitable for cropland if appropriate soil management practices are considered. Class 5 has little erosion limitation however because of excess water, its use is restricted. LCC 6 to 8 have severe restrictions that make them unsuitable for crop cultivation and largely these classes are used for pasture, grassland, wild life, and recreation purposes. LCC subclasses are used to help define the limitation. The most common subclass limitations are erosion hazard (e), wetness (w), rooting- zone limitations (s), and climate (c).

Results and Discussion

Land use changes in Nebraska from 2006 to 2012

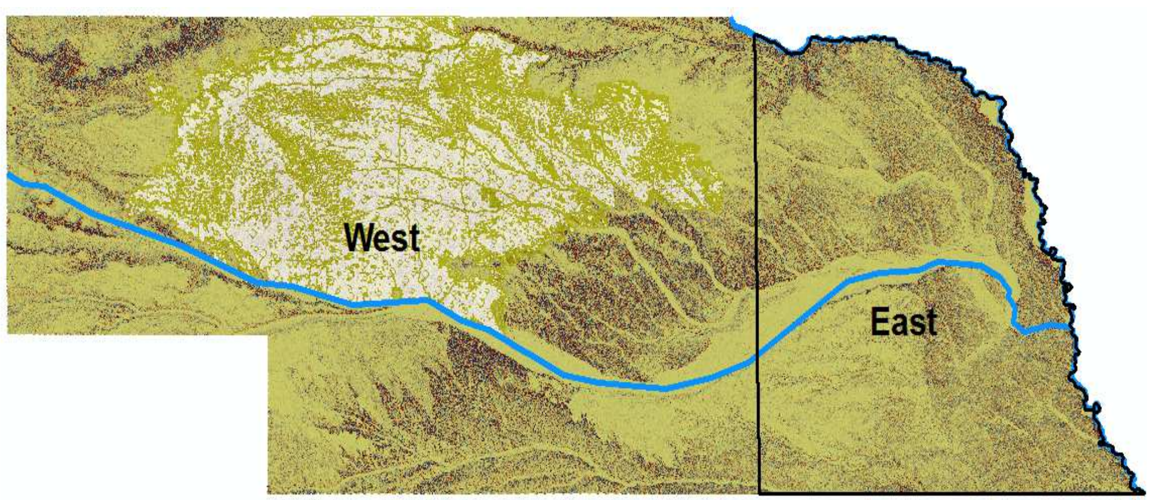

Fig 1. 3. Eastern and western Regions of Nebraska
(Source of Data, USDA – NASS)

In Nebraska**,** 43% of the selected points were in croplands and 45% of the selected points were in grasslands in 2006 and 2012. Based on the selected point data it appears that between 2006 and 2012, 250,000 hectares of grassland were converted to cropland at the rate of 41,670 ha year^{-1}. At the grassland to cropland converted sites, 92 % had Land capability classes that were 4 or less. For comparison, 67.9 % of the grassland sampling sites had LCC values > 5 (Table 1.1). In Nebraska, the state was separated into eastern and western portions (Fig. 1.3). The eastern portion contained 3 NASS regions, whereas the western region contained 5 regions. In eastern Nebraska, 130,000 ha grassland, an average 21,670 ha year^{-1} were converted to cropland between 2006 and 2012. At these converted sites, 89.8 % had LCC values less than or equal to 4. The Grassland to Cropland change category had 10.2 % of sampling site in higher LCC classes (6, and 7). In western Nebraska, 120,000 ha grassland at an annual rate of 20,000 ha year^{-1} were estimated to change from the grassland to cropland category. At these converted sites, 56.6% occurred on soils with LCC values that were less than or equal to 4. Based on these findings, western Nebraska grassland to cropland changed occurred in soils with higher LCC classes.

Table 1. 1. Land Use Change in different Soil Type of Nebraska from 2006 to 2012

			Land Capability Class(LCC) within a category with confidence interval for each proportion in parentheses								
Change category		Location	LCC I	LCC II	LCC III	LCC IV	LCC V	LCC VI	LCC VII	Points	Estimated Land
2006	2012					%					ha x 1000
Crop	Crop	NE	7.42(0.35)	47.95(0.67)	24.66(0.58)	12.02(0.44)	0.15(0.05)	7.71(0.36)	0.04(0.03)	5514	7100
Crop	Grass	NE	9.09(8.67)	54.55(15.01)	0	36.36(14.20)	0	0	0	11	15
Grass	Crop	NE	2.72(1.20)	21.74(3.04)	24.46(3.17)	27.17(3.28)	1.09(0.76)	22.83(3.09)	0	184	250
Grass	Grass	NE	0.37(0.08)	7.58(0.35)	10.61(0.41)	13.59(0.45)	1.41(0.16)	60.75(0.64)	5.02(0.29)	5740	10750
Crop	Crop	East	11.80(1.18)	41.11(1.79)	30.35(1.68)	13.49(1.25)	0.10(0.12)	2.98(0.62)	0	2890	3600
Crop	Grass	East	14.29(25.92)	57.14(36.66)	0	28.57(33.47)	0	0	0	7	9
Grass	Crop	East	4.63(3.96)	25(8.17)	27.78(8.45)	32.41(8.83)	0.93(1.81)	9.26(5.47)	0	108	130
Grass	Grass	East	1.67(0.76)	18.87(2.33)	30.71(2.75)	26.46(2.63)	1.11(0.62)	20.26(2.40)	0.46(0.40)	1081	1310
Crop	Crop	West	2.59(0.61)	55.49(1.90)	18.29(1.48)	10.40(1.17)	0.19(0.17)	12.92(1.28)	0.08(0.11)	2624	3500
Crop	Grass	West	0	50(49)	0	50(49)	0	0	0	4	6
Grass	Crop	West	0	17.11(8.47)	19.74(8.95)	19.74(8.95)	1.32(2.56)	42.11(11.10)	0	76	120
Grass	Grass	West	0.06(0.07)	4.96(0.62)	5.95(0.68)	10.60(0.88)	1.48(0.35)	70.14(1.31)	6.07(0.69)	4659	9440

Land Use Changes in Nebraska from 2012 to 2014

Between 2012 and 2014, 110,000 ha, of grassland were converted to cropland. At these sites, 83.8% had LCC values of 4 or less.

In eastern Nebraska, 60,000 ha, of grassland were changed to cropland. At these sites, 87.8 % occurred on soils with LCC values of 4 or less. The rate of change between 2012 and 2014 represents an increase, relative to the 2006 to 2012 that change occurred. In western Nebraska, 50,000 ha, at an annual rate of 25,000 ha $year^{-1}$ of grassland was converted to cropland between 2012 and 2014. At these sites, 76 % of changes occurred in soils with LCC values that were less than or equal to 4. These values suggest that land-use change primarily occurred on land considered suitable for crop production.

Table 1. 2. Land-Use Change in different Soil Type of Nebraska from 2012 to 2014

			Land Capability Class(LCC) within a category with standard errors for each proportion in parentheses								
Change category		Location	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Points	Estimated Land
2012	2014		%								ha x 1000
Crop	Crop	NE	7.27(0.67)	47.09(47.09)	24.65(1.12)	12.52(0.86)	0.18(0.11)	8.20(0.17)	0.04(0.05)	5695	7370
Crop	Grass	NE	0	37.5(33.5)	37.5(33.5)	12.5(22.92)	0	12.5(22.92)	0	8	12
Grass	Crop	NE	1.35(2.63)	25.68(9.95)	32.43(10.67)	24.32(9.78)	0	16.22(8.40)	0	74	110
Grass	Grass	NE	0.37(0.16)	7.40(0.68)	10.27(0.79)	13.51(0.89)	1.44(0.31)	61.24(1.27)	5.07(0.57)	5679	10670
Crop	Crop	East	11.55(1.14)	40.52(1.76)	30.34(1.65)	14.19(1.25)	0.13(0.13)	3.20(0.63)	0	2996	3710
Crop	Grass	East	0	25(42.44)	50(49.0)	25(42.44)	0	0	0	4	5
Grass	Crop	East	2.04(3.96)	30.61(12.90)	30.61(12.90)	24.49(12.04)	0	12.24(9.18)	0	49	60
Grass	Grass	East	1.73(0.79)	18.40(2.36)	30.44(2.80)	26.59(2.69)	1.16(0.65)	20.71(2.47)	0.48(0.42)	1038	1260
Crop	Crop	West	2.58(0.61)	55.80(1.90)	18.81(1.49)	10.95(1.19)	0.23(0.18)	14.10(1.33)	0.08(0.11)	2699	3660
Crop	Grass	West	0	50(49)	25(42.44)	0	0	25(42.44)	0	4	7
Grass	Crop	West	0	16(14.37)	36(18.82)	24(16.74)	0	24(16.74)	0	25	50
Grass	Grass	West	0.06(0.07)	4.93(0.62)	5.75(0.67)	10.58(0.88)	1.51(0.35)	70.31(1.31)	6.10(0.69)	4641	9410

Land Use Changes in South Dakota from 2006 to 2012

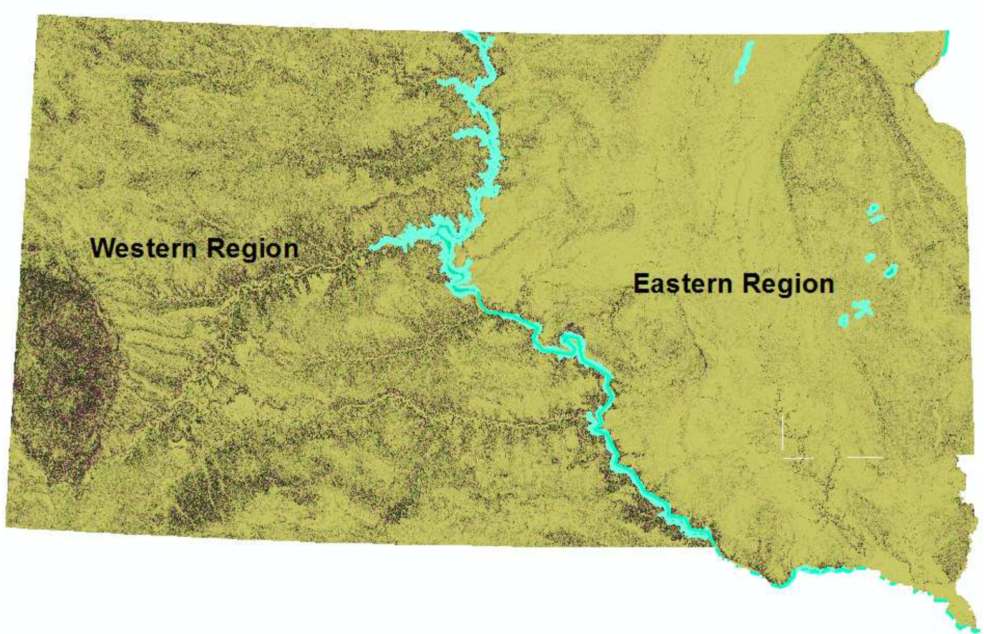

Fig 1. 4. Eastern and Western Region of South Dakota State
(Source of Data, USDA – NASS)

Between 2006 and 2012, 5.78% (700,000 ha) of total state grassland (12,120,000 ha), was converted to cropland. 50.9% of this change occurred on soils with a LCC class of 2, and 92.6 % occurred in soils with LCC values that were 4 or less (Table 1.3).

South Dakota was split into eastern and western portions (Fig. 1.4). In Eastern South Dakota, 480,000 ha of grasslands were converted to cropland between 2006 and 2012. In this region, 94.5% occurred in soils with LCC values of 4 or less. In western South Dakota, 220,000 ha of grassland were converted to cropland. In western South Dakota, 86.8% of the sites has LCC values of 4 or less.

Table 1. 3. Land Use Change in different Soil Type of South Dakota from 2006 to 2012

			Land Capability Class (LCC) within a category with confidence interval for each proportion in parentheses								
Change category		Location	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Number Points	Estimate Land
2006	2012		%								ha x 1000
Crop	Crop	SD	7.82(0.41)	63.35(0.74)	14.89(0.54)	10.16(0.46)	0.61(0.12)	2.88(0.26)	0.23(0.07)	4270	5130
Crop	Grass	SD	4.76(1.55)	54.5(3.62)	17.46(2.76)	12.17(2.38)	4.23(1.46)	5.29(1.63)	1.59(0.91)	189	270
Grass	Crop	SD	2.6(0.69)	50.93(2.16)	24.72(1.86)	14.31(1.51)	0.56(0.32)	6.13(1.03)	0.74(0.37)	538	700
Grass	Grass	SD	0.45(0.08)	16.79(0.44)	15.11(0.42)	16.95(0.44)	1.02(0.12)	30.24(0.53)	17.3(0.44)	7381	11420
Crop	Crop	East	8.94(0.92)	67.60(1.50)	11.30(1.02)	9.35(0.93)	0.67(0.26)	2.04(0.45)	0.08(0.09)	3734	4210
Crop	Grass	East	5.96(3.78)	62.91(7.70)	9.27(4.63)	11.26(5.04)	5.30(3.57)	3.97(3.12)	1.32(1.82)	151	200
Grass	Crop	East	3.48(1.79)	59.45(4.80)	19.40(3.87)	12.19(3.20)	0.75(0.84)	3.98(1.91)	0.75(0.84)	402	480
Grass	Grass	East	1.38(0.47)	38.48(1.95)	14.81(1.42)	17.82(1.53)	2.47(0.62)	15.77(1.46)	8.20(1.10)	2391	2890
Crop	Crop	West	0	33.77(4)	39.93(4.15)	15.86(3.09)	0.19(0.37)	8.77(2.39)	1.31(0.96)	536	920
Crop	Grass	West	0	21.05(12.96)	50(15.90)	15.79(11.59)	0	10.53(9.76)	2.63(5.09)	38	70
Grass	Crop	West	0	25.74(7.35)	40.44(8.25)	20.59(6.80)	0	12.50(5.56)	0.74(1.44)	136	220
Grass	Grass	West	0	6.39(0.68)	15.25(1)	16.53(1.03)	0.32(0.16)	37.17(1.34)	21.66(1.14)	4990	8530

Land Use Changes in South Dakota from 2012 to 2014

From 2012 to 2014, 1.79% of South Dakota's grasslands were converted to cropland at the rate of 105,000 ha year^{-1} which was slightly lower (116,700 ha/year) than the rate between 2006 and 2012. At these sites, 91.7% occurred in soils with LCC values of 4 or less (Table 1.4). The conversion of grasslands to croplands was concentrated in Eastern South Dakota and 92.5% of changes occurred on soils characterized as LCC 4 or less. Less than 5% of the change occurred on soils characterized as 6 or 7.

19.1% of state grassland to cropland changes occurred in western South Dakota. Of the converted sites, 85.7% of the grassland to cropland category occurred in soils with LCC values of 4 or less. Less than 15% of the change occurred in soils with LCC classes that were 6 or greater.

Table 1. 4. Land Use Change in different Soil Type of South Dakota from 2012 to 2014

Land Capability Class (LCC) within a category with confidence interval for each proportion in parentheses

Change category		Location	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Estimate Land
2012	2014					%				ha x 1000
Crop	Crop	SD	7.42(0.74)	62.37(1.37)	15.59(1.02)	10.42(0.86)	0.66(0.23)	3.14(0.49)	0.37(0.17)	5810
Crop	Grass	SD	0.94(1.84)	47.17(9.50)	22.64(7.97)	18.87(7.45)	1.87(2.59)	7.55(5.03)	7.55(5.03)	150
Grass	Crop	SD	2.38(2.31)	61.90(7.34)	10.71(4.68)	16.67(5.64)	2.38(2.31)	5.95(3.58)	0	210
Grass	Grass	SD	0.56(0.17)	17.58(0.86)	15.10(0.81)	16.78(0.84)	1.07(0.23)	29.82(1.03)	17.01(0.85)	11540
Crop	Crop	East	8.56(0.85)	66.89(1.42)	11.86(0.98)	9.47(0.89)	0.74(0.26)	2.17(0.44)	0.24(0.15)	4720
Crop	Grass	East	1.23(2.40)	58.02(10.75)	14.81(7.74)	17.28(8.23)	2.47(3.38)	6.17(5.24)	0	100
Grass	Crop	East	2.72(2.63)	67.35(7.58)	7.48(4.25)	14.97(5.77)	2.72(2.63)	4.76(3.44)	0	170
Grass	Grass	East	1.66(0.29)	39.57(1.90)	14.39(1.37)	17.26(1.47)	2.60(0.62)	15.53(1.41)	8.08(1.06)	3000
Crop	Crop	West	0	32.92(3.62)	39.72(3.77)	16.54(2.86)	0.15(0.30)	9.43(2.25)	1.24(0.85)	1090
Crop	Grass	West	0	12(12.74)	48(19.58)	24(16.74)	0	12(12.74)	0	50
Grass	Crop	West	0	23.81(18.22)	33.33(20.16)	28.57(19.32)	0	14.29(14.97)	0	40
Grass	Grass	West	0	6.42(0.68)	15.47(1)	16.53(1.03)	0.30(0.15)	37.07(1.34)	21.55(1.14)	8540

Land use change in adjacent grassland dominated NASS region

To compare land use changes in South Dakota and Nebraska, two adjacent NASS regions North (N) region of Nebraska and South Central region of South Dakota were compared. The Nebraska North NASS region is composed of almost entirely of the Sand Hills. This area is a zone where grass has stabilized the sand dunes. In this region, the thickness of sand layer ranges from a few meters to 122 m (Huntzinger and Ellis, 1993). Sandy soils of this region have Low water holding capacity which allows high infiltration rates and no or low surface water runoff. Due to deep sandy soils, Sand hills land use is mostly limited to rangeland, shrub land and hay production. The South Central NASS region of South Dakota is just adjacent NASS region to sand hill. It expands on the west side of Missouri river with semi-arid climate and is mostly dominated with grassland.

In the North NASS region of Nebraska 840,000 ha of land was cropland in both 2006 and 2012. Most of this land (77.6%) had a LCC value that was 4 or less (Table.6). In this region, 90.2% of grasslands occurred on soils with a LCC greater than 4. Whereas in South central region of South Dakota, most of the croplands (94.75% of 620,000 ha) had LCC values that were 4 or less. Grasslands are equally distributed among the different LCC categories as 44.9% of total grassland (3140, 000 ha) were found to have LCC values that were 4 or less with the remaining having LCC values > 4. Between 2006 and 2012, 87,000 ha of land were converted from grasslands to croplands in in North Nebraska. This change primarily (61%) occurred on land with LCC of 6. In the South Dakota region directly north of the Nebraska North region (South Dakota South-central (Table 1.5 and 1.6), 210,000 ha of land were converted from grassland to croplands.

Out of 210,000 ha of grassland that were converted, only 13.51 % of total conversion occurred on land with a LCC value of 6 (Table 1.5).

Between 2012 and 2014, land-use changes continued in these regions. In North Nebraska, 80,000 ha of grassland were converted to cropland between 2012 and 2014. Approximately 1/3 of this change occurred in land with a LCC value of 6. Lower rates of change occurred in the South Dakota's South Central region where 10,000 ha of land were converted. Differences between the two states are attributed to the availability of irrigation.

Table 1. 5. Land Use-Changes in the South Central region as impacted by LCC from 2006 to 2012 and 2012 to 2014

Change category		LCC I	LCC II	LCC III	LCC IV	LCC V	LCC VI	LCC VII	Estimated Land
		Land Capability Class(LCC) within a category with confidence interval for each proportion in parentheses							
2006	2012	%							ha x 1000
Crop	Crop	0	36(6.31)	43.05(6.50)	15.70(4.77)	0.45(0.88)	4.04(2.58)	0.45(0.88)	620
Crop	Grass	0	33.33(30.80)	33.33(30.80)	33.33(30.80)		0	0	25
Grass	Crop	0	28.38(10.27)	37.84(11.05)	20.27(9.16)	0	13.51(7.79)	0	210
Grass	Grass	0	6.61(1.45)	18.48(2.27)	19.82(2.33)	0.80(0.52)	32.41(2.74)	20.36(2.36)	3140
2012	2014								
Crop	Crop	0	34.24(5.41)	41.69(5.63)	16.95(4.28)	0.34(0.66)	6.44(2.80)	0.34(0.66)	820
Crop	Grass	0	50(69.30)	50(69.30)	0	0	0	0	6
Grass	Crop	0	40(42.94)	20(35.06)	20(35.06)	0	20(35.06)	0	14
Grass	Grass	0	6.59(1.45)	18.61(2.28)	20.04(2.34)	0.80(0.52)	32.15(2.73)	20.30(2.35)	3130

Table 1. 6. Land Use Change in different Soil Type of North Nebraska from 2006 to 2012 and 2012 to 2014

		Land Capability Class(LCC) within a category with confidence interval for each proportion in parentheses							
Change category		LCC I	LCC II	LCC III	LCC IV	LCC V	LCC VI	LCC VII	Estimated Land
2006	2012				%				ha x 1000
Crop	Crop	2.40(2.68)	29.60(8.00)	21.60(7.49)	24(7.49)	1.60(2.20)	20.80(7.12)	0	838
Crop	Grass	0	0	0	0	0	0	0	0
Grass	Crop	0	7.69(14.49)	15.38(19.61)	15.38(19.61)	0	61.54(26.45)	0	87
Grass	Grass	0	1.16(0.57)	2.25(0.78)	6.32(1.29)	3.92(1.03)	83.28(1.97)	2.54(0.83)	9230
2012	2014								
Crop	Crop	2.16(2.42)	28.06(7.47)	20.86(6.76)	23.02(7)	1.44(1.98)	24.46(7.15)	0	930
Crop	Grass	0	0	0	0	0	0	0	0
Grass	Crop	0	8.33(15.64)	33.33(26.67)	25(24.50)	0	33.33(26.67)	0	80
Grass	Grass	0	1.10(0.55)	1.98(0.74)	6.16(1.28)	3.96(1.03)	83.65(1.96)	2.57(0.84)	9150

Land use change in adjacent Cropland dominated NASS region

For the comparison of land use change and soil quality of the region dominated with croplands, South East (SE) NASS district of South Dakota and North East (NE) NASS region of Nebraska were selected. Both NASS districts are adjacent to each other, with cropland as dominated land use. South East South Dakota had 1,710,000 ha of cropland in 2006 and 96.83% of this total cropland had n LCC values <4. The 25,000 ha of Grassland that were converted to cropland between 2006 and 2012, was primarily concentrated on land with LCC values less than 4 (92.3%) (Table.1.7). However, from 2012 to 2014, the grassland to cropland changes accelerated (50,000 ha). North East Nebraska had 2,590,000 ha of cropland in 2006 and most of these croplands were in suitable soil, LCC <4 (Table1.8). From 2006 to 2012 and 2012 to 2014, 160,000 and 70,000 ha of grassland was converted to cropland in North NASS region of Nebraska. Unlike South East South Dakota, this region had higher proportion of changes that occurred on soils with higher LCC values. During first six years period 11.29% of total conversion occurred on soils with LCC values greater than 4.

Table 1. 7. Land Use Change in different soil type of South East South Dakota and North East Nebraska

Land Use Change in different Soil Type of South East South Dakota from 2006 to 2012 and 2012 to 2014

Change category		LCC I	LCC II	LCC III	LCC IV	LCC V	LCC VI	LCC VII	Estimated Land
2006	2012				%				ha x 1000
Crop	Crop	18.03(2.54)	60.54(3.23)	7.26(1.71)	11(2.06)	1.02(0.66)	2.15(0.96)	0	1710
Crop	Grass	10.13(6.65)	56.96(10.92)	7.59(5.84)	10.13(6.65)	8.86(6.27)	5.06(4.83)	1.27(2.47)	140
Grass	Crop	15.38(19.61)	53.85(27.10)	15.38(19.61)	7.69(14.49)	0	7.69(14.49)	0	25
Grass	Grass	1.24(1.71)	39.75(7.56)	8.70(4.35)	10.56(4.75)	0	25.47(6.73)	14.29(5.41)	310
2012	2014								
Crop	Crop	17.08(2.32)	60.91(3)	7.31(1.60)	10.76(1.91)	1.18(0.67)	2.17(0.90)	0.39(0.39)	2000
Crop	Grass	0	75(24.50)	0	8.33(15.64)	16.67(21.09)	0	0	20
Grass	Crop	3.70(7.12)	85.19(13.40)	0	7.41(9.88)	3.70(7.12)	0	0	50
Grass	Grass	3.06(1.78)	48.47(5.17)	8.64(2.91)	10.58(3.18)	3.06(1.78)	17.83(3.96)	8.36(2.86)	700

Land Use Change in different Soil Type of North East Nebraska from 2006 to 2012 and 2012 to 2014

Change category		LCC I	LCC II	LCC III	LCC IV	LCC V	LCC VI	LCC VII	Estimated Land
2006	2012				%				ha x 1000
Crop	Crop	8.12(1.71)	32.79(2.93)	35.03(2.98)	19.90(2.49)	0.10(0.20)	3.96(1.22)	0	2590
Crop	Grass	100(0.0)	0	0	0	0	0	0	3
Grass	Crop	0	24.19(10.66)	25.81(10.89)	38.71(12.12)	0	11.29(7.88)	0	160
Grass	Grass	1.16(1.13)	18.84(4.13)	13.62(3.62)	33.04(4.96)	2.32(1.59)	29.86(4.83)	1.16(1.13)	910
2012	2014								
Crop	Crop	7.63(1.61)	32.32(2.83)	34.41(2.88)	21.07(2.47)	0.10(0.19)	4.39(1.24)	0.10(0.19)	2500
Crop	Grass	0	0	0	100(0)	0	0	0	3
Grass	Crop	0	26.92(17.05)	23.08(16.20)	34.62(18.29)	0	15.38(13.87)	0	70
Grass	Grass	1.56(1.35)	18.07(4.21)	12.77(3.65)	32.71(5.13)	2.49(1.71)	31.15(5.07)	1.25(1.21)	840

Land Use Change, Soil and Environmental Sustainability

The land capability class system was used to assess the risks of different land uses and it classifies soil into 8 different classes on the basis of their capabilities for use. Classes 1 to 4 are considered suitable for cropland and farming if appropriate soil management practices are considered. For these classes, the restrictions and slope generally increase with the category number. Class 5 has little erosion limitation, however because of excess water, its use is restricted. LCC 6 to 8 have severe restriction that make them unsuitable for crop cultivation and largely these classes are used for pasture, grassland, wild life and recreation purposes. For soils with LCC values 6 to 8, the restrictions and the slope generally increase with the value. New expansion of cropland and cultivated areas cannot be sustainable if it occurred in marginal land having severe limitation of cultivation. As a result, cultivation in such areas can be detrimental to the environment by reducing soil health, depletion in organic carbon, and increasing soil erosion and salinization.

Grasslands, increase plant and animal diversity. Often these areas produce more ecosystem services than cropland (Werling et al., 2014). Ecosystem services include methane consumption, pest suppression, pollination and protection of wildlife like grassland birds. However, due to reduced root density in newly expanded cropland, grassland to cropland conversion often results in less stable soil structure and reduced soil water infiltration. Thus ultimately, the conversion of grasslands to croplands can result in increased erosion if suitable management practices are not adopted (Lindstrom et al., 1994; Clay et al., 2012). Moreover, with cultivation, soil temperature and microbial activity together enhance decomposition of organic matter resulting in soil organic carbon losses (Zhang et al., 1988). Similarly, conversion of perennial grasses to annual crop reduces the root biomass production and ultimately reduces total carbon input in the soil from root biomass (Richter et al 1990).

Land use changes may be driven by a desire to stabilize economic returns in an environment of high climatic variability. In the northern Great Plains, changing climatic condition is impacting agriculture in various ways. Higher temperature, changing precipitation pattern, increasing CO_2 levels and extreme climatic events like drought, directly affect food production and land-use. Higher temperature are providing more suitable condition to grow annual crops by lengthening growing season (Schrag, 2011). Precipitation variability is projected to increase in Northern Great Plains (Schrag, 2011; Clay et al., 2014), while increasing atmospheric CO_2 level helps by improve water-use efficiency and crop productivity (van der Steen et al., 2015). Similarly, droughts result in losses in crop yield, grazing capacity, ground water, and plant composition and hydrologic condition of rangeland.

As discussed earlier, one of the primary factor influencing land-use change is economics. Farm economics is influenced by prices received by farmers, and yield and crop production costs (Janssen et al., 2013; Pflueger, 2011; Bourlionet al., 2013). These potential returns and cost vary in time and space. For example, during the period of 2006-2012, Corn prices doubled from 3.04 \$/bu to 6.89 \$/bu. Although the corn cost of production was lowest in 2000 (\$395 ha^{-1}) and peaked in 2012 (\$ 1,192.5 ha^{-1}) and then decreased to \$ 1,002.5 ha^{-1} in 2015. Similarly, soybean had similar changes in production cost and selling prices. Marketing year average soybeans price received doubled from \$ 236.24 Mg^{-1} in 2006 to \$529.06 Mg^{-1} in 2012. However, during the period between 2012 and 2014, the Soybean price decreased from \$529.06 Mg^{-1} to \$371.07 Mg^{-1} and corn prices decreased from \$253.14 Mg^{-1} to \$135.94 Mg^{-1} (US Department of Agriculture, NASS, 2015).

Agricultural land market trend in South Dakota and Nebraska

From 2011 to 2014, the average value of all agricultural land in South Dakota increased from \$3,350 ha^{-1} to \$6,175 ha^{-1}. The largest gains were observed in highly productive eastern South Dakota. For example, in the south east and east central South Dakota NASS regions, non-irrigated cropland had value of \$15,827.5 ha^{-1} and \$17,785ha^{-1} respectively in 2014. Slightly lower values were observed in the in the Northeast where land values increased from \$7,295 ha^{-1} in 2011 to \$13,227 ha^{-1} in 2014. Similar increases were observed in the North central and central regions. In Southwest South Dakota, land value increases were much lower and from 2011 to 2014 it increased from \$1,562 ha^{-1} to \$2,050 ha^{-1}.

Native rangelands are highly concentrated in the western and central regions of South Dakota, whereas managed pastures are scattered without any particular region of state. Rangeland and pasture values also tends to cluster in three different groups. East central and southeast regions had the highest rangeland values of \$7,152 and \$6,745 ha^{-1} respectively. When compared with 2011, these values represent a 60.82% and 69.79% increase in value. In the second cluster which consist Northeast, North-central and central

NASS regions with the per hectare value $4647.5, $4000, $4570 dollars respectively. These regions had value increases of 52.75, 68.42, 80.81 % change from 2011 to 2014. The regions with lowest range value were located in the western part of state and were $ 2,967.5 ha^{-1} in South Central, $ 1,427.5 ha^{-1} in South West and $ 1,090 ha^{-1} in North West in 2014. The SC, SW, and NE regions had 87.2, 39.6 and 41.1 % increase in rangeland value from 2011 to 2014.

Like South Dakota**,** Nebraska regional cropland values were clustered into the Northeast, central, and western regions. From 2006 to 2014, the value of dry land cropland with irrigation potential in the Northeast increased from $4,102 to 16,075 per hectare. Similar increases were observed in the east and south east areas. In the Central region, land value increased from $3,625 ha^{-1} in 2006 to $12,275 ha^{-1} in 2014. Similar gains were observed in the Southern region. Western regions of the state had the lowest price per hectare acre and value increases. For example, in the Northwest land value increased from $1,137 ha^{-1} to $ 2,337 ha^{-1} from 2006 to 2014.

Summary

In many situations, land-use changes are driven by a desire to create wealth and produce jobs. Along with economic opportunities to local families, recent technological improvements, land ownership structure changes, climate variability, various governmental policies, and aging workforce are major driving factor for changing grassland to cropland. Along with these factors, it may also be driven by a desire to stabilize economic returns in an environment of high climatic variability and a goal of increasing the land value. For example, irrigated cropland had a higher value than grazing lands.

It is possible that increased land use change from 2012 to 2014 may be related to actions taken to respond the 2012 drought. For example, ranchers who faced severe drought during 2012 to 2014, sold their cattle and bulls and may have plowed their grassland in order to produce an economic return. However total changes in land use are not random.

In the northern Great Plains, changing climatic condition is impacting agriculture in various ways. Higher temperature, changing precipitation pattern, increasing CO_2 levels and extreme climatic events like drought, directly affect food production and land use. Our research shows that South Dakota State had higher amount of grassland to cropland changes than Nebraska during both study periods. During first six year period, 700,000 hectares of grassland was changed to cropland in South Dakota, whereas it was only 250,000 ha in Nebraska. From 2012 to 2014, cropland increase by 210,000 ha in South Dakota. During this time Nebraska had only 110,000 ha of new cropland. The higher conversion rates in South Dakota than Nebraska, are attributed to the type of land available for conversion. In Nebraska, between 2006 and 2012 and between 2012 and 2014, about 25% of the change occurred on soil considered not suitable for cropland (LCC < 4) respectively. However, in South Dakota, over 90% of the land that was converted was considered suitable for croplands. In the North Nebraska NASS region, 80,000 ha of grassland were converted to cropland between 2012 and 2014. Approximately 1/3 of this change occurred in land with a LCC value of 6. Lower rates of change occurred in the South Dakota's South Central region where 10,000 ha of land were converted. Differences between the two states most likely are related to availability of an irrigation supply.

Different results were observed in South central South Dakota, where, 28.4, 37.8 and 20.3% of total change occurred in LCC 2, 3, and 4 respectively and only 13.5 % of total conversion occurred on lands classified with LCC 6.

Between 2012 and 2014, the Nebraska sand hills region (North) had higher proportion of grassland that were converted to cropland with higher LCC values than the South Dakota South central region. Soil type of the grasslands in Sand hill region of Nebraska are in higher LCC values and grassland to cropland conversion in this region are occurring in higher LCC values. Again, soil types with higher LCC values are not considered suitable for cropland and this conversion may be less sustainable. Thus, Nebraska grassland conversions may be unsustainable. However, in both of the states, most of the land use changes occurred in eastern regions of the states in comparison to the western regions and land use changes more clustered in the regions with higher land values. As higher increase in per hectare value was in the East central and southeast regions whereas lowest range value were in the western part of state.

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Chapter 2

Change in Carbon Turnover rate due to seasonal change

Abstract

Northern Great Plain grassland possesses a large amount of soil and plant carbon. The cycling of carbon among the plants, soil, and atmosphere is influenced by many factors including seasonal climate variation, soil properties, grass morphology, and tissue chemistry. To understand the complexity of above ground litter decomposition, we assessed the influence of biomass quality and soil moisture on annual litter decomposition rates. We hypothesized that net annual carbon turnover is influenced by seasonal climate variability and biomass quality. The study was conducted in 2014 and 2015 at three sites in central South Dakota – Oacoma, Highmore and White River. At each site, the research was conducted in an areas with high and low plant diversity and productivity. The litter bag technique was used to determine the biomass-C turnover rates. Within each study site, shoot and root production was higher in moderately grazed high plant diversity area (HP) than the intensively grazed low plant diversity area (LP). The percentage of litter that was decomposed was higher in the HP than the LP areas at White River and Oacoma. The winter season exhibit the lowest rate of litter decomposition, followed by spring and summer. The results indicated that the plant biomass C: N ratio and temperature explained 52 and 45%, respectively, of the measured changes in biomass decomposition. Sites producing biomass with a low C: N ratio had

higher first order rate constants than sites with high C: N ratios. These findings indicate that the winter period cannot be ignored when assessing carbon turnover.

Introduction

Accurate predictions of carbon turnover in rangeland systems is dependent on accurate measurements of the above and below ground plant part turnover rates. Techniques to assess below ground plant parts and feces were previously discussed in (Chang et al., 2016) and (Chang et al., 2017) respectively. Given, that a large percentage of the above ground biomass remains in grassland system from one year to the next, research was conducted to determine the seasonal changes in surface residue decomposition.

The amount of plant biomass returned to the soil depends on grazing intensity. Plants are the input carbon source in the ecosystem. Carbon budgets are based on the amount of accurate measurements of carbon inputs and carbon losses (Chapin III et al., 2002). Total carbon within a grassland ecosystem depends on carbon input, which is produced during photosynthesis. The organic C inputs are decomposed to CO_2 by earthworms, soil bacteria, fungi, and many insects (Clay et al., 2006). The amount of carbon sequestered within the soil is the difference between carbon inputs and decomposition and it influences plant available water, resilience, and adaptability. The amount of carbon stored in soil can be increased by increasing productivity and reducing the amount of biomass harvested (Brown et al., 2010; Derner and Schuman, 2007; Silver et al., 2010). Moreover, different management practices may alter plant biodiversity and composition (Milchunas and Lauenroth, 1993; Milchunas et al., 1988).

Management activities like livestock grazing intensity affect the total quantity and amount of carbon stored in grassland soil (Derner and Schuman, 2007). Thus higher biomass production means higher C inputs into the grassland carbon pool (Jobbágy and Jackson, 2000). Moderately grazed systems generally leave approximately 50% of the above ground biomass, whereas intensively grazed systems only leave 25% of the above ground plant biomass. The rate that these materials are decomposed influences many factors including spring soil temperature, seed germination, evaporation, nutrient cycling, and possibly plant composition. In addition, intensive grazing reduces surface cover leading to higher soil temperatures and rapid mineralization which may encourage the growth of cool season grasses over warm season grasses.

Techniques that have been used to assess carbon turnover in grassland systems include the direct measurement of CO_2 emissions, frequent measurements of surface and subsurface non-harvested plant material, and the use litter bags where carbon loss is determined by difference (Chang et al., 2016). This work has shown that the amount of carbon retained in the soil is dependent on the amount added, and that decomposition can be calculated using first order kinetics.

Various factors are responsible for biomass-C mineralization in northern Great Plains grasslands including soil texture, time, climate and leaf quality (Jenny, 1980). For instance, the plant biomass C: N ratio has been used as index of leaf quality (Kelly et al., 2000; Murphy et al., 2002; Schimel et al., 1996; Schimel et al., 1997; Throop et al., 2004). Plant biomass that has high C: N ratios generally mineralize slower than biomass with low ratios (Swift et al., 1979). Moreover, plant functional composition and morphological characteristics influences decomposition (Jobbágy and Jackson, 2000; Knapp et al., 2002; Sala et al., 1988). For example, legumes, cool season, and warm season grasses have different nutrient requirements, resulting in different C: N ratios (Field et al., 1983; Kemp et al., 1994; Wedin and Tilman, 1990).

Secondly, soil textures influence the litter decomposition rates and plant available water. For example, clay provides physical and chemical protection of plant biomass that is not provided by sand (Monreal et al., 1981; Oades, 1988). Barnes and Harrison (1982) found a relationship between soil texture and plant species composition. For example, the intensity of a drought can favor one group of species over another (Lauenroth et al., 1978). Likewise, management and climate induced changes in soil structures can impact the decomposition process (Cotrufo et al., 2013; McGuire and Treseder, 2010; Wieder et al., 2013). Greater soil microbial populations have been reported in silt and clay soils than sandy soil (Kandeler et al., 1999; Kandeler et al., 2000; Monrozier et al., 2006; Poll et al., 2003; Qin et al., 2010) and lead to greater decomposition. Clay texture of soil affect infiltration and results in higher water runoff (Wischmeier and Mannering, 1969) whereas areas with higher silt and sand content increases water percolation and infiltration (Wischmeier and Mannering, 1969). This higher water content may also result in greater decomposition.

Another factor that adds to the complexity to calculating plant biomass carbon turnover is seasonal temperature changes. Higher summer temperatures than winter temperatures, influence the litter decomposition rate (Franz, 1990; Johansson et al., 1995; Kirschbaum, 1995; Trumbore et al., 1996). However, decomposition rates of litter when it is buried by snow is often not reported. Most previous studies have focused on the spring and summer seasons, and have ignored the winter season. The objective of this research was to determine the influence of plant composition on seasonal changes in biomass mineralization. The hypothesis for this study was that plant biomass mineralization rates were indirectly related to the C to N ratio and although slowed during the winter.

Materials and methods

Study Sites

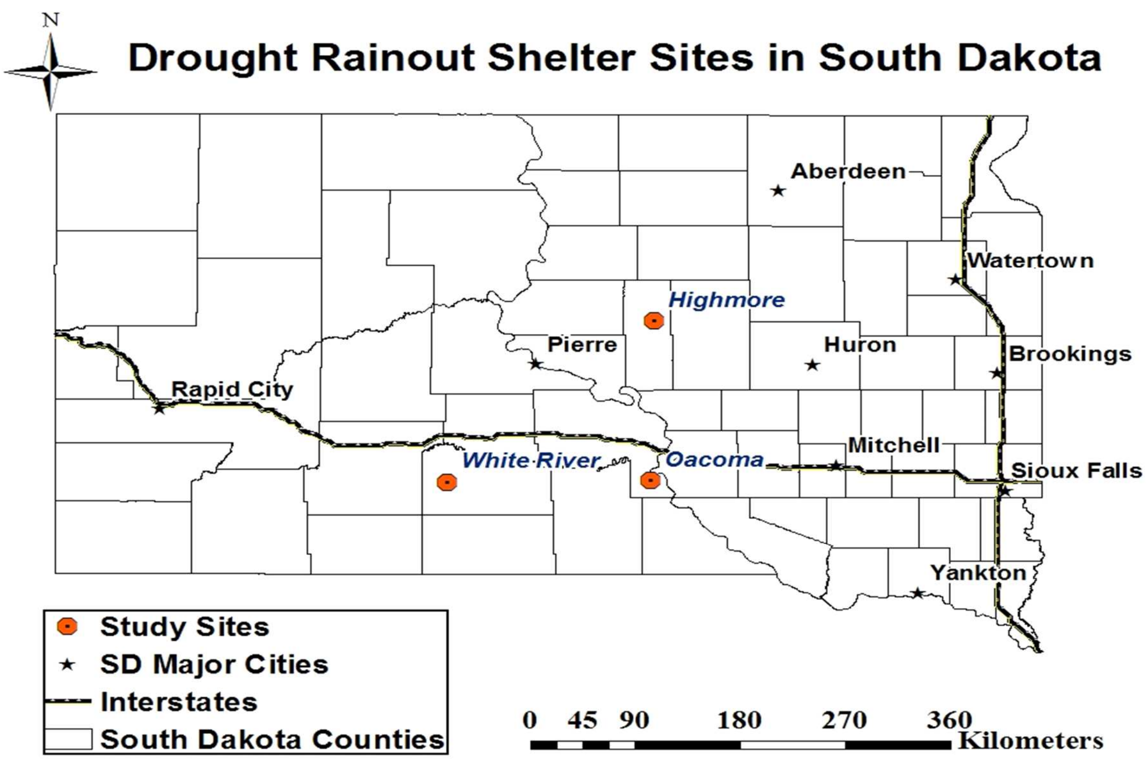

Fig 2. 1. Three study sites with South Dakota Map

Source: Bennett, Joe (2015)

This study was conducted in 2014 and 2015 at Oacoma (43°37'23.40"N and -99°28'16.78"W), Highmore (44°41'31.23"N and - 99°23'40.09"W) and White River (43°36'38.70"N and -101° 6'1.81"W) (Fig 2.1). These sites were located within the mixed northern Great Plains prairie and they had continental climates. The average precipitation, which primarily occurred during the growing season, at Oacoma, Highmore, and White River were 540, 590, and 390 mm, respectively (Smart et al., 2005; Smart et al., 2007).

The details about soil types at different study locations are provided below (Table 2. 1) -

Table 2. 1. The soil characteristics at the three study sites

Location	MU	Map Unit Name	Texture	Taxonomic Classification	%Sand	%Silt	%Clay	LCC	Slope %
White River HP	Ka	Kadoka-Kube silt loams	Silt loam	Fine-silty, mixed, mesic Aridic Argiustolls	9.4	67.1	23.5	2c	0 to 3
White River LP	TuB	Tuthill and Whitelake fine sandy loams	Fine sandy loam	Fine-loamy over sandy or sandy-skeletal, mixed, mesic Aridic Argiustolls	65.4	26.5	15	3e	0 to 5
Highmore HP	SvA	Stickney-Java-Hoven complex	Loam	Fine, montmorillonitic, mesic Glossic Natrustolls	39.2	37.3	23.5	3s	0 to 4
Highmore LP	SvA	Stickney-Java-Hoven complex	Loam	Fine, montmorillonitic, mesic Glossic Natrustolls	39.2	37.3	23.5	3s	0 to 4
Oacoma HP	SbE	Sansarc-Opal clays	Clay	Clayey, smectitic, calcareous, mesic, shallow Typic Ustorthents	12	38	50	7e	9 to 25
Oacoma LP	OnD	Opal-Sansarc clays	Clay	Fine, smectitic, mesic Leptic Haplusterts	6	39	55	6e	6 to 15

Experimental and Treatments

At each research site, research was conducted in two areas with different plant communities. One site was characterized as an area with high diversity and productivity (HP), whereas the other area had low diversity and productivity (LP). The high diversity sites had history of moderate grazing intensity and contained many native plant species including *Pascopyron smithii (Rydb.[A.Love])*, *Nassella viridula (Trin.[Barkworth]), Hesperostipa comata (Trin. & Rupr. [Barkworth]), Bouteloua gracilis (Willd. Ex Kunth [Lag. Ex Griffiths])*, and *Bouteloua dactyloides (Nutt [J. T Columbus]*. The low plant diversity sites had a history of intensive grazing and contained cool-season perennials (*Bromus inermis (Leyss), Poa pratensis (L.),* and *Agropyron cristatum (L. [Gaertn])*) and the annual grass *Bromus tectorum (L.).* Each grazing intensity experiment was replicated two times.

Soil and plant Sampling

Soil samples from the 0- to 15- cm depth were collected from each 0.25 m^2 plot in the spring and fall. Six cores from each plot were composited in each soil sample. Soil samples were analyzed for gravimetric soil water content, following which they were dried, ground, and analyzed for total N, total C and inorganic carbon.

Above ground biomass was measured at the end of the 2014 and 2015 growing seasons. The entire sample was dried at 60^{o} C for 120 hours and weighed. A portion of the harvested biomass was ground and analyzed for total carbon and nitrogen analysis. The above ground biomass was then used in the litter bag experiments where decomposition rates were determined.

Below ground biomass in the surface 15 cm was measured at the end of the 2015 growing season. Composite soil samples, consisting of three cores that had a diameter of 7.62 cm were collected and stored in a cold room having a 5^{o} C temperature. A hydro pneumatic elutriator was used to separate the roots from the soil (Chang et al., 2014; Smucker et al., 1982b) (Clay et al., 2012). After washing and separating the root biomass from the soil particles, the extracted roots were dried at 60 ^{o}C and weighed. During washing, roots and other organic materials were separated from the fine soil particles with a submerged low kinetic energy primary sieve (#925). The minimum kinetic energy of water moving across the submerged sieve permitted retention of very fine roots on a relatively coarse sieve without breaking laterals and root hairs. The primary sieved materials were transferred onto a very fine secondary sieve (#437) (Smucker et al., 1982a). The roots and other organic materials were hand separated in clean water. The measured root values did not account for exudates, and therefore based on Kuzyakov and Domanski (2000) and Kuzyakov and Lorionova (2005, 2006) (Kuzyakov and Domanski, 2000; Kuzyakov and Larionova, 2005; Kuzyakov and Larionova, 2006) the root + exudates values were calculated using the equation,

$$\text{Roots + exudates} = \text{measured roots} \times 2$$

Above Ground Plant Decomposition

Insitu above ground decomposition rates were measured in the winter, spring and summer. Above ground clipped biomass collected from each plots were dried as explained above. These dried biomass sample were kept in 1.5 mm mesh fiberglass bags that had the dimensions of 20 by 20 cm. Average weight of biomass in each litter bag was 15 g of dried biomass. In each HP and LP areas, 72 litter bags were placed on the soil surface on November 1, 2014. In total, 432 litter bags were installed at the study sites. Out of 72 litter bags in each productive area, twenty four residue bags from each productive were collected after three different time intervals- 150 days (after winter season), 240 days (after winter + spring together) and 365 days (after winter + spring + summer).

Data and Statistical Analysis

Data were analyzed using the R-statistical program. ANOVA was performed to compare soil moisture, total biomass, C: N ratio in different productive areas of each location. Mean and p-value was calculated for each parameter. Above ground biomass decomposition followed first order exponential function and degradation rate was calculated using the equation:

$$\ln(y_t) = \ln(y_0) - k(t)$$

where, y_t was amount of biomass remaining at time t, k was first order rate constant and y_0 was amount of biomass at time Zero. The half-life biomass was calculated by:

y1/2= ln2/k

Amount of biomass degraded was calculated for three different time periods (winter, winter + spring and Winter+ spring + summer) separately at two different productive areas of each study sites. To determine spring season decomposition, amount of biomass lost during winter and spring together was subtracted with season loss only. Similarly, to calculate summer season decomposition the combined lost that occurred during the winter and spring were used to correct for winter and spring deposition. Linear regression analyses between biomass C: N Ratio and percent biomass lost due to decomposition was use to evaluate the importance of litter quality on decomposition. Similarly, linear regression was conducted to determine the influence of soil moisture on the percent litter decomposed. In the text, when it is stated that two differences are different, it is implied that the differences are significant at the 5% level.

Results

Total above and Below Ground Biomass Production

Table 2. 2. Above and below ground biomass (0-15 cm depth) Production at different productive area of three study sites

	White River			Highmore			Oacoma		
	Shoot	Root+Exudates	R/S ratio	Shoot	Root+Exudates	R/S ratio	Shoot	Root+Exudates	R/S ratio
	g/m^2			g/m^2			g/m^2		
HP	544	354	0.33	667	518	0.39	456	318	0.35
LP	314	260	0.42	375	362	0.48	237	214	0.45
p-value	<0.001	0.1024		<0.001	0.03		<0.001	0.02274	

Highmore had the highest shoot and root production with greater root/shoot ratio than other sites (Table 2.2). These results were attributed to due to higher soil moisture contents. At each study site, shoot and root production was higher in the HP than the LP area. The HP area had 544, 668 and 457 g/m^2 above ground biomass production at White River, Highmore and Oacoma respectively. However, in the LP areas at White River, Highmore, and Oacoma, approximately 314, 375 and 237 g/m^2, respectively of above ground biomass was produced. Sites with higher above ground biomass had higher root biomass. For example, Highmore which had highest shoot biomass production had 259 and 181 g/m^2 of root biomass in the HP and LP area, respectively. Whereas, Oacoma which had lowest shoot biomass production had only 159 and 107g/m^2 of root production at HP and LP area respectively.

Above Ground Decomposition Rate due to Locations, productive area and season

Data was analyzed first to see if there is influence of Location, productive area and season on decomposition rate and percent loss. White river and Oacoma had significantly different in decomposition rate constant than Highmore. However we did not find significant different between white river and Oacoma (Table 2.3). Percent litter loss was significantly different among all three location. However we did not find any significant different in decomposition rate constant and percent litter lost between two productive areas. Three different seasons (winter, spring and summer) had significant influence in decomposition rate and percent litter lost. Winter had the lowest followed by spring and summer had greater.

Table 2.3. Decomposition influenced by Location, productive area and season

Location			Productive Area			Season		
Location	Rate Constant	% Loss	Productive Area	Rate Constant	% Loss	Season	Rate Constant	% Loss
White River	1.77 a	17.64 a	HP	1.71 a	17.01 a	Winter	0.77 c	10.49 c
Highmore	1.39 b	13.6 b	LP	1.68 a	16.45 a	Spring	1.93 b	14.78 b
Oacoma	1.93 a	18.97 c				Summer	2.40 a	24.93 a
p-value	0.04	0.02	p-value	0.71	0.62	p-value	<0.001	<0.001

The same letters within column are not significantly different (p=0.05)

Within each location, High productive (HP) and low productive (LP) rate constant and percent loss was not significantly different (Table 2.4). At white river and Highmore summer percent litter loss was significantly greater during summer than spring and winter. Decomposition rate constant during winter was differ with spring and summer but summer rate constant was numerically greater than spring however not significant.

At Oacoma we found significant difference in percent litter loss among all three seasons. Summer had fastest decomposition rate followed by spring and winter had the slowest rate of decomposition.

Table 2.4. Decomposition within each location due to season and productive area

	White River		Highmore		Oacoma	
Season	% Loss	Rate Constant	% Loss	Rate Constant	% Loss	Rate Constant
Winter	12.06 b	0.86 b	7.36 b	0.57 b	12.05 c	0.86 b
Spring	15.60 b	2.07 a	11.21 b	1.49 ab	17.53 b	2.22 a
Summer	25.26 a	2.38 a	22.21 a	2.12 a	27.31 a	2.69 a
p-value	0.005	0.004	0.02	0.027	0.0012	0.001
LSD	5.45	0.96	9.56	0.96	4.09	0.56
Productive Area						
HP	17.82 a	1.73 a	13.84 a	1.34 a	19.87 a	2.06 a
LP	17.46 a	1.81 a	13.35 a	1.45 a	18.05 a	1.79 a
p-value	0.81	0.49	0.88	0.52	0.25	0.27
LSD	14.72	1.55	33.91	1.55	9.6	1.56

The same letters within a column are not significantly different (p = 0.05)

Biomass C: N Ratio vs. litter decomposition

At Oacoma and Highmore the C: N ratios of the HP and LP biomass were identical (Table 2.5). Biomass with lower C: N ratios tended to have higher decomposition rates than residue with high ratios (Fig. 2.2). This relationship suggests that decomposition was N limited.

Table 2. 5. C: N Ratio of original biomass used for litter bag at three different sites. The two productivity zones were HP (high productivity) and LP (low productivity)

	White River	Highmore	Oacoma
HP	32	57.3	30.6
LP	43	56.9	31.2
P-value	0.00185	0.9234	0.7799

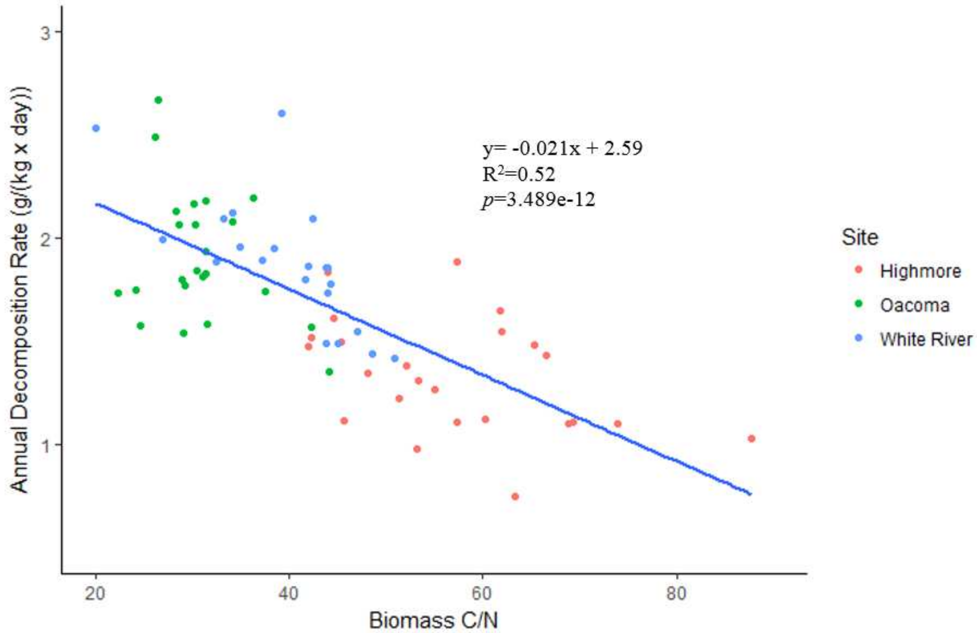

Fig 2. 2. Relation between C: N ratio in the plant biomass and the decomposition rate (g/(kg ×day).

The C: N ratio of plant biomass appeared to impact winter decomposition. When all sites were considered together, C: N ratio explained 42% of the winter decomposition variation (Fig.2.2). Similarly, for spring decomposition, C: N ratio explained 33% of decomposition variability (Fig 2.3), and 11% of the summer decomposition variability. This decreasing correlation suggest that the C: N ratio of the original biomass became less important.

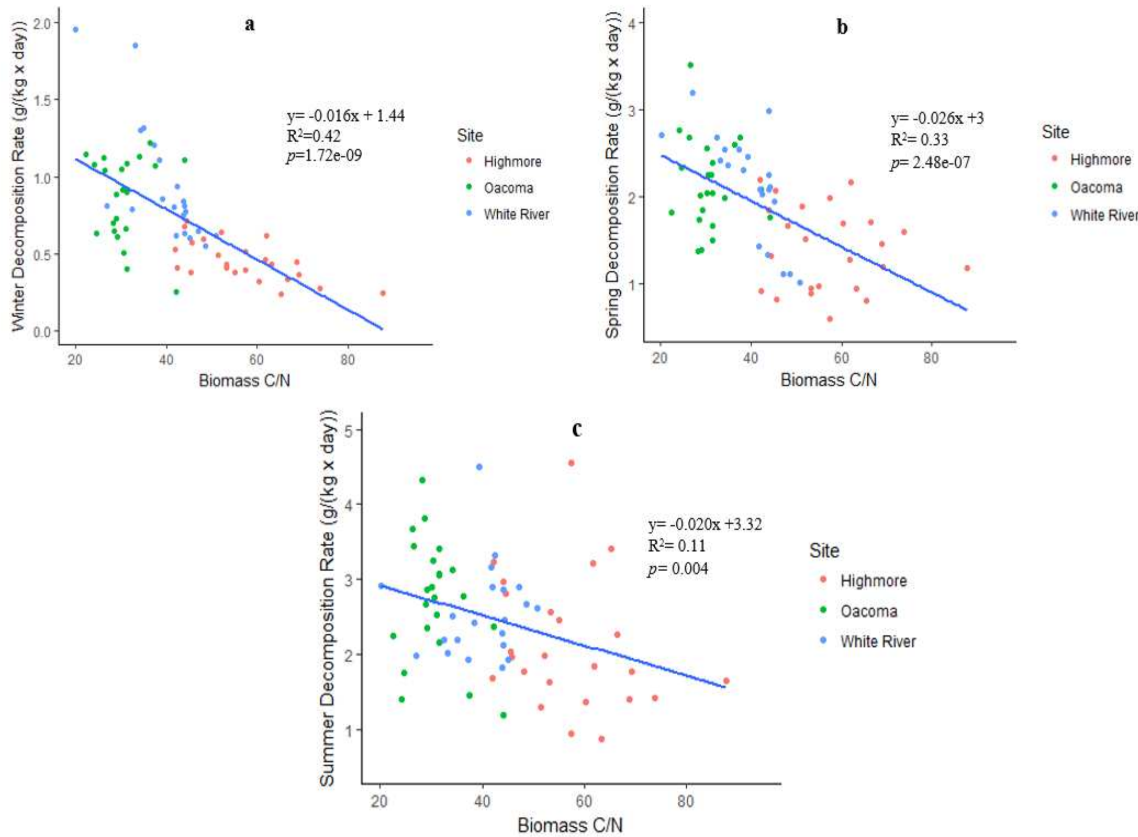

Fig 2. 3. Decomposition rate and biomass C:N ratio during different season

Temperature vs. Decomposition

Highmore had cooler temperatures than the other sites (Table 2.6). Sites with warm temperature had greater decomposition. For example, Highmore which had the lower temperature during winter, spring and summer had slower biomass decomposition rates. Unlike litter C: N ratio, temperature had positive correlation with biomass decomposition. Temperature explained 45% of decomposition variability (Fig. 2.4).

Table 2. 6. The mean seasonal temperature (ºC) at the three study sites

	White River	Highmore	Oacoma
Winter	-1.51	-4.77	-2.25
Spring	13.79	13.10	14.59
Summer	18.44	17.54	19.27
Annual	10.24	8.62	10.54

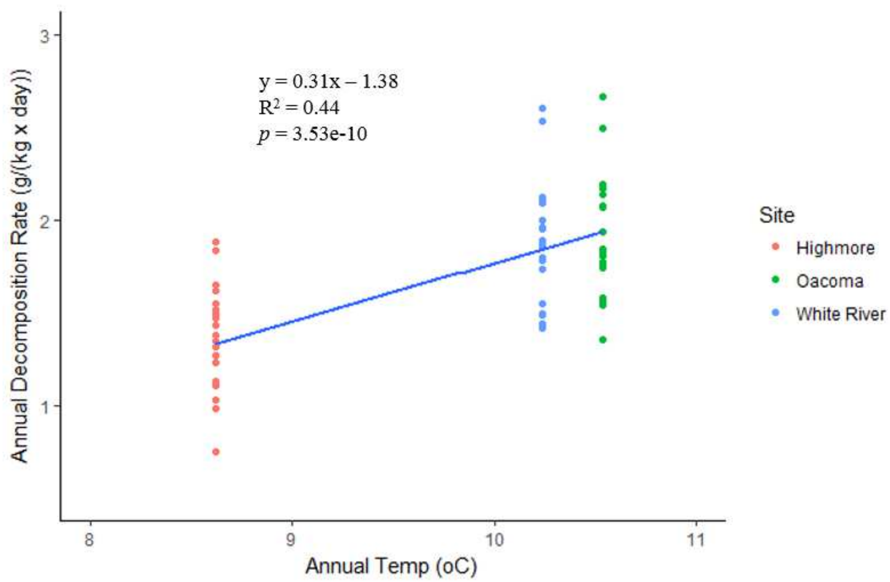

Fig 2. 4. Relation between temperature and litter decomposition rate at the three study sites.

Decomposition Rate vs. Soil Moisture

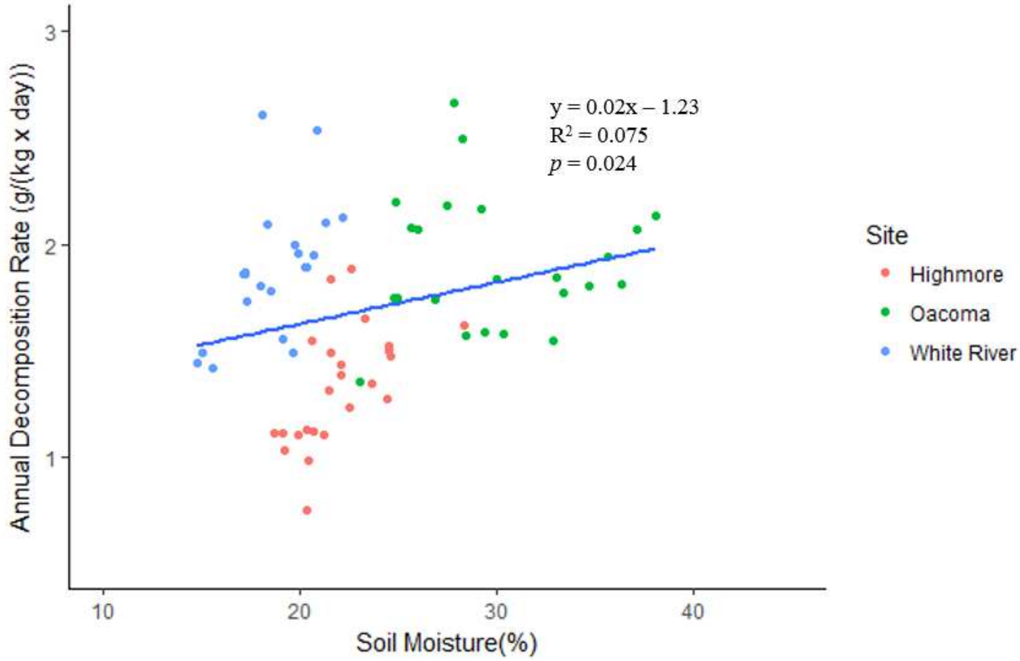

Fig 2. 5. Relation between Soil moisture and decomposition rate at the three study sites.

Plant composition vs. decomposition

Highmore had greater percentage of warm season grasses when compared with the other sites (Table 2.7). Greater amount of warm season grasses at Highmore site may be attributed to higher rainfall. Previous research showed that above ground biomass quality is inversely related to precipitation (Murphy et al., 2002). Higher rainfall areas have higher litter C:N ratio resulting in slower decomposition rate (Aber and Melillo, 1982).

Table 2. 7. Plant composition at the different study sites. The HP and LP values refer to high productivity and low productivity sites

	White River		Highmore		Oacoma	
Functional Group	HP	LP	HP	LP	HP	LP
			%			
Warm-season grasses	13.24	35.56	57.07	35.73	0.57	0.28
Native Cool-season grasses	59.49	21.04	16.59	2.48	87.05	0.00
Invasive Cool-season grasses	1.33	0.57	16.24	55.00	0.27	65.52
Native Forb	0.67	6.93	8.05	4.84	1.49	2.56
Invasive Forb	21.97	0.00	0.00	0.00	10.63	30.19
Shrub	0.00	0.00	1.54	0.00	0.00	0.00
Annual grasses	3.29	35.56	0.00	1.70	0.00	1.45
Sedge	0.00	0.34	0.51	0.26	0.00	0.00

Total Carbon and Nitrogen in soil

Table 2. 8. Amount of carbon and nitrogen in soil of different sites. The HP and LP values refer to high productivity and low productivity sites

	White River			Highmore			Oacoma		
	N%	C%	C/N	N%	C%	C/N	N%	C%	C/N
HP	0.16	1.59	9.68	0.22	2.47	11.26	0.28	2.81	9.86
LP	0.13	1.28	9.42	0.26	2.80	10.63	0.22	2.20	9.86
p-value	< 0.001	< 0.001	0.056	<0.001	0.006	0.015	<0.001	0.0003	0 0.99

Soil at White River contained less total N and C than the other sites s (Table 2.8). At White River and Oacoma, the HP area had greater N and C than LP sites. However, different at Highmore, the LP sites had greater N and C than the HP site.

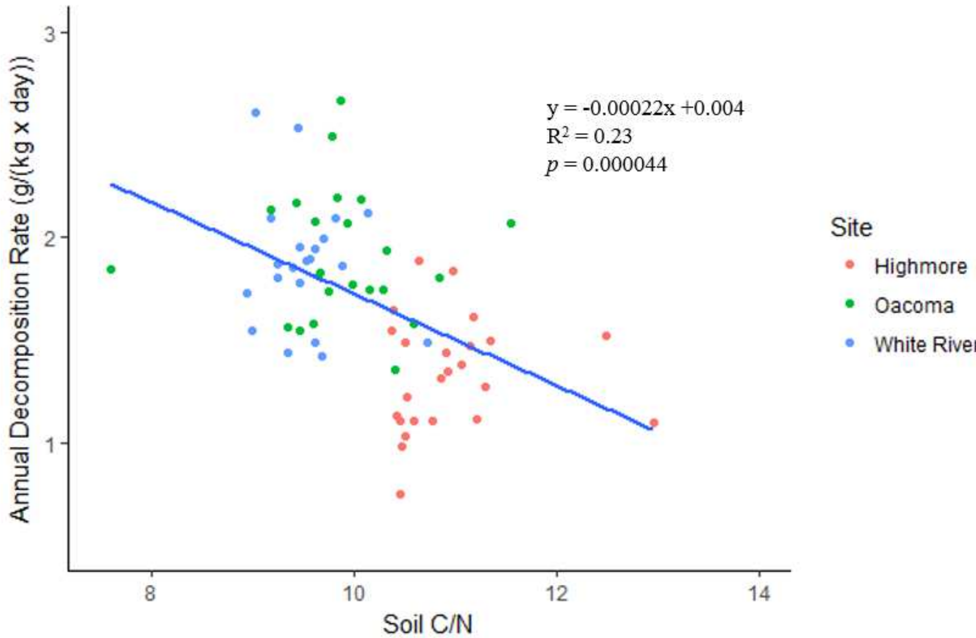

Fig 2. 6. Relation between soil C/N and Annual decomposition rate.

Correlation between different variables

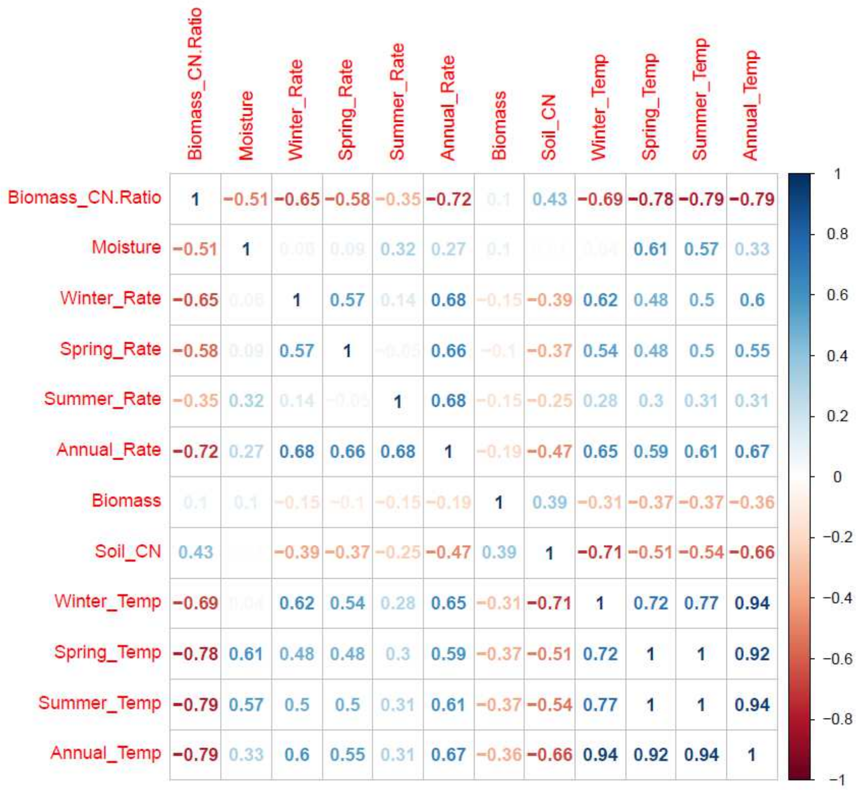

Fig 2. 7. Correlation coefficients (r) between measured values in this experiment. Values greater than 0.25 and less than -0.25 are significant at the 5% level.

Discussion

Our findings suggest that management and plant composition influenced productivity and the rate that biomass is decomposed. Plant materials with high C: N ratios tended to decompose slower than plant biomass with low C: N ratios. The HP sites tended to have higher productivity values then the LP sites. For example, the HP areas at White River had 544 and 177 g/m^2 of above and below ground biomass production, respectively. Whereas, the LP area, yielded 314 and 131 g/m^2 of above and below ground production, respectively. Highmore and Oacoma had similar results. However, other researchers have had different (Li et al., 2012).

We found inverse relation between the plant biomass C/N ratio and turnover rate. Plant biomass with low C/N ratios tended to have higher decomposition rates. For example, plant biomass from the White River HP area had a C/N ratio of 32 and an decomposition rate of 1.73 g/(kg×day) whereas plant biomass from the Highmore HP area had a C/N ratio of 57.3 and a decomposition rate of 1.29 g/(kg×day)..

Another factor determent to the total carbon turnover was the plant species composition of the litter. For example, the Highmore HP site had a higher percentage of warm season grasses than the other sites. Higher proportion of warm season grass could be the reason for having higher C/N ratio at Highmore resulting in slower decomposition rate. In the other had White River and Oacoma had greater proportion of cool season grass than warm season resulting in narrower biomass C/N ratio and faster carbon turnover rate.

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Chapter 3

The impact of Fire on Carbon Cycling in Range Systems

Abstract

Fire and grazing are natural components of the northern Great Plains grasslands. These activities have potential to affect different physical and biological aspects of grassland ecosystems thus impacting net carbon budgeting and long term sustainability. The primary objectives of the study were to determine effect of fire and control on the CO_2 emissions and to quantify their impact on soil temperature and soil moisture. Research was conducted during 2014 and 2015 at two sites in Brookings country. CO_2 fluxes were measured in two treatments, annual fire and control. There were two replications for each treatment. The CO_2 fluxes were measured with an 8100A Automated Soil CO_2 Flux System (LI-COR, Lincoln, NE) was used which was connected

to four gas chambers. Soil surface temperatures were measured continuously with thermocouples. In 2014, CO_2 flux was measured every two hours for 90 seconds over 20 days, whereas in 2015, it was measured over 48 days. Total carbon lost, soil temperature and moisture contents were higher in fire than control.

Introduction

Northern Great Plains grasslands contain high amount of indigenous soil organic matter along with higher below ground biomass (root) and microbial population providing important carbon dioxide (CO_2) sources (Frank et al., 2002). Soils with high soil organic matter and extensive root systems, create favorable conditions for soil microbes (Conant et al., 2001). Our hypothesis is that fire impacts soil respiration and soil carbon mineralization kinetics.

Fire is a natural component of the northern Great Plains grasslands. Following the settlement of the Great Plains, fire was prevented from many ecosystems (Komarek, 1974). The lack of fire resulted in a buildup of fuels and in many situations changed the types of vegetation observed on the land (Parsons et al., 1979). Early spring fires or grazing provides a competitive advantage to warm season grasses over cool-season grasses by removing the above ground portions of the invasive plants and by converting nutrients contained through decomposition and decay into soil available nutrients (Hover and Bragg, 1981; Augustine et al., 2014).

Fire can be integrated into all of these systems. In a patch-burn grazing system, a different portion of the field is burned every year. In this system, cattle spend a large percentage of their time in recently burned areas of the pasture. Burning releases nutrients and plants growing in these areas are often more nutritious. The productivity and resilience of the grasslands within the region are influenced by management practices, such as grazing intensity and fire (Smart et al., 2013). Depending on the fire temperature and amount of standing biomass, the fire can contribute to the loss of N and C from the system (Hobbs et al., 1991). Interactions between management (fire and grazing intensity) and site characteristics (soil and climatic variability) have the potential to produce landscape position specific impacts on long-term sustainability. For example, in areas with high slopes, fire and heavy grazing can reduce surface cover and increase the risk of erosion and gully formation (Smart et al., 2015).

The impact of a fire on soil organic matter and nutrient cycling depends upon the amount of available fuel. If 100% of the above ground biomass was consumed by grazing animals, fire would produce few benefits. Reducing the amount of fuel reduces the temperature and the amount of nutrients that can be recycled (Haile 2011; Mataix-Solera et al. 2009; Neary et al.1999; Raison 1979). During combustion, the organic carbon with the biomass is released and portion of the nutrients contained in the vegetation are returned to the soil. Ojima et al. (1994) reported that the percentage of N and biomass that was lost during combustion were similar. However, the loss of P was negligible.

Fire can also combust soil organic matter (Richter et al., 2000; Johnson and Curtis, 2001; O'Neill et al., 2002, 2003), increase soil temperature (Viereck et al., 1983), and reduce soil moisture (Imeson et al., 1992; O'Neill et al., 2002), microbial activity, and microbial diversity (Fritze et al., 1994; Waldrop et al., 2003, Hart et al., 2005; Waldrop and Harden 2008). The impact of fire on soil moisture has been mixed. Due to reduction in evapotranspiration and rainfall interception by plants (Moody and Martin 2001) fire can increase soil moisture (Klock and Helvey 1976; Moore and Keeley 2000), whereas because of hydrophobicity, fire can increase runoff thereby reducing soil moisture may (Imeson et al., 1992; Harden et al., 2006). After a fire, the soil surface is darkened from the ash and charcoal deposited on the soil surface (Eckmeier et al., 2007; Pereira et al., 2014). Soil darkening generally increases soil temperature and elevates microbiological activities (Certini, 2005; Gomez-Heras et al., 2006). Total Soil CO_2 Flux depend on the autotrophic soil CO_2 flux by plant roots and mycorrhizal fungi and heterotrophic soil CO_2 flux by various soil microorganisms (Ryan et al.,2005; Luo et al., 2006; Raich et al., 2000 and Subke et al., 2006) .

Fire can also reduce above ground biomass, surface litter, and photosynthesis, and soil N (Knapp and Seastedt 1986, Seastedt and Knapp 1993, Ojima et al. 1994). Fire result in combustion loss of nitrogen (Blair et al. 1998), which over the long term can reduce N mineralization. To compensate for reduced N, plants may increase root development (Ojima et al. 1994.

Therefore, due all these physical and biological factors, fire likely plays an important role in net ecosystem carbon budget (Chapin et., 2006). The primary objectives of the study were to determine effect of fire on the CO_2 emissions and to quantify the impact of fire on soil temperature and soil moisture.

Methodology

Study Site

Research was conducted during 2014 and 2015 at two sites in Brookings country. The first site, nearest to the city of Brookings (44°20’6.33″N, 96°48’28.62″W), had well drained Barnes clay loam (fine-loamy, mixed, frigid Udic Haploborolls), with a 0 to 2 % slope (NRCS, 2010a, 2010b). This site was seeded with big bluestem (Andropogon gerardii Vitman) in 2005. Kentucky bluegrass (Poa pratensis L.), big bluestem, and smooth bromegrass (Bromus inermis Leyss. subsp. inermis) were the dominant grass species and yellow sweet clover [Melilotus officinalis (L.) Lam.] was the predominant forb species. This soil contained 40.4 g SOC kg^{-1}.

The second site, located near the city of Volga (44°23’91.53″N, 96°57’29.39″W) was a well-drained native prairie. The soil was a Buse Poinsett complex with a 9 to 15% slope (NRCS, 2010a, b). The dominant plant species included at little bluestem [Schizachyrium scoparium (Michx.)], big bluestem, sideoats grama [Bouteloua curtipendula (Michx.) Torr.], smooth bromegrass, and yellow sweetclover.

Field plots were established in 2009 in a Randomized Complete Block design containing four replicates at each site. Fire treatments were applied to 6 X 6 m blocks and consisted of annual fire (fire every year), fire every two year (fire after two years) fire, and fire every three years (fire after every three years). Simulated grazing consisted of clipping vegetation to 2 cm height and clipped biomass was removed from the study plots. The three simulated grazing treatments were annual simulated grazing (clipping every year), simulated grazing every other year (clipping after every two years), and simulated grazing every 3rd year (Clipping after every three years). The two year fire and simulated grazing treatments were conducted in 2009, 2011, 2013 and 2015 whereas three year fire and simulated grazing treatments were initiated in 2009, 2012 and 2015.

A cosine function was used to determine the diurnal cycles the air temperatures and CO_2-C emissions using the equation,

$$y_c(t) = A_c\left[\cos\left(\frac{2\pi ct}{T} - \phi_c\right)\right]$$

[1]

where T is the interval, $y_c(t)$ is the gas concentration at time t, A_c is amplitude of the cosine curve, ϕ_c is phase angle of the cosine cure, and c is the frequency of the wave cycles (Carr, 1995). The amplitude represents the height of diurnal cycle peak, whereas the phase angle, or shift, represents the offset of the peak in the cosine wave. The peak time of diurnal cycle was determined by converting the phase angle to a 24 hour basis. In this experiment, T is 1 (a day in 24 hour period) and c is 1 (a complete cycle).

Sampling

CO_2 fluxes were measured in two treatments, Annual Fire and control. There were two replications for each treatment. The CO_2 fluxes were measured with an 8100A Automated Soil CO2 Flux System (LI-COR, Lincoln, NE) was used which was connected to four gas chambers. Soil surface temperatures were measured continuously with thermocouples. In 2014, CO_2 flux was measured every two hours for 90 seconds over 20 days, whereas in 2015, it was measured over 48 days.

Soil sampling was conducted in 2014 and 2015. Soil samples were separated into three soil depths (0- to 7.5-, 7.5- to 15- and 15- to 30.5- cm). For Bulk Density, a 3 cm diameter bulk density probe was used to collect soils from these depths, and water infiltration was measured with a single ring infiltrometer.

Results and Discussions

Soil Carbon Dioxide Emission

In 2014, soil CO_2 –C emissions, soil temperature and soil moisture followed diurnal cycles (Fig 1, 2 & 3). Average daily carbon loss during first seven days was 4.37 and 5.92 g $(m^2 \times day)^{-1}$ from unburned and burned plot respectively ($p < 0.1$ using T-test). Similarly, there was fire induced phase shift in CO_2-C emissions. Fire plot had higher phase shift (4.20 h) than the grazing (3.89 h) (Table 3.2). This phase shift suggests that the fire delayed when the CO_2-C was emitted.

Soil CO_2 –C emissions during the 8 to 20 day period in the annual fire treatment was numerically lower than first 7 days than the control treatment. For the 8 to 20 day period, CO_2 –C losses per day from fire and control were 5.16 and 4.66 g (m^2 x day)$^{-1}$. In addition, the amplitude (0.17 **g m^{-2}**) and phase (4.04 **g m^{-2})** shift in annual fire treatment were higher than the control treatment ($P < 0.1$ using T-test). This difference in CO_2 –C loss per day, may can be attributed to increased microbial activities due to better soil moisture (0.33%), and higher soil temperature (17.95 °C) than control.

For the 21-32 days period, CO_2 –C loss per day from fire treatment was numerically higher than control treatment, however it was not significantly different. During this time interval, soil temperature and moisture contents were similar. During 33rd to 48th day, the fire treatment had significantly higher per day CO_2 –C loss (8.13 g ($m^2 \times$ day)$^{-1}$) than the control treatment (6.95 g ($m^2 \times$ day)$^{-1}$). Similarly, the amplitude was higher in fire treatment than control treatment. Numerically, the soil temperature and moisture contents were higher in fire than control treatment.

. 1. Influence of Annual Fire and Annual Clipping on the Amplitude, phase shift and loss from soil in 2014

	1-7 days			8-20 days			21-32 days			33-48 days		
Treatments	Amp	Phase shift	Co2-C loss	Amp	Phase shift	Co2-C loss	Amp	Phase shift	Co2-C loss	Amp	Phase shift	Co2-C loss
	g m^{-2}	hour	g$(m^2$ x day$)^{-1}$	g m^{-2}	hour	g$(m^2$ x day$)^{-1}$	g m^{-2}	hour	g$(m^2$ x day$)^{-1}$	g m^{-2}	hour	g$(m^2$ x day$)^{-1}$
Control	0.1	3.89	4.37	0.09	3.75	4.66	0.11	4.11	5.23	0.12	4.04	6.95
Fire	0.1	4.2	5.92	0.17	4.04	5.16	0.2	4.3	5.54	0.19	4.13	8.13
p-value	0.1	0.06	0.07	0.02	0.03	0.18	0.11	0.17	0.68	0.05	0.4	0.05
		Temp (ºC)	Moisture (%)		Temp (ºC)	Moisture (%)		Temp (ºC)	Moisture (%)		Temp (ºC)	Moisture (%)
Control		19.74	0.18		15.83	0.3		17.13	0.31		18.5	0.23
Fire		16.36	0.28		17.95	0.33		18.5	0.33		20	0.28
p-value		0.13	0.03		0.24	0.05		0.41	0.4		0.39	0.33

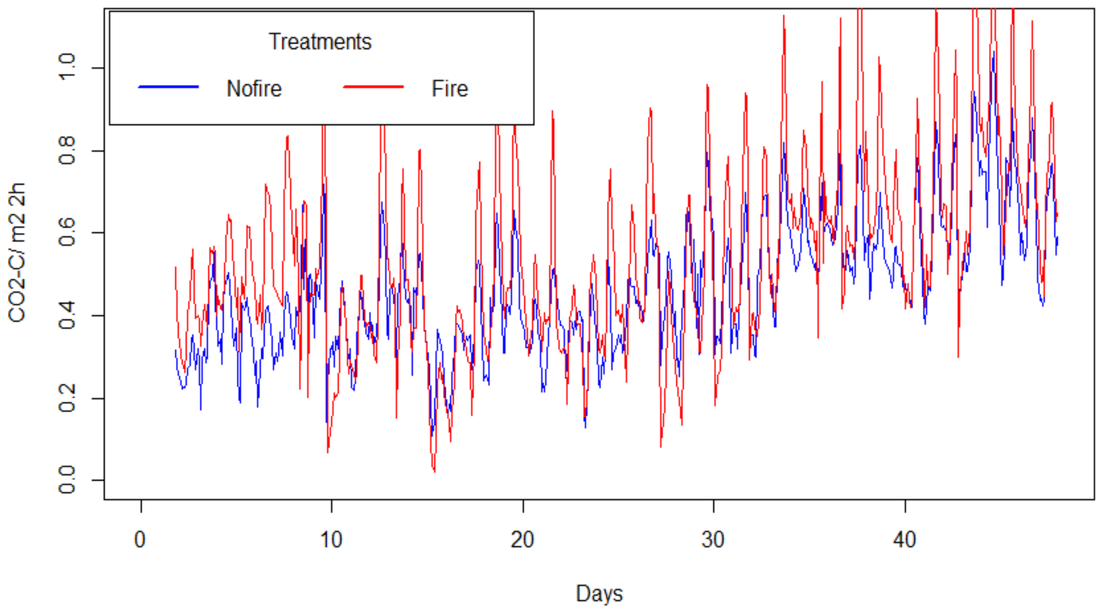

Fig 3. 1. Gram CO_2-C emission from the annual fire and control treatment in 2014

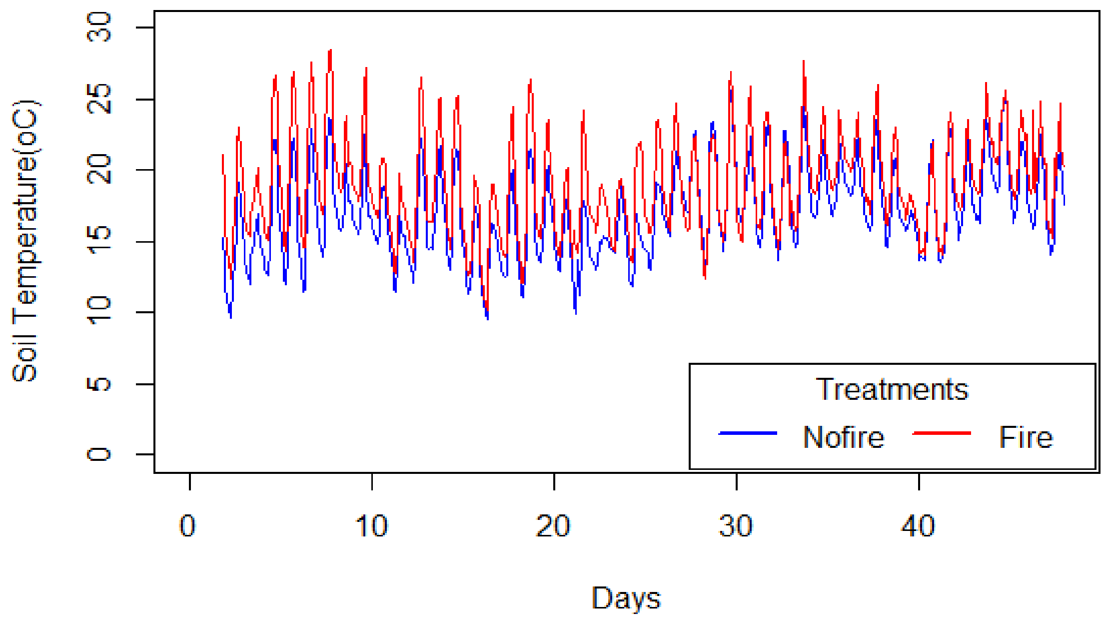

Fig 3. 2. Soil temperatures in the annual fire and no fire (control) treatments in 2014

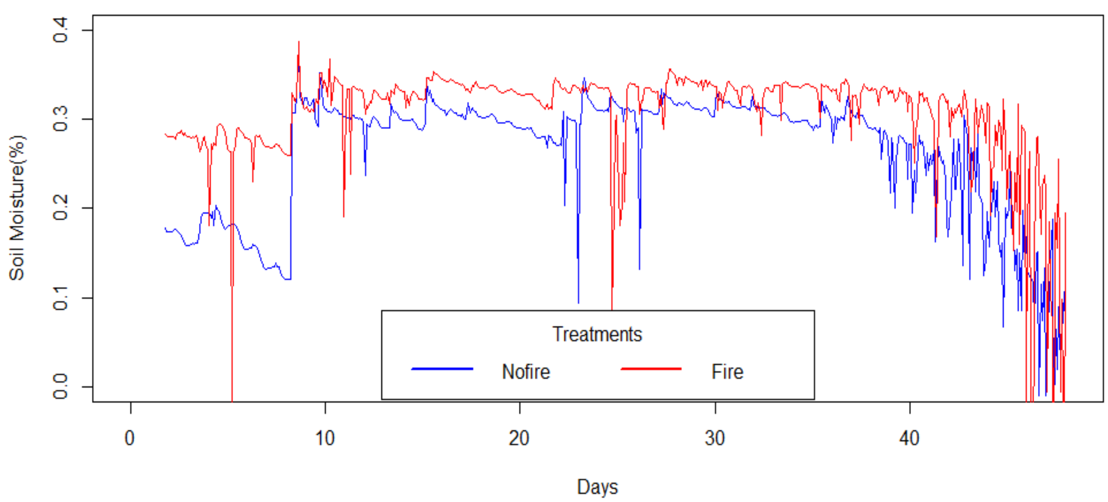

Fig 3. 3. Soil moisture in the annual fire and no fire (control) treatment in 2014.

Carbon dioxide emissions 2015

In 2015, CO2 –C emissions and soil temperature followed diurnal cycles (Fig 3.4 & 3.5). The per day CO_2 –C emissions from both treatments were lower in 2015 than 2014. Average daily carbon loss during first seven days was 2.70 and 3.31 g(m^2 x day)$^{-1}$ from control and annually burned plot, respectively (Table 3.3). During the first 7 days, the amplitudes, phase shifts and soil temperatures were similar.

The CO_2 –C emissions from 8 to 20 days were higher than the first 7 days in the annual fire and control treatments. For the 8 to 20 day period, CO_2 –C loss per day from the annual fire and control treatments were 3.69 and 4.07g (m^2 x day)$^{-1}$, respectively. Again, the amplitudes, phase shifts and soil temperatures for the 8- to 20- day period were similar in both treatments.

Table 3. 2. Influence of the annual fire and control on CO2-C emissions, and the amplitude and phase sift of the diurnal cycle in 2015

Treatments	1-7 days			8-20 days		
	Amp	Phase shift	CO_2-C loss	Amp	Phase shift	CO_2-C loss
	g m^{-2}	hour	g(m^2 x day)$^{-1}$	g m^{-2}	hour	g(m^2 x day)$^{-1}$
Control	0.04	4.15	2.70	0.08	4.11	4.07
Fire	0.03	3.95	3.31	0.06	3.93	3.69
p-value	0.59	0.71	0.046	0.47	0.45	0.11
			Temp(ºC)			Temp(ºC)
Control			18.85			18.03
Fire			16.88			17.2
p-value			0.34			0.55

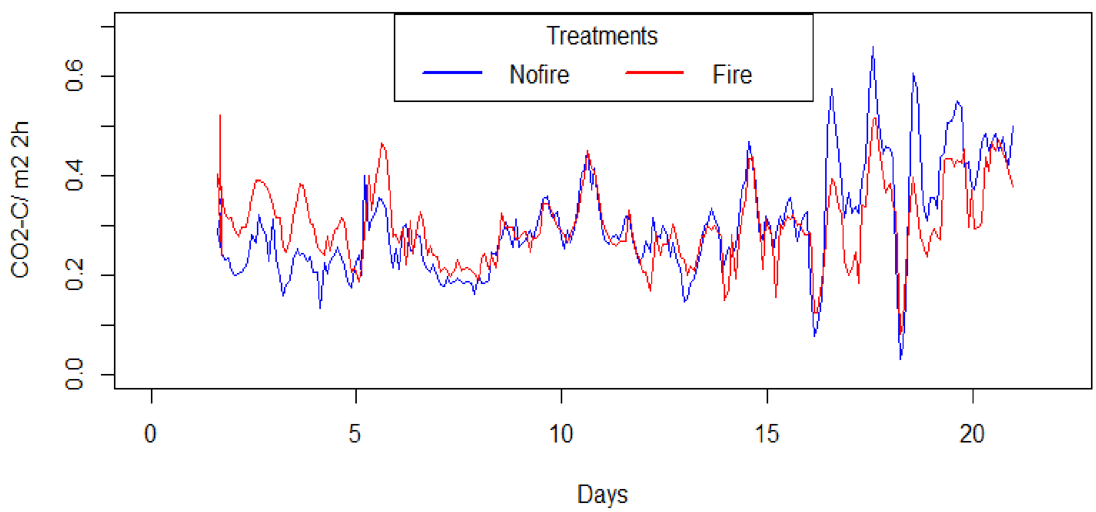

Fig 3. 4. CO_2-C emission from soil in 2015

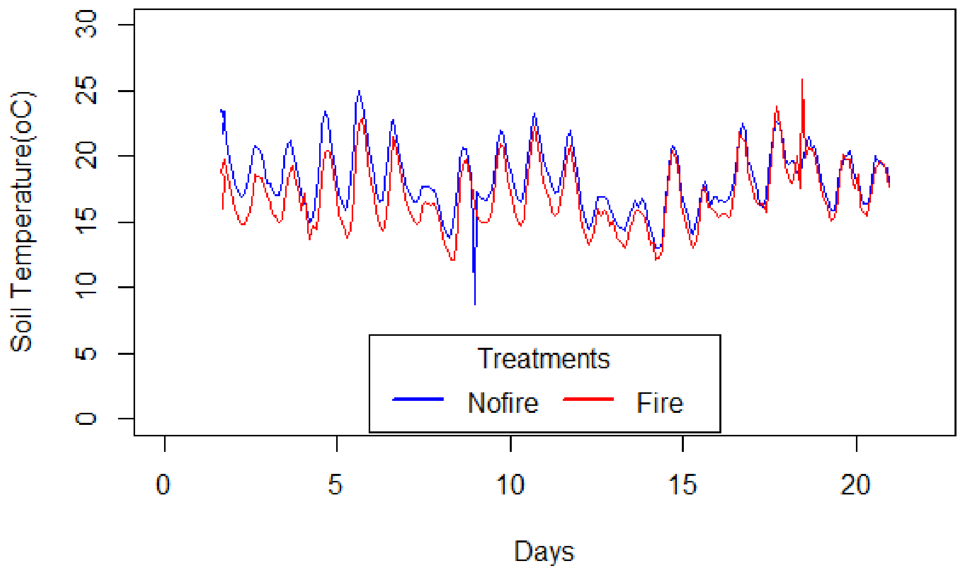

Fig 3. 5. Soil Temperature in 2015

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Thesis Conclusion and Summary

In the northern Great Plains, changing climatic condition is impacting agriculture in various ways. Higher temperature, changing precipitation pattern, increasing CO_2 levels and extreme climatic events like drought, directly affect land use, soil carbon sequestration and food production. Activities like land use change are driven by a desire to create wealth and produce jobs. Along with economic opportunities to local families, recent technological improvements, land ownership structure changes, climate variability, various governmental policies, and aging workforce are major driving factor for changing grassland to cropland. Along with these factors, it may also be driven by a desire to stabilize economic returns in an environment of high climatic variability and a goal of increasing the land value. For example, irrigated cropland had a higher value than grazing lands. Our research shows that South Dakota State had higher amount of grassland to cropland changes than Nebraska during both study periods. During first six year period, 700,000 hector grassland was changed to cropland in South Dakota, whereas it was only 250,000 ha in Nebraska. Similarly, 210,000 ha newly expanded cropland was estimated during later two-year period in South Dakota. Contrarily Nebraska State had only 110,000 ha of new cropland. The higher conversion rates in South Dakota than Nebraska, are attribute to the type of land available for conversion. In Nebraska, between 2006 and 2012 and between 2012 and 2014, 76.1% and 83.8% of the change occurred on soil considered suitable for cropland (LCC < 4) respectively. However, in South Dakota, over

90% of the land that was converted was considered suitable for croplands. In the North Nebraska NASS region, 80,000 ha of grassland were converted to cropland between 2012 and 2014. Approximately 1/3 of this change occurred in land with a LCC value of 6. Lower rates of change occurred in the South Dakota's South Central region where 10,000 ha of land were converted. Differences between the two states most likely are related to availability of an irrigation supply.

From second study we concluded that, the Northern Great Plain grassland possess a large amount of soil and plant carbon. The cycling of carbon between the plants, soil, and atmosphere is influenced by many factors including seasonal climate variation, soil properties, grass morphology, and tissue chemistry. We found shoot and root production was higher in moderately grazed high plant diversity area (HP) than the intensively grazed low plant diversity area (LP). The percentage of litter that was decomposed was higher in the HP than the LP areas at White River and Oacoma. The winter season exhibit the lowest rate of litter decomposition, followed by spring and summer. The results indicated that the plant biomass C: N ratio and temperature explained 52 and 45%, respectively of the measured changes in biomass decomposition. Sites producing biomass with a low C: N ratio had higher first order rate constants than sites with high C: N ratios. These findings indicate that the winter period cannot be ignored when assessing carbon turnover.

Lastly, third study compared total carbon flux from fired and grazed grassland plots. Activities like fire and grazing which have potential to affect different physical and biological aspect of grassland ecosystem impacting net carbon budget and long term sustainability. Our study resulted that annual fire treatment had higher above and below ground biomass production than the annual grazing. Moreover total carbon lost, soil temperature and moisture contents were higher in fire than grazing.

Future Research

Sustainable land management involves the management of land, soil, water, biodiversity and other resource's that meets human requirements while maintaining ecosystem services. In the northern Great Plains (NGP), the combined impacts of land-use and climate variability have placed many soils at the tipping point of sustainability. Various management practices like the maintenance of soil health along with soil organic carbon, erosion minimization, protection from salt accumulation and consideration of several services provided by various resources are main factors impacting sustainability in South Dakota. Our three study investigated sustainability of land use change and soil carbon of Northern great plain. The findings from the land use change assessment could be a very useful to researcher, extension workers and policy makers for the making policies and decisions related to conservation and sustainable agriculture in the future. This study could provide information balancing economic development with the environmental impacts. Moreover a decision of a land owner during land use change are affected by their biological and financial resources available, experience of climate variability in the region and different management practices and actions during drought periods . However our study have not included farmers and ranchers real life responses to drought severity, different grazing management system and prices of agricultural prices which are very important to a land owner during decision making process of land use. Thus in coming future, incorporating such real life experiences of farmers though survey could strengthen the impact and finding of this kind of studies.

Moreover, we designed rainout shelters to simulate different seasonal drought to investigate their impact on soil carbon sequestration. However, due to excess water run-off from the surrounding, we failed to simulate target seasonal drought. Thus to study the impact of climate variability like drought on the soil heal and carbon, we need to redesign and engineer rainout shelters such a way that to meet our target reduction of precipitation.