Spatial Variability Analysis and Reclamation of Saline-Sodic Soils in the Northern Great Plains

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SPATIAL VARIABILITY ANALYSIS AND RECLAMATION OF SALINE-SODIC
SOILS IN THE NORTHERN GREAT PLAINS

BY
GIRMA A. BIRRU

A dissertation submitted in partial fulfillment of the requirements for
Doctor of Philosophy
Major in Plant Science
South Dakota State University
2016
SPATIAL VARIABILITY ANALYSIS AND RECLAMATION OF SALINE SODIC
SOILS IN THE NORTHERN GREAT PLAINS

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

The challenges were enormous but with the grace of God and unprecedented support from my family, advisor, and project members this study has come to an end. First of all I would like to thank my advisor, Dr. Douglas Malo, for the wonderful guidance, mentoring, and for giving me this opportunity. I thank Dr. David Clay (for giving me the opportunity) and Dr. Cheryl Reese for their support and mentoring during the period of my study. My daughters (Merry, Abenezer, and Bethlehem) and my wife (Mesoret Abay) were always supporting. I am deeply grateful for my late mother (Almaze Mengesha) for what she did in my life. She was everything to me. I dedicate this work to her. I also thank my brother Yared for his support. I also thank once again all the committee members (Dr. Douglas Malo, Dr. David Clay, Dr. Cheryl Reese, Dr. Gregg Carlson, and Dr. George Hamer) for all their support and time. I would like to thank Dr. Sharon Clay for her advice I received in the beginning of the project. I also thank Graig Reicks, Stephanie Bruggeman, Janet Miller, Tulsi Kharel, Rachel Kern, John Green, Dr. Chang Jiyul, Dr. Sandeep Kumar, Mfuka Confiance, and a number of others which I cannot list here. My thanks also go to Dr. Tom DeSutter and his lab assistant at North Dakota State University (NDSU) for allowing us to use the lab at NDSU for some of the soil analyses used in this study. I would like to thank Dr. Howard Woodard for the encouragement and support he has provided to me and to my family. I also want to thank Martha Wanous for her guidance and support. Many thanks to all undergrad students who helped me in the lab and with field work. I also want to acknowledge all the producers who allowed us to work in their fields and provided their farm equipment for our use. I also thank USDA-NRCS CIG project 69-3A75-12-185 and the South Dakota Corn Utilization Council for funding. Finally, I thank the Department of Agronomy, Horticulture and Plant Science, SDSU for covering my stipend for a few months.
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ABBREVIATIONS

% – percent
° – degree
″ – degree
′ – minutes
°C – degree Centigrade
A – cross-sectional area of the soil columns
a – range of spatial dependence
ac – acres
ANOVA – analysis of variance
C – partial sill semi-variance
C₀ – nugget Semi-variance
Ca²⁺ – calcium ion
CC – cover crop
CEC – cation exchange capacity
CIG – Conservation Innovation Grant
Cl⁻ – chloride ion
cm – centimeter
CO₂ – carbon dioxide
CO₃²⁻ – carbonate ion
CS – cropping system
CV – coefficient of variation
DEM – digital elevation map
dS/m – deciSiemens per meter
EC – Emergence (crop)
EC – electrical conductivity
ECa – apparent electrical conductivity
ECe – saturated paste extraction electrical conductivity
ESP – exchangeable sodium percentage
GPS – global positioning system
h – lag distance
ha – hectare
HCO₃⁻ – bicarbonate ion
IDW – inverse distance weighting
IR – infiltration rate
k – class of nearest neighbor
K⁺ – potassium ion
kg/ha – kilogram per hectare
m – meters
M – molarity
Mg²⁺ – magnesium
MIR – mid-infrared
mL – milliliters
MLRA – Major Land Resource Area
mm – millimeters
MSR – multispectral radiometer
N – North
n – number of samples
Na⁺ - sodium ion
NCC – non cover crop
NDSU – North Dakota State University
NDVI – Normalized Difference Vegetation Index
NGP – Northern Great Plains
NIR – near-infrared
nm – nanometer
NO₃⁻ – nitrate ion
NRCS - Natural Resources Conservation Service
NTU – Nephelometric Turbidity Unit
O₂ – oxygen
pH – a measure of acidity or basicity (alkalinity)
r – correlation coefficient
R1 – beginning flowering
RMSE – Root Mean Square Error
S – elemental sulfur
s⁻¹ – per second
SA – surface amendment
SAR – sodium adsorption ratio
SD – South Dakota, USA
SDSU – South Dakota State University
SM – soil moisture
SO₄²⁻ – sulfate ion
SOM – soil organic matter
USA – United States of America
USDA – United States Department of Agriculture
USGS – United States Geological Survey
V1 – first-leaf growth stage
V4 – four visible leaf collars
V6 – sixth-leaf growth stage
γ – semi-variance
ΔQ – volume of water collected
Δt – change in time
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ABSTRACT

SPATIAL VARIABILITY ANALYSIS AND RECLAMATION OF SALINE SODIC-SOILS IN THE NORTHERN GREAT PLAINS

GIRMA A. BIRRU

2016

Increased spring rainfall and higher temperatures when combined with changing land-uses and extensive tile drainage installation have contributed to the development of sodic and saline/sodic soils in the Northern Great Plains. The objectives of this dissertation were: 1) determine the impact of surface chemical treatments and cover crop on crop yields and soil remediation; 2) determine and describe soil spatial variability and develop a model to identify saline-sodic soils; and 3) evaluate cation impact on dispersion of bentonite clay and selected soils. The research was conducted between 2013 and 2016 at Redfield (Argiustolls, Natrudolls, Calciustolls), White Lake (Argiudolls, Natrudolls), and Pierpont (Hapludolls, Natrudolls), in eastern South Dakota. A randomized complete block design with 4 replications was used. Treatments were cover cropping and surface amendments [gypsum, calcium chloride, elemental sulfur (S), and no amendments]. A mixture of barley (*Hordaeum vulgare*) and sugar beet (*Beta vulgaris*) was used as the cover crop. At 169 sampling points, yield, soil properties, and reflectance were measured. Spatial class was developed using nugget to sill ratio. The impacts of chemical amendments on reducing soil dispersion were determined. Surface chemical amendment and cover crop treatments did not show significant differences in crop yield and soil properties in most locations. Hence, the amendments did not work in the Northern Great Plain soils with a glacial parent material that has high salt, calcium carbonate, and gypsum levels. Other management strategies that can reduce soil pH and mimic the native prairie grasses (deep-
rooted perennial grasses that can use water from deeper in the soil profile) could be useful for future study. The exponential semivariogram model was found to be the optimal model for NDVI and yield with the spatial dependence (nugget/sill ratio) of 14.4 and 0%, respectively. Similarly, the exponential model was the optimum fit for mollic depth, lime depth, pH, EC, and SAR with nugget to sill ratio of 0, 0, 45, 17 and 49 respectively. Local Moran’s I and semivariogram modelling of soil attributes and NDVI data could help locate saline hot spots and quantify spatial heterogeneity respectively in saline-sodic soils. Higher turbidity was recorded in Na salt treated soil and bentonite clay than Ca and Mg salts. Turbidity was useful in measuring clay dispersion and could be used as an indicator of clay dispersion in salt-affected soils.

Keywords: Argiustolls, bentonite clay, Calciustolls, dispersion, Hapludolls, Natrudolls, NDVI, semivariograms, SAR, saline-sodic soil, soil spatial variability, surface amendments, turbidity, reclamation, water infiltration.
1. CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Rapid world population growth has increased the demand for agricultural products and has sometimes resulted in natural resource degradation. To maintain the food supply and meet the growing world population, agricultural production has to grow substantially (Foley et al., 2011; Tscharntke et al., 2012). In the last few decades, suitable cultivable land for crop production has decreased significantly and the alternative option is improving the productivity of degraded land including salt-affected soils (Ladeiro, 2012; Rengasamy, 2006).

Estimates identify at least 950 million ha of the world’s soils that are salt-affected with different proportions of saline and sodic soil (Szabolcs, 1994). These hundreds of millions of hectares of land are not used for agricultural production due to high levels of salts (Northcote and Srene, 1972) and the increased incidence of salt-affected soils has resulted in environmental quality degradation and reduced crop yields (Rengasamy, 2006). Salt-affected soils are found almost in all climatic regions, where evapotranspiration exceeds precipitation at least some portion of the year (Rengasamy, 2006; Sumner and Naidu, 1998).

Secondary dryland salinity (human-induced salinity in non-irrigated areas) has become a major concern in the Northern Great Plains (NGP) region of USA (South Dakota, North Dakota, and Montana) and Canada (the prairie provinces of Manitoba, Saskatchewan, and Alberta) (Pannell and Ewing, 2006). Thus, these salt-affected soils require special management measures to improve their productivity and to reduce their environmental impact (Allen et al., 1998; Gabrijel et al., 2011). Therefore, a comprehensive understanding of the interrelationship between different environmental conditions that affect saline and sodic soils expansion is vital to
designing effective and sound management strategies and to reduce the expansion of the problem.

1.1 Source and Classification

Detailed reviews of the chemistry and formation of salt-affected soils have been reported (McBride, 1994; Suarez et al., 2005). Geochemical weathering of parent rock materials is the main source of salts in most soils (Maas et al., 1999). However, the expansion of salts in soils and water bodies is mainly affected by land-use (Suarez et al., 2005) and precipitation changes. During weathering, the primary minerals react with water and O\(_2\) and CO\(_2\) to form secondary minerals and salts which are transported by water to depressions in the landscape and oceans (Maas et al., 1999; Suarez et al., 2005). Salts consist mostly of various proportions of Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), Cl\(^-\), SO\(_4^{2-}\), HCO\(_3^-\) and occasionally K\(^+\), CO\(_3^{2-}\), and NO\(_3^-\) ions (McBride, 1994).

The processes of salinization and alkalization of soils are the consequences of a number of factors of surface and ground waters, soil physical properties, climate, relief, geomorphology, and man’s and other biological activities (Maas et al., 1999). Similarly, salinization and alkalization of NGP soils are the result of a combination of several factors including: 1) the weathering of primary materials with high salt levels (Cerling and Quade, 1993; Kohut and Dudas, 1993); 2) changes in land use and vegetation (conversion of grass land to cropland) (Anderson et al., 2015; Kim et al., 2012); 3) increases in precipitation (Karl and Knight, 1998); and 4) changes in land management practices (no-till, summer fallow, and expansion tile drainage) (Karlen et al., 1997).

Classification of salt-affected soils is based on their chemical properties and ease of reclamation. The key chemical properties are pH, electrical conductivity (EC), and exchangeable
sodium percentage (ESP) or sodium adsorption ratio (SAR) (Rhoades, 1982; Szabolcs et al., 1974). According to the US Salinity Laboratory Staff, (1954) salt-affected soils are traditionally classified into three groups. These are: 1) saline soils; 2) saline-sodic soils; and 3) sodic soils.

Saline soils contain soluble salt levels that can affect the growth and productivity of most crop plants (US Salinity Laboratory Staff, 1954; Wallender and Tanji, 2011). Saline soils are composed mainly of the ions Cl\(^-\), SO\(_4^{2-}\), Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\) and small amounts of NO\(_3^-\), HCO\(_3^-\), and K\(^+\). Saline-sodic soils contain both soluble salts and exchangeable sodium in higher quantities that affect growth and productivity of the of crop plants (US Salinity Laboratory Staff, 1954; Wallender and Tanji, 2011). Electrical conductivity (EC) is the common method of estimating salinity levels in soils. In most cases, the uncontrolled removal of soluble salts from saline-sodic soils can result in the formation of sodic (dispersed) soils (Kelley, 1951). Soils that contain high levels of exchangeable sodium on their exchange complex which can affect the growth and production of most crop plants and dispersed soil structure are sodic soils (Sumner and Naidu, 1998). Commonly, sodic soils have very low permeability (Kelley, 1951; Sumner, 1993; Sumner and Naidu, 1998). The surface horizons of sodic soils are often dense (compacted) with poor (dispersed and columnar) subsurface structure. Soil alkalinity is determined by the amount of exchangeable sodium percentage (ESP), the concentration of exchangeable sodium (Na\(^+\)) expressed as percent of Na\(^+\) retained by the soils cation exchange capacity (CEC) or by the sodium adsorption ratio (SAR).

1.2 Plant Response and Salt Affected Soils

Salt stress affects plants in a variety of ways including reducing growth rate (stunted growth and darker green leaf color) and changes in plant physiology (Maas and Hoffman, 1977;
Munns, 1993, 2002; Netondo et al., 2004; Volkmar et al., 1998). The level of injury and reduction in growth varies among crop plants (Maas et al., 1999). However, a high concentration of a single salt is likely to cause specific ion effect (toxicity or nutritional imbalances) (Bernstein, 1975; Grattan and Grieve, 1999; Lauchli and Epstein, 1990; Shainberg and Letey, 1984). The osmotic effect (due to high salinity levels) is the main cause of annual crop yield reduction in saline soils (Maas et al., 1999; Stavridou et al., 2016). Whereas the impact of high sodium levels is on soil structure, nutrient availability, and plant growth (Bernstein, 1975; Bertness and Hacker, 1994; Bronick and Lal, 2005)

1.3 Reclamation and Management

Reclamation and management strategies of saline, sodic, or saline-sodic soils should be developed based on the baseline data of a specific site (Gupta and Abrol, 1990; Qadir and Oster, 2004; Qadir et al., 2008). The key factor in reclamation of saline soil is water movement into and through soils (Oster et al., 1996). Reclamation can be done by the combination of one or more of the following practices: tillage and other cultural practices, water management, tolerant crops and cropping systems, and use of soil amendments to improve crop productivity (Kelley, 1951; Oster et al., 1996).

Some of the suggested strategies and methods to control salinity and sodicity in the short-term and medium-term include: the use of quality water related measures including post-planting leaching; mulching; application of farmyard manure; maintaining high levels of available water in the plant root zone; use of good quality irrigation water; establishing and rehabilitating sub-surface drainage systems and drainage canals; and proper land drainage (Gupta and Abrol, 1990; Haque, 2006; Heuperman, 1999; Qadir et al., 2003). Additional strategies could include
selection and seedbed preparation including avoiding cultivation of lands with high water tables and hard pans; avoiding irregular water intake to prevent accumulation of salts; and minimum tillage to avoid soil compaction (Abrol et al., 1988; Lal, 2000). There are also suggested biological and agronomic management measures that could help combat the effect of salt-affected soil including the selection of salt tolerant crops, growing salinity and sodicity ameliorating crop species, and selecting proper seeding or planting methods (Qadir and Oster, 2004; Rietz and Haynes, 2003).

Some of the strategies and methods to control salinity and sodicity in the long-term start with field observations, investigating the sources, soil classification studies, irrigation effects, determine suitable management practices (irrigation, drainage, leaching, groundwater management, land levelling, and cultural practices), evaluating the agronomic practices, and identifying representative area(s) to test the prescribed practices (Abrol et al., 1988; Oster et al., 1996; Qadir and Oster, 2004).

1.4 Objectives

**Experiment 1 (Chapter II):** To compare the impact of surface chemical treatments, and cover crop on crop yields and soil quality.

**Experiment 2 (Chapter III):** to select the appropriate model that can define or predict spatial variability of NDVI and yield and to compare the effectiveness of spatial interpolation methods.

**Experiment 3 (Chapter IV):** To evaluate the effectiveness of surface chemical amendments and cover crops on improving water infiltration in saline-sodic soils and to evaluate the effect of variable cation concentrations on the dispersion of bentonite clay and selected soil samples.

**Experiment 4 (Chapter V):** Describe spatial variability of selected soil properties.
1.5 Literature Cited


US Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. In: L. Richards, editor Agricultural Handbook 60. USDA, Riverside, CA.


2. CHAPTER II

CROP YIELD AND SOIL PROPERTIES AS AFFECTED BY SOIL SURFACE CHEMICAL AMENDMENTS AND COVER CROP

Abstract

Changing climatic conditions when combined with an opportunity to install tile drainage has placed many Northern Great Plains (NGP) soils at the tipping point of sustainability. A field study was conducted to compare the impact of surface chemical treatments and cover crop on crop yields and soil quality. The eastern South Dakota study locations were White Lake (dominant soils: Argiustolls, Natrudolls, and Calciustolls), Redfield (dominant soils: Argiudolls and Natrudolls) and Pierpont (dominant soils: Hapludolls and Natrudolls). A randomized complete block design with four replications was used. The treatments were cover crop and surface amendments. A barley (Hordeum vulgare L.) and sugar beet (Beta vulgaris subsp. vulgaris) mixture was seeded as the cover crop at the rate of 34 kg ha\(^{-1}\) and 4.5 kg ha\(^{-1}\), respectively. Soil surface amendments were gypsum (CaSO\(_4\)·2H\(_2\)O), CaCl\(_2\), and elemental sulfur. No amendment was used as a control. Grain yield, stover weight, and other agronomic traits were measured. Initial and final soil samples from each plot and three soil depths were analyzed for basic soil parameters. Soil chemical properties improved when compared with baseline data in all locations and years for surface chemical amendments. However, the surface amendments did not show any significant difference in most locations years indicating these treatments did not work for glacial parent material soils with high salt levels (calcium carbonate and gypsum). Other management strategies that can reduce soil pH and mimic the native prairie grasses (deep-rooted perennial grasses that can use water deeper in the soil profile) could be
useful for future study. Generally, the spatial area of saline and saline-sodic soils is increasing in the NGP region of the United States resulting in a significant reduction of productive of arable land due to reduced soil organic matter which affects soil chemical properties and degrades soil structure and increases the downstream sediment deposition due to the erosion of sodic soils.

**Keywords:** saline-sodic soil, saline soil, sodic soil, sodium adsorption ratio (SAR), gypsum, sulfur, calcium chloride, Northern Great Plains, Argiustolls, Calciustolls, Natrudolls, Hapludolls, electrical conductivity (EC).
2.1 Introduction

Over 950 million ha of the world’s soils are salt-affected (with different proportions of saline and sodic soils, [(Szabolcs, 1994). Soil salinity and sodicity are major forms of land degradation affecting the world soils (Qadir and Schubert, 2002; Rengasamy, 2006). Secondary dryland salinity (human-induced salinity in non-irrigated areas) has become a major concern in the North America Northern Great Plains, NGP (Pannell and Ewing, 2006).

Factors attributing to increasing salinity include changes in land use and vegetation, mainly the conversion of grass land to cropland (Reitsma et al., 2015; Reitsma et al., 2016); increases in precipitation (Karl and Knight, 1998); changes in management practices (no-till, summer fallow, and expansion of tile drainage) (Karlen et al., 1997); and parent materials containing high level of salts (Cerling and Quade, 1993) mainly Pierre shale (Malo et al., 2010). These factors contribute to higher exchangeable sodium concentrations in soil exchange sites which lead to natric horizon formation and soil dispersion. Ultimately, yields can be reduced and environmental quality can be diminished (Chi et al., 2012; Hulugalle et al., 2010; Rengasamy, 2006). In the NGP regions, drainage has been used to increase the productivity of wet soils by removing excess water from the root zone (Olson and DeBoer, 1988). Installation of tile drainage has increased in recent years and there have been concerns as to the negative impact of tile drainage on the conversion of a large area of saline soils to sodic soils. However, the effect of integrated soil and water management and agronomic practices on crop productivity and soil health in salt-affected soils of these areas was not investigated. Therefore, this study was conducted to determine the effectiveness of selected soil surface amendments and cover crop in reducing sodicity, improving the soil physical and chemical properties, and improving crop yield in saline-sodic and sodic soils in Eastern South Dakota.
2.2 Materials and Methods

2.2.1 Description of the study sites

A three-year field study (2013 to 2015 growing seasons) was conducted near Redfield, SD (44°58′10″N, -98°27′52″W) and near White Lake, SD (43°40′31″N, -98°45′50″W). Additional sites were selected in 2014 and a two-year field study (2014 to 2015 growing seasons) was conducted near Pierpont, SD (45°30′31″N, -97°53′50″W). The study sites were selected to provide a range of possible salt levels. The dominant soils at the Redfield study site were Harmony-Aberdeen silty clay loams (0-2 % slopes), Winship-Tonka silt loams (0-1 % slopes), and Great Bend-Beotia silt loams (0-2 % slopes). The dominant soils at White Lake were Beadle-Dudley complex (0-3 % slopes), Delmont-Talmo complex (6-15 % slopes), and Houdek and Ethan loams (2-6 % slopes) (USDA-NRCS, 2016a; 2016b). Kranzburg-Brookings silt loams and Nahon-Aberdeen-Exline silt loams with slopes of 2 to 6 % and 0 to 2 % slopes, respectively, were the dominant soil series at the Pierpont study site. Detailed classification of soils is provided in the Appendix II (Table 1). The baseline soil chemical properties are presented in Table 2.1.
Table 2.1 Initial (baseline) average soil chemical composition of the research plots in Redfield (2013), White Lake (2013), and Pierpont (2014), SD.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Soil class</th>
<th>Electrical Conductivity (EC) (dS/m)</th>
<th>Soil pH</th>
<th>Sodium Adsorption Ratio (SAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Depth (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-7.5</td>
<td>7.5-15</td>
<td>15-30</td>
</tr>
<tr>
<td>Redfield*</td>
<td>Saline</td>
<td>8.0</td>
<td>6.2</td>
<td>6.5</td>
</tr>
<tr>
<td>White Lake**</td>
<td>Saline-sodic</td>
<td>10.2</td>
<td>8.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Pierpont*</td>
<td>Saline-sodic</td>
<td>20.0</td>
<td>19.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30'31"N, -97°53'50"W (Dominant soils: Hapludolls, Natrudolls).
n= 4 (Redfield); n=5 (White Lake); n=5 (Pierpont).

Table 2.2 Surface amendment application rates by location.

<table>
<thead>
<tr>
<th>Salt Treatment</th>
<th>Rate applied in kg ha⁻¹ (0-15 cm soil depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Redfield* White Lake** Pierpont*** (East) Pierpont (West)</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>4980 4970 8735 6119</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>4258 4281 7517 5224</td>
</tr>
<tr>
<td>Elemental S</td>
<td>923 922 1616 1139</td>
</tr>
<tr>
<td>No Salt</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>

*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30'31"N, -97°53'50"W (Dominant soils: Hapludolls, Natrudolls).

2.2.2 Experimental design and treatments

The research design used at all sites (Redfield, White Lake, and Pierpont) was a randomized complete block design with 4 replications. The treatments were cover cropping (includes cover crop and non-cover crop) and surface chemical amendments [gypsum (CaSO₄·2H₂O), calcium chloride (CaCl₂), elemental sulfur (S) and control (no-application)]. The area of each plot was 9 m x 9 m for Redfield and 9 m by 6 m in White Lake and Pierpont. The
rate of application of the surface chemical amendments was determined based on the initial soil test results. The surface amendment application rate was calculated from the amount of calcium (Ca\(^{2+}\)) required to replace sodium (Na\(^{+}\)) at each study location for the 0 to 15 cm soil depth. The target exchangeable sodium percentage (ESP) value of the soil was 5 (at this ESP the effect of Na\(^{+}\) on plants and soils is minimal) (Horneck et al., 2007) and is critical value for most NGP soils (Kharel, 2016). The chemical amendment applications rates at each site are presented in Table 2.2. Surface treatments were broadcast onto the soil surface and incorporated using a hand-operated motorized rototiller before planting.

A combination of sugar beet (Beta vulgaris) and barley (Hordeum vulgare) was used as an in-season cover crop. The seeding rates for sugar beet and barley were 34 kg/ha and 4.5 kg/ha. Cover crop planting at each site depended on the growth stage of the main crop (June). Accordingly, for the corn (Zea mays) and sorghum (Sorghum bicolor) crops the cover crop was planted when the main crop growth stage was between V4 (four visible leaf collars) and V6 (sixth leaf growth stage). Whereas, for soybeans (Glycine max) cover crops were seeded between n V stage- nth trifoliate (V stages continue with the unfolding of trifoliate leaves and the final number of trifoliate depends on the soybean variety and the environmental conditions) and R1 (beginning flowering - plants have at least one flower on any node (Clark, 2008; Fehr et al., 1971; Vaughan and Evanylo, 1998).

2.2.3 Data collection and analysis

Soil Sampling and Chemical Analysis
Soil samples were taken from each plot in each fall and spring seasons from 2013 to 2015. Soil sampling was done at start of the cropping season (May/June) and after harvest
(October/November). Soil samples from three different depths (0-7.5, 7.5-15, and 15-30 cm) consisted of 10 subsamples collected with a 1.9 cm diameter soil probe. Each sample was dried at 40°C, ground, sieved (<2 mm), stored in plastic bags, and analyzed for pH, electrical conductivity (EC), water soluble cations, sodium adsorption ratio (SAR), carbon, ammonium and nitrate-N (Page, 1982).

Water soluble cation concentrations (Na\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\)), EC, and pH and were determined from a saturated extract. One hundred and fifty grams of air-dry soil was weighed and mixed with distilled water until saturated. The mixture was covered and allowed to equilibrate for 24 hours. After 24 hours, the soil solution was extracted using a Büchner funnel apparatus and vacuum. All extracts were stored at 4°C until they were analyzed for pH, EC, Ca, Mg, and Na (PC 2700, Oakton Instruments, Vernon Hills, IL) (Rhoades, 1982). Sodium adsorption ratio (SAR) was calculated using Equation 2.1.

\[
SAR = \frac{[Na^+] \cdot \left(\frac{[Ca^{2+}] + [Mg^{2+}]}{2}\right)^{1/2}}
\]

Equation 2.1

**Yield and other agronomic traits**

The plots were planted with corn (Zea mays), sorghum (Sorghum bicolor), and soybean (Glycine max), fertilized, and pesticides applied by the producer collaborators (Table 2.3). Grain and stover harvest for corn and sorghum were done by hand and, soybean harvest was conducted by a combine. A total area of 1.5 m x 3 m (5.25 m\(^2\)) for corn and sorghum were harvested to estimate grain yield and stover biomass. Whereas, a 12 m\(^2\) area of soybeans was harvested and converted to yield on a hectare basis.
Table 2.3 Crops planted and agronomic management practices at the study locations.

<table>
<thead>
<tr>
<th>Site</th>
<th>Crop</th>
<th>Row Spacing (cm)</th>
<th>Crop</th>
<th>Row x Plant Spacing (cm)</th>
<th>Crop</th>
<th>Row Spacing (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redfield*</td>
<td>Corn</td>
<td>75</td>
<td>Soy</td>
<td>50</td>
<td>Soy</td>
<td>50</td>
</tr>
<tr>
<td>White Lake**</td>
<td>Sor</td>
<td>75</td>
<td>Corn</td>
<td>75</td>
<td>Soy</td>
<td>50</td>
</tr>
<tr>
<td>Pierpont***</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Corn</td>
<td>75</td>
</tr>
</tbody>
</table>

Soy = soybean (*Glycine max*); Sor = sorghum (*Sorghum bicolor*)
*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30'31"N, -97°53'50"W (Dominant soils: Hapludolls, Natrudolls).

Chlorophyll content and stomatal conductance

Stomatal conductance was measured using Leaf Porometer-Model SC-1. Five plants from each plot were measured from 11 am to 1 pm when the sun was overhead on a sunny day. The third leaf from the top was measured for all plants. Chlorophyll content was measured using MINOLTA chlorophyll meter, SPAD-502. A fully matured leaf was measured for chlorophyll content. Eight plants per plots were measured.

2.2.4 Statistical analysis

Data was analyzed using SAS version, SAS Institute, Cary, NC (SAS, 2007). Differences found between the different treatments were subjected to an analysis of variance (ANOVA).
2.3 Results and Discussion

2.3.1 Crop response

Average growing season (April to October) precipitation and temperature for each research sites are shown Table 2.4. The monthly precipitation and temperature of the two study sites are plotted in Figure 2.1, 2.2, 2.3, 2.4, and 2.5. Note that White Lake precipitation was at least 15 cm below average in all years studied, while at Redfield the precipitation was either much lower or much higher than long-term average. The growing season temperatures were near average for White Lake and much warmer for Redfield.

Table 2.4 Climatic data of the research sites over 2013 to 2015 years and long-term average.

<table>
<thead>
<tr>
<th>Research Sites</th>
<th>Average April to October Precipitation (mm)</th>
<th>Average April to October Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redfield*</td>
<td>-</td>
<td>46</td>
</tr>
<tr>
<td>White Lake**</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>Pierpont***</td>
<td>66 (9 years average)</td>
<td>16 (9 years average)</td>
</tr>
</tbody>
</table>

*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30'31"N, -97°53'50"W (Dominant soils: Hapludolls, Natrudolls).
Figure 2.1 Twenty-five year and 2014 average monthly temperature and precipitation at Redfield, SD.

Redfield GPS: 44°58'10"N, -98°27'52"W.
Source: South Dakota Climate and Weather, 2016.

Figure 2.2 Twenty-five year and 2015 average monthly temperature and precipitation at Redfield, SD.

Redfield GPS: 44°58'10"N, -98°27'52"W.
Source: South Dakota Climate and Weather, 2016.
Figure 2.3 Thirty-year and 2013 average monthly temperature and precipitation at White Lake, SD.

White Lake GPS: 43°40'31"N, -98°45'50"W.
Source: South Dakota Climate and Weather, 2016.

Figure 2.4 Thirty-year and 2014 average monthly temperature and precipitation at White Lake, SD.

White Lake GPS: 43°40'31"N, -98°45'50"W.
Source: South Dakota Climate and Weather, 2016.
In 2013 and 2015 at Redfield, there were no significant differences in corn yield due to the treatments, surface amendments, or cover crop. There was also no significant difference on the interaction of the treatments (Table 2.5). Similarly, there was no significant difference in stover weight due to treatments, surface amendments, or cover crop.

However, in 2014, one year after treatment application, there was a significant yield decline in soybean yields for CaCl$_2$ among the surface amendments treatments ($p < 0.001$; Table 2.5). The highest soybean yields were obtained from sulfur treated plots followed by gypsum, control, and calcium chloride. The cover crop treatments were not significantly different. During the three growing seasons there was no significant yield increase in grain yield between the
control and the three treatments tested and CaCl$_2$ actually significantly lowered soybean yields in 2014.

Grain yields of sorghum (2013) and soybean (2015) in White Lake were not significantly affected by the surface amendments and cover crop treatments (Table 2.6). The cover crop treatments gave numerically better (75% of the time) grain yield than the non-cover crop treatments in White Lake 2013 (Table 2.6). The one-year (2015) field trial at Pierpont showed no significant differences in both corn grain yield and stover weight due to surface amendments or cover crop and there was also no significant difference in the interaction of the treatments. The cover crop treatments numerically increased both grain yield and stover weight (Table 2.7), but were not statistically different.

These data demonstrate slight numerical (but not statistically significant) increases in grain yield and stover weight in surface amendments plots (mainly sulfur and gypsum) when compared to the control that may have resulted from slight change in soil chemical properties (reduction in soil pH, EC, and exchangeable sodium), soil physical properties (infiltration and water hydraulic conductivity of the soil), or a combination of one or more factors. In sodic soils with high levels of lime, sulfur reacts with lime and produce gypsum, a soluble Ca$^{2+}$ form, which can then replace exchangeable Na$^+$ (Stroehlein et al., 1978). The variable responses of the treatments over the years could be attributed to differences precipitation, temperature, and soil parent materials at each research site. For instance, in year 2015 annual rainfall increased from the previous years (see Table 2.4 and Figures 2.1, 2.2, 2.3, 2.4, and 2.5). That may have resulted leaching of soluble salts from the topsoil. Previous work has shown improving sodic soil productivity with the application of gypsum and sulfuric acid (Abrol and Bhumbla, 1979; Noble and Kleinig, 1971; Shainberg et al., 1989; Stroehlein et al., 1978). In addition to increasing the
solubility of Ca\textsuperscript{2+}, sulfuric acid increases the availability of essential plant nutrients (Fe, Mn, Zn and P) by lowering soil pH. Availability of nutrients as a result of lowering pH could be cited as an advantage of sulfur (sulfuric acid) application over using gypsum as amendment (Gupta and Abrol, 1990; Qadir et al., 2001; Ryan et al., 1975). Therefore, the results of this study showed that adding amendments like sulfur to NGP sodic soils could be more effective than gypsum or calcium chloride when reclaiming saline-sodic soils. However, in general the chemical amendments in NGP soils did not work as anticipated.

Table 2.5 Grain yield and dry stover weight as affected by surface amendment and cover crop treatments at Redfield, South Dakota.

<table>
<thead>
<tr>
<th>Treatments at Redfield*</th>
<th>Corn, 2013</th>
<th></th>
<th>Soybean, 2014</th>
<th></th>
<th>Soybean, 2015</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain Yield (kg/ha)</td>
<td>n</td>
<td>Stover Yield (kg/ha)</td>
<td>n</td>
<td>Grain Yield (kg/ha)</td>
<td>n</td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl\textsubscript{2} ‡</td>
<td>6340 ± 1240 †</td>
<td>8</td>
<td>3470 ± 1150 †</td>
<td>7</td>
<td>1540 ± 1050 †</td>
<td>18</td>
</tr>
<tr>
<td>No-treatment</td>
<td>6910 ± 1190 *</td>
<td>6</td>
<td>3550 ± 630 *</td>
<td>4</td>
<td>2360 ± 880 *</td>
<td>15</td>
</tr>
<tr>
<td>Gypsum (CaSO\textsubscript{4}·2H\textsubscript{2}O)</td>
<td>6850 ± 1480 a</td>
<td>8</td>
<td>3570 ± 910 a</td>
<td>7</td>
<td>2740 ± 1080 a</td>
<td>17</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>6920 ± 1020 a</td>
<td>7</td>
<td>3130 ± 500 a</td>
<td>6</td>
<td>2790 ± 1260 a</td>
<td>17</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>6810 ± 1300 a</td>
<td>14</td>
<td>3324 ± 950 a</td>
<td>14</td>
<td>2180 ± 1180 a</td>
<td>34</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>6700 ± 1180 a</td>
<td>15</td>
<td>3534 ± 700 a</td>
<td>10</td>
<td>2530 ± 1180 a</td>
<td>33</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.662</td>
<td>0.630</td>
<td>0.001</td>
<td>0.640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0.785</td>
<td>0.447</td>
<td>0.105</td>
<td>0.529</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.281</td>
<td>0.112</td>
<td>0.397</td>
<td>0.554</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Means with different letters within a column, treatment are significantly different at $P < 0.05$.
‡ Surface Treatment =ST; Cropping System =CS.
*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
Table 2.6 Grain yield and dry stover weight as affected by surface amendment and cover crop treatments at White Lake, South Dakota.

<table>
<thead>
<tr>
<th>Treatments at White Lake**</th>
<th>Sorghum, 2013</th>
<th>Soybean, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain Yield (kg/ha)</td>
<td>n</td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂ ‡</td>
<td>3150 ± 1650 a†</td>
<td>10</td>
</tr>
<tr>
<td>No-treatment</td>
<td>3100 ± 1360 a</td>
<td>14</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>3370 ± 1940 a</td>
<td>13</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>3480 ± 2310 a</td>
<td>18</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>3549 ± 1740 a</td>
<td></td>
</tr>
<tr>
<td>No-cover crop</td>
<td>2996 ± 1930 a</td>
<td></td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.918</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.923</td>
<td></td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡Surface Treatment =ST; Cropping System =CS.
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).

Table 2.7 Comparison of grain yield and dry stover weight as affected by surface amendment and cover crop treatments at Pierpont, South Dakota.

<table>
<thead>
<tr>
<th>Treatments at Pierpont***</th>
<th>Corn, 2015</th>
<th>Stover Yield (kg/ha)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain Yield (kg/ha)</td>
<td>n</td>
<td></td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>1970 ± 1580 a†</td>
<td>9</td>
<td>1900 ± 1120 a</td>
</tr>
<tr>
<td>No-treatment</td>
<td>1410 ± 1130 a</td>
<td>11</td>
<td>1460 ± 680 a</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>2300± 1550 a</td>
<td>10</td>
<td>2240 ± 1290 a</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>1660± 1100 a</td>
<td>11</td>
<td>1940 ± 1790 a</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>2160 ± 1490 a</td>
<td>22</td>
<td>2160 ± 1690 a</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>1500 ± 1100 a</td>
<td>21</td>
<td>1615 ± 840 a</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.097</td>
<td></td>
<td>0.610</td>
</tr>
<tr>
<td>CS</td>
<td>0.447</td>
<td></td>
<td>0.185</td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.822</td>
<td></td>
<td>0.640</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡Surface Treatment =ST; Cropping System =CS.
***45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls).
**Chlorophyll content and stomatal conductance**

This study showed significant differences in final sorghum populations at White Lake among the surface amendments (Table 2.8). However, there were no significant differences in plant populations due to cover crop treatment and the interaction at White Lake 2013. Chlorophyll contents for White Lake were not significantly different for surface amendments for both years (2013 and 2015). There were no significant differences in stomatal conductance for surface amendments in 2013. In 2015, there were significant differences in soybean stomatal conductance due to surface treatments (Table 2.8).

During the three years of study (corn [2013] and soybean [2014, 2015]) final plant populations, chlorophyll content, and stomatal conductance measurements at Redfield, SD indicate that there were no significant differences in all studied parameters due to surface amendments or cover crop (Table 2.9). Cover crop did numerically enhance stomatal conductance and plant populations.

**2.3.2 Soil chemical properties**

Surface chemical amendments and cover crop did not show significant differences in improving the topsoil properties. Surface soil (0 – 0.5 cm) chemical properties appeared to improve (Tables 2.10, 2.11, and 2.12) when compared with the baseline data (Table 2.1). At White Lake surface soil pH reduced from 7.6 to 7.3, EC from 10.2 dS/m to 7.9 dS/m, and SAR from 17 to 12.6 in sulfur treated plots over the study period. However, when treatments at all depths and cover crops were compared to the control there were no significant differences in pH, EC, or SAR. Similarly, in Redfield, the surface soil (0 – 7.5 cm) pH was reduced from 7.3 to 7.1 (gypsum treated plots), EC from 8.0 dS/m to 4.9 dS/m, and SAR from 3.6 to 1.3 during the three-
year period. However, when treatments at all depths and cover crop were compared to the control there were no significant differences in pH, EC, or SAR (except for SAR in soybeans at 7.5 cm depth in 2015). Soil chemical properties changes due to surface chemical amendments and cover crops at different depth are presented in Figures 2.6 to 2.12.

The changes in soil chemical properties were attributed to the increase in precipitation that may have leached the salts from the topsoil and also a slight positive impact of sulfur and gypsum on soils, acidifying the soil and making the existing Ca\(^{2+}\) more available in the exchange complex. The Ca\(^{2+}\) then replaces Na\(^{+}\) resulting in reductions of soil pH and SAR. Gypsum decreases the ratio of sodium to other soluble salts and as a result, reduces sodicity and increases Ca\(^{2+}\) exchange system (Frenkel et al., 1989).

Other research on different soils have shown improvement in soil chemical properties after application of gypsum and sulfuric acid (Hamza and Anderson, 2003; Rengasamy and Olsson, 1991; Shainberg et al., 1989; Shanmuganathan and Oades, 1983). There have been reports of increased yield (Abrol and Bhumbla, 1979; Noble and Kleinig, 1971; Shainberg et al., 1989) and increased seed emergence (Lauchli and Epstein, 1990; McKenzie et al., 1993) under specific soil treatments.
Table 2.8 Plant population and selected physiological measurements of sorghum (*Sorghum bicolor*) and soybean (*Glycine max*) as affected by surface amendment and cover crop treatments in White Lake, SD in 2013 and 2015

<table>
<thead>
<tr>
<th>Treatments at White Lake**</th>
<th>Sorghum, 2013</th>
<th>Soybeans, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Plants/ha</td>
<td>Chlorophyll Content (%)</td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>21310²ab†</td>
<td>12</td>
</tr>
<tr>
<td>No-treatment</td>
<td>16810b</td>
<td>15</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>25800²ab</td>
<td>13</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>32510²a</td>
<td>17</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>20490²a</td>
<td>28</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>27720²a</td>
<td>29</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.154</td>
<td>0.923</td>
</tr>
<tr>
<td>CS</td>
<td>0.173</td>
<td>-</td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.977</td>
<td>-</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at $P < 0.05$.
‡Surface Treatment =ST; Cropping System =CS.
**43°40’31”N, -98°45’50”W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
Measurements were done between V4 (four leaves) and V6 (six leaves) stage for sorghum and R1 (flowering) stage for soybean.
Table 2.9 Plant population and selected physiological measurements of corn (*Zea mays*) and soybean (*Glycine max*) as affected by under surface amendment and cover crop treatments in Redfield, SD in 2013, 2014, and 2015.

<table>
<thead>
<tr>
<th>Treatments at Redfield*</th>
<th>Number of Plants/ha</th>
<th>Corn, 2013</th>
<th>Soybean, 2013</th>
<th>Soybean, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Chlorophyll Content (%)</td>
<td>Stomatal conductance (mmol m⁻² s⁻¹)</td>
<td>Chlorophyll Content (%)</td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong> ‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>33970 ± 6520 a†</td>
<td>14</td>
<td>43 ± 5 a</td>
<td>15</td>
</tr>
<tr>
<td>No-treatment</td>
<td>35070 ± 5350 a</td>
<td>18</td>
<td>44 ± 6 a</td>
<td>18</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>34720 ± 6070 a</td>
<td>17</td>
<td>45 ± 6 a</td>
<td>18</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>36550 ± 5800 a</td>
<td>15</td>
<td>44 ± 5 a</td>
<td>18</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>35587 ± 5471 a</td>
<td>33</td>
<td>43 ± 5 a</td>
<td>35</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>34571 ± 6222 a</td>
<td>31</td>
<td>43 ± 6 a</td>
<td>34</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.462</td>
<td>0.543</td>
<td>0.855</td>
<td>0.740</td>
</tr>
<tr>
<td>CS</td>
<td>0.361</td>
<td>0.731</td>
<td>0.078</td>
<td>0.675</td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.952</td>
<td>0.664</td>
<td>0.793</td>
<td>0.443</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡ Surface Treatment =ST; Cropping System =CS.
*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
Measurements were done between V4 (four leaves) and V6 (six leaves) stage for sorghum and R1 (flowering) stage for soybean.
Table 2.10 Soil pH change by depth at White Lake and Redfield, SD.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Soil pH After Harvest</th>
<th>Soybean (<em>Glycine max</em>), 2015 at White Lake**</th>
<th>Soybean (<em>Glycine max</em>), 2015 at Redfield*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-7.5cm n 7.5-15cm n 15-30cm n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline soil pH</td>
<td>7.6 ± 0.2 6 7.8 ± 0.1 6 7.8 ± 0.2 6</td>
<td>7.3 ± 0.3 5 7.8 ± 0.4 5 7.8 ± 0.3 5</td>
<td></td>
</tr>
<tr>
<td>Surface Treatment (ST)‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-treatment</td>
<td>7.4 ± 0.5 a† 8 7.4 ± 0.3 a 7 7.5 ± 0.3 a 9</td>
<td>7.1 ± 0.6 a 13 7.7 ± 0.3 a 15 7.7 ± 0.3 a 15</td>
<td></td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>7.5 ± 0.3 a 9</td>
<td>7.4 ± 0.4 a 9 7.4 ± 0.1 a 3</td>
<td>7.1 ± 0.5 a 17 7.7 ± 0.4 a 15 7.6 ± 0.2 a 17</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>7.3 ± 0.3 a 6</td>
<td>7.4 ± 0.3 a 7 7.4 ± 0.5 a 8</td>
<td>7.8 ± 0.5 a 18 7.6 ± 0.3 a 18 7.6 ± 0.3 a 18</td>
</tr>
<tr>
<td>Cropping System (CS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>7.3 ± 0.3 a 6</td>
<td>7.5 ± 0.3 a 8 7.5 ± 0.4 a 7</td>
<td>8.0 ± 0.6 a 25 7.8 ± 0.4 a 24 7.7 ± 0.3 a 26</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>7.5 ± 0.4 a 17</td>
<td>7.4 ± 0.4 a 15 7.4 ± 0.4 a 13</td>
<td>7.8 ± 0.6 a 23 7.6 ± 0.3 b 24 7.6 ± 0.2 a 24</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.426</td>
<td>0.623</td>
<td>0.711</td>
</tr>
<tr>
<td>CS</td>
<td>0.463</td>
<td>0.526</td>
<td>0.882</td>
</tr>
<tr>
<td>ST*CS</td>
<td>0.528</td>
<td>0.396</td>
<td>0.642</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at $P < 0.05$.
‡Surface Treatment =ST; Cropping System =CS.
*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
Note: Baseline soil samples were taken in May 2013.
Table 2.11 Electrical conductivity (EC) change by soil depth at White Lake and Redfield, SD.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>After Harvest EC (dS/m)</th>
<th>Soybean (Glycine max), 2015 at White Lake**</th>
<th>Soybean (Glycine max), 2015 at Redfield*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-7.5cm</td>
<td>7.5-15cm</td>
<td>15-30cm</td>
</tr>
<tr>
<td>Baseline (EC in dS/m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.2 ± 2.4</td>
<td>6</td>
<td>8.2 ± 1.0</td>
</tr>
<tr>
<td>Surface Treatment (ST)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-treatment</td>
<td>9.2 ± 3.5a</td>
<td>8</td>
<td>8.7 ± 2.7a</td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td>9.8 ± 3.2a</td>
<td>9</td>
<td>9.2 ± 1.8a</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>7.9 ± 6.2a</td>
<td>6</td>
<td>7.7 ± 3.3a</td>
</tr>
<tr>
<td>Cropping System (CS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>7.3 ± 2.0a</td>
<td>6</td>
<td>8.2 ± 2.7a</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>9.8 ± 3.9a</td>
<td>17</td>
<td>8.7 ± 2.2a</td>
</tr>
</tbody>
</table>

ANOVA P>F

<table>
<thead>
<tr>
<th></th>
<th>ST</th>
<th>0.336</th>
<th>0.336</th>
<th>0.396</th>
<th>0.594</th>
<th>0.229</th>
<th>0.640</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>0.131</td>
<td>0.131</td>
<td>0.085</td>
<td>0.346</td>
<td>0.614</td>
<td>0.860</td>
</tr>
<tr>
<td>ST*CS</td>
<td></td>
<td>0.425</td>
<td>0.425</td>
<td>0.905</td>
<td>0.463</td>
<td>0.343</td>
<td>0.211</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡Surface Treatment =ST; Cropping System =CS.
*44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
dS/m = decisiemens per meter
Note: Baseline soil samples were taken in May 2013.
Table 2.12 Sodium adsorption ratio (SAR) change by soil depth at White Lake and Redfield, SD.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>After Harvest SAR</th>
<th>Soybean (<em>Glycine max</em>), 2014 at White Lake**</th>
<th>Soybean (<em>Glycine max</em>), 2015 at Redfield*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-7.5cm</td>
<td>n</td>
<td>7.5-15cm</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>17 ± 5.2</td>
<td>6</td>
<td>17.8 ± 4.1</td>
</tr>
<tr>
<td><strong>Surface Treatment (ST)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-treatment</td>
<td>13.6 ± 3.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
<td>12.4 ± 2.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gypsum (CaSO&lt;sub&gt;4&lt;/sub&gt;·2H&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>13.7 ± 4.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11</td>
<td>11.3 ± 4.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Sulfur (S)</strong></td>
<td>12.6 ± 2.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
<td>10.4 ± 4.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover crop</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No-cover crop</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.850</td>
<td>0.570</td>
<td>0.237</td>
</tr>
<tr>
<td>CS</td>
<td>0.061</td>
<td>0.596</td>
<td>0.066</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at $P < 0.05$.
‡Surface Treatment = ST; Cropping System = CS.
*44°58’10”N, -98°27’52”W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40’31”N, -98°45’50”W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
Note: Baseline soil samples were taken in May 2013.
Figure 2.6  Electrical conductivity (EC) as affected by cover crop at different soil depths at White Lake, SD (3 years after treatment applied).
GPS: 43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).

Figure 2.7  Electrical conductivity (EC) as affected by cover crop at different soil depths at Redfield, SD (3 years after treatment applied).
GPS: 44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
Figure 2.8 Electrical conductivity (EC) as affected by surface chemical amendments at different soil depths at White Lake, SD (3 years after treatment applied).

GPS: 43°40’31″N, -98°45’50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).

Figure 2.9 Electrical conductivity (EC) as affected by surface chemical amendments at different soil depths at Redfield, SD (3 years after treatment applied).

GPS: 44°58’10″N, -98°27’52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
Figure 2.10 Sodium adsorption ratio (SAR) as affected by surface chemical amendments at different soil depths at White Lake, SD (3 years after treatment applied).
GPS: 43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).

Figure 2.11 Sodium adsorption ratio (SAR) as affected by cover crop at different soil depths at Redfield, SD (3 years after treatment applied).
GPS: 44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
Figure 2.12 Sodium adsorption ratio (SAR) as affected by surface chemical amendments at different soil depths at Redfield, SD (3 years after treatment applied). GPS: 44°58’10”N, -98°27’52”W (Dominant soils: Hapludolls, Natrudolls, Argiudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.
2.4 Conclusions

The area coverage of saline and saline sodic soils is increasing in the NGP region of the United States and that is resulting in a significant reduction of productive of arable land (degraded soil organic levels, soil chemical properties, and soil structure) and increases the downstream sediment deposition (due to increased erosion rates associated with sodic soils).

The effects of chemical amendments on improving crop yield have been shown in earlier research in other parts of the world; however the information on the role of these amendments in NGP saline-sodic soils is scarce. The results of this study showed that the selected surface treatments of gypsum, CaCl$_2$, and sulfur did not significantly enhance crop yield and most soil properties studied. Although, there were a few encouraging responses of gypsum and elemental sulfur amendments, the effect of these treatments both on crop and soil has to be monitored for the long-term and under a larger variety of crops, parent materials, and climatic conditions.

The use of cover crops in saline-sodic soil management was mixed in increasing crop yields, improving soil quality (soil pH, EC, and exchangeable sodium), and water infiltration in some of the tested sites. Elemental sulfur and gypsum were usually, numerically better than calcium chloride and control. Information on the role of perennial and annual ameliorating crops in improving saline-sodic soils needs to be further examined in the future research. The effect of chemical amendments on nutrient availability the impacts of amendments (reclamation) on soil C level in the salt-affected areas of NGP soils are other important areas of future research. Designing a system that mimic the use of deep rooted prairie grasses that utilize the water in most of the year could be useful.
2.5 Literature Cited


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USDA-NRCS. 2016b. Web Soil Survey. USDA-NRCS, 

3. CHAPTER III

SPATIAL MODEL DEFINING NDVI AND CORN YIELDS IN SALINE-SODIC SOILS

Abstract

Geospatial tools coupled with remote sensing methods can assist in making sound natural resource management decisions. The objective of this chapter is to select appropriate models that can define or predict spatial variability of Normalized Difference Vegetation Index (NDVI) and crop yield. This experiment was conducted at Pierpont, SD [44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W in Major Land Resource Area (MLRA) 55C]. The dominant soils in the study area were Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls. A total of 169 grid points (62 x 62 m grid) were laid out in the field in 2014. Reflectance (485-1050 nm of the reflectance bands) readings were made using crop scan [Multispectral Radiometer (MSR)] between seeding and the corn (Zea mays) growth stage V1. Corn yields were measured with a yield monitor at harvest. The normalized difference vegetation indices [NDVI = (NIR - Red) / (NIR + Red)] was computed from reflectance in red and near infrared (NIR) bands. Semi-variograms for the spherical, exponential, and Gaussian models were determined. The exponential semivariogram model for yield and NDVI was the optimal model with the spatial dependence (nugget/sill ratio) of 14.4 and 0 %, respectively. The spatial dependence also extends up to a range of 178 m and 105 m for NDVI and yield, respectively. Comparative analysis of spatial interpolation methods (Trend Surface Analysis, Inverse Distance Weighting, Ordinary Kriging, and Linear Regression models) using elevation as an independent variable were used to map NDVI and yield at the field scale. The Ordinary Kriging was the
optimal model for NDVI with a correlation coefficient of 0.544 ($R^2=0.33$) and root mean square error (RMSE) of 0.089 when compared to other methods. For yield the Inverse Distance Weighting (IDW) method with class of nearest neighbor ($k=2$) was found to be optimal with a correlation coefficient of 0.413 ($R^2=0.24$) and RMSE of 0.223. Therefore, the study clearly showed that geospatial models coupled with remote sensing methods can be used as potential tools to analyze and predict the spatial dependence of NDVI values and crop yield, and aid in the spatial prediction of un-sampled spatial variables in salt-affected soils.

Keywords: Argiudolls, Calciaquolls, Endoaquolls, Hapludolls, interpolation, Natrudolls, radiometer, salinity, Calciudolls, Normalized Difference Vegetation Index (NDVI), semivariograms, spatial interpolation methods, sodicity.
3.1 Introduction

Worldwide saline and Na\(^+\) affected soils are separated into at least three groups: saline (high total salts), saline/sodic (high total salts and Na\(^+\)), and sodic (high Na\(^+\)) (Halvorson and Rhoades, 1976). The classification of salt-affected soils into one of these groups is based on the soil electrical conductivity (EC) and the amount of Na\(^+\) on the cation exchange sites expressed as ESP (exchangeable Na\(^+\) percentage) or SAR (Na\(^+\) adsorption ratio). Historically, sodic soils are characterized as having a Na\(^+\) adsorption ratio (SAR) > 13, whereas in the NGP, soils are at risk when the SAR > 4 (He et al., 2014; Qadir et al., 2007). Saline soils have high salt concentrations and soil electrical conductivities, and these soils reduce yields by decreasing seed germination and slowing plant growth due to high osmotic forces. Sodic soils have high Na\(^+\) concentrations which can result in soil dispersion, decreased water infiltration, and increased erosion.

The development of saline soils is growing problem and in the Northern Great Plains (NGP) high salinity and sodic concentrations impact productivity on over 10 million hectares of land. World-wide high salt concentrations impact growth on over 930 million hectares of land (Cook and Muller, 1997; Szabolcs, 1989). Historically, salinity and sodicity problems were most often observed on irrigated lands, whereas in the NGP salinity and sodicity problems are often observed in dryland agriculture (Cheeseman, 2015; Rengasamy, 2006).

To develop effective solutions, which may include reseeding to grasslands or installing tile drainage, the extent of the problem must be identified and the effectiveness of remediation measured assessed. Techniques for characterizing a soil’s saline and sodic characteristics include measuring, pH, electrical conductivity, and ESP and/or SAR. High salt areas can be identified by conducting a visual survey of the area, conducting an apparent electrical
conductivity survey using a Geonics EM 38 (Geonics Inc., Mississauge, Ontario, Canada, 2016) or the Veris Soil EC Mapping System (Veris Technologies, Salina, Kansas, 2016), tracking changes in yield over multiple years, and collecting and analyzing soil samples for electrical conductivity (EC). Historically, saline management recommendations were based on the EC of a saturated paste extraction (ECe). Most commercial soil testing laboratories do not analyze EC from a saturated paste as part of their “normal” analysis (Owen, 2014). They generally determine the EC of a solution containing 10 mL (= 10 g) of water to 10 g of soil (1:1). The soil water extracted from a 1:1 extraction and saturated paste extraction produce different EC values.

Geospatial techniques coupled with remote sensing may overcome these barriers (Barnes et al., 2003). In the past, several methods have been used to identify and map salt-affected areas (Eldiery et al., 2005). However, spatial models that can easily determine the spatial variability of some selected attributes on salt affected soils were not investigated. Semivariograms are a graphical representation of the spatial variability in a given dataset (Cohen, 1994) and help to determining the spatial autocorrelation of spatial variables. (Lam, 1983). Comparing the different interpolation methods could also help to select the best way to map NDVI, yield, and other soil attributes.

The objectives of this study were to select appropriate models that can define or predict spatial variability of NDVI and yield and compare the efficiency of spatial interpolation methods.
3.2 Materials and Methods

The experiment was conducted in Pierpont in Day County, South Dakota (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W, representing Major Land Resource Area, MLRA, 55C), in April 2014. A yield interpolated map was plotted (Figure 3.1). The dominant soils in the study area were Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls (USDA-NRCS, 2016a; 2016b). Detailed soil and site characteristics of the study area are shown in Appendix II.

Figure 3.1 The study area plotted with 2014 corn (Zea mays) yield values from yield monitor at each data point

Coordinates: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).

3.2.1 Data analysis

A total of 169 grid points (62 x 62 m) were laid out in the field. Multispectral Radiometer (MSR) readings was taken by holding the MSR 2 m above the surface and 1 m diameter data was collected at each grid point in corn (*Zea mays*) field in April 2014. The readings were taken between 10 am to 3 pm. Reflectance readings bands range from 485 to 1050 nm. Reflectance reading broad bands included: blue, 485 ± 2.1 nm; green, 560 ± 2.6 nm; red, 660 ± 3.4 nm; NIR, 830 ± 4.3; and MIR, 1650 ± 5.5; and narrow bands included: 510 ± 2.3 nm; 566 ± 2.7 nm; 610 ± 3.0 nm; 661 ± 3.4; 710 ± 3.8 nm; 760 ± 4.0 nm; 810 ± 4.2; 840 ± 4.4 nm; 870 ± 4.5 nm; 905 ± 4.5 nm; and 1050 ± 4.9 nm.

The following equation was used to calculate percentage reflectance:

$$\text{Reflectance} \% = \left( \frac{\text{Down sensor reading}}{\text{Up sensor reading}} \right) \times 100$$  \hspace{1cm} (3.1)

The normalized difference vegetation indices (NDVI) were computed using the following equation:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$  \hspace{1cm} (3.2)

Grain yield was measured at the site by a combine equipped with a yield monitoring system and Global Positioning System (GPS). Standard protocols were followed to insure data accuracy. Yield data at each grid point was extracted from the yield monitor data using SMS™ Ag Leader® developed software (Ag Leader Inc., 2016).

*SMS™ is software that helps to make management decisions and is produced by Ag Leader. The use of a trade or commercial name is for educational purposes and does not imply endorsement of the product by the author, the Agronomy, Horticulture and Plant Science Department, or South Dakota State University.*
Digital elevation map (DEM) of 30m x 30m was downloaded from United States Geological Survey (USGS, 2016). Landfire website and elevation points were extracted from DEM. (http://www.landfire.gov/NationalProductDescriptions7.php).

Semi-variances were calculated using Equation 3.3, where \( \gamma(h) \) is the semi-variance for lag distance \( h \), \( N \) is the number of samples, \( A \) is the test value for sample \( i \), \( X \) is the location of sample \( i \). and \( X_i + h \) represents the distance between two sample locations (Nielsen and Wendroth, 2003).

\[
\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [A_i(X_i) - A_i(X_i + h)]^2
\]

The selected interpolation methods tested were: Trend Surface Analysis (TSA), Inverse Distance Weighting (IDW), Ordinary Kriging (OK), and Linear Regression (LR) using elevation as an independent variable. These interpolation models were tested to map NDVI and crop yield. Finally, interpolation accuracy was evaluated using Root Mean Square Error (RMSE) and correlation coefficient (Trangmar et al., 1985).

The relationship between distance and the semi-variance values were determined using the spherical, exponential, and Gaussian models. Crop yield and NDVI maps were developed. Interpolation accuracy was evaluated using RMSE and correlation coefficient (r).
The RMSE was calculated:

\[ \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (X_{\text{obs},i} - X_{\text{model},i})^2}{n}} \]  

(3.4)

Where, \(X_{\text{obs}}\) is observed values and \(X_{\text{model}}\) is modelled values at time/place \(i\).

\[(\text{Correlation Coefficient}) \ r = \frac{\sum X Y - n \bar{X} \bar{Y}}{\sqrt{\sum X^2 - n \bar{X}^2} \sqrt{\sum Y^2 - n \bar{Y}^2}} \]  

(3.5)

### 3.3 Results and Discussion

The NDVI data was positively skewed with the Skewness and Kurtosis values of 0.25 and 2.28, respectively. Similarly, the yield data was positively skewed with the skewness and Kurtosis values of 2.82 and 120.2, respectively. The kurtosis for a normal distribution is 3.0. The NDVI kurtosis value indicates that there are fewer and less extreme outliers when compared to a normal distribution while for yield has more outliers and is more peaked than normal.

If the \((\text{nugget/sill}) \times 100 < 25\%\) then the spatial distribution of the data has a strong relationship, while 26-75\% is a moderate relationship, and > 75\% is a weak spatial dependence. Whereas, 100\% shows there is no spatial correlation (Di Virgilio et al., 2007). Accordingly, in our data the best spatial dependence of NDVI and crop yield was found by using the Exponential semivariogram models, when compared to Spherical and Gaussian due to the lower nugget to sill ratio criteria (See Figures 3.2a, 3.2b, and Tables 3.1, 3.2).
Figure 3.2 2014 Exponential semivariogram models fit for Normalized Difference Vegetation Index- NDVI (a) and corn (Zea mays) yield (b) at Pierpont.

Coordinates 44°55′30″ to 45°28′30″ N and 97°50′9″ to 98°28′34″ W. Dominant study site soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b].
Table 3.1 2014 Semivariogram models and parameters for models for Normalized Difference Vegetation Index (NDVI) at Pierpont, SD.

<table>
<thead>
<tr>
<th>Parameters at Pierpont*</th>
<th>Semivariogram Model</th>
<th>Nugget ($C_0$)</th>
<th>Sill ($C_0+C_1$)</th>
<th>Nugget/Sill (%)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>Spherical</td>
<td>0.00404</td>
<td>0.0056</td>
<td>71.7</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>Exponential</td>
<td>0.00125</td>
<td>0.0087</td>
<td>14.4</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.00573</td>
<td>0.0040</td>
<td>142.1</td>
<td>101</td>
</tr>
</tbody>
</table>

*44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W. (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

$C_0$ = Nugget Semi-variance, $C_1$ = Partial sill semi-variance

Table 3.2 2014 Semivariogram models and parameters for models for corn (Zea mays) yield at Pierpont, SD.

<table>
<thead>
<tr>
<th>Parameters at Pierpont*</th>
<th>Semivariogram Model</th>
<th>Nugget ($C_0$)</th>
<th>Sill ($C_0+C_1$)</th>
<th>Nugget/Sill (%)</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>Spherical</td>
<td>0.0241</td>
<td>0.025</td>
<td>95</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Exponential</td>
<td>0</td>
<td>0.051</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.0088</td>
<td>0.040</td>
<td>22</td>
<td>34</td>
</tr>
</tbody>
</table>

*44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W. (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

$C_0$ = Nugget Semi-variance, $C_1$ = Partial sill semi-variance
Table 3.3  2014 Comparative analysis of interpolation methods and their correlation coefficient and Root Mean Square Error (RMSE) for Normalized Difference Vegetation Index (NDVI) at Pierpont, SD.

<table>
<thead>
<tr>
<th>Element at Pierpont*</th>
<th>Interpolation Method</th>
<th>Correlation Coefficient</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>TSA: Linear TS</td>
<td>0.422</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>TSA: Quadratic TS</td>
<td>0.429</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>IDW: k = 1</td>
<td>0.463</td>
<td>0.099</td>
</tr>
<tr>
<td></td>
<td>IDW: k = 2</td>
<td>0.478</td>
<td>0.094</td>
</tr>
<tr>
<td></td>
<td>OK</td>
<td>0.544</td>
<td>0.089</td>
</tr>
<tr>
<td></td>
<td>Linear Regression (LR)</td>
<td>0.460</td>
<td>0.093</td>
</tr>
</tbody>
</table>

TSA= Trend Surface Analysis, TS=Trend Surface IDW= Inverse Distance Weighting OK= Ordinary Kriging, LR el IV= Linear regression using elevation as an independent variable k= class of nearest neighbor

*44°55’30″ to 45°28’30″N and 97°50’9″ to 98°28’34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

Spatial interpolation methods were tested for interpolating NDVI and crop yield, Tables 3.3 and 3.4, respectively. Ordinary Kriging was found to have relatively highest correlation coefficient (0.544) or $R^2=0.3$ and lowest RMSE (0.089), respectively for NDVI and therefore was selected for interpolation. Whereas, Inverse Distance Weighting (IDW) with $k=2$ was found to have relatively highest correlation coefficient (0.413) or $R^2=0.2$ and lowest RMSE (0.223) for yield and therefore was selected for interpolation.
Table 3.4 Comparative analysis of interpolation methods and their correlation coefficient and Root Mean Square Error (RMSE) for 2014 corn (*Zea mays*) yield at Pierpont, SD.

<table>
<thead>
<tr>
<th>Element at Pierpont*</th>
<th>Interpolation Method</th>
<th>Correlation Coefficient</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TSA: Linear TS</td>
<td>0.262</td>
<td>0.235</td>
</tr>
<tr>
<td></td>
<td>TSA: Quadratic TS</td>
<td>0.364</td>
<td>0.228</td>
</tr>
<tr>
<td>Yield</td>
<td>IDW: k = 1</td>
<td>0.368</td>
<td>0.233</td>
</tr>
<tr>
<td></td>
<td>IDW: k = 2</td>
<td>0.413</td>
<td>0.223</td>
</tr>
<tr>
<td></td>
<td>OK</td>
<td>0.396</td>
<td>0.235</td>
</tr>
</tbody>
</table>

TSA= Trend Surface Analysis, TS=Trend Surface, IDW= Inverse Distance Weighting, OK= Ordinary Kriging, k= class of nearest neighbor
*44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″N (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

Figures 3.3, 3.4, and 3.5 demonstrate the interpolated surfaces of 2014 corn yield using different interpolation methods. The lower values of yield were obtained in areas where there were low NDVIs and that could be attributed to lower elevations, accumulation of salts, water logging, or a combination of one or more factors. Figures 3.6, 3.7, 3.8, and 3.9 shows the interpolated surfaces of NDVI using different interpolators. Previous research on yield variability on a small plots and large fields have shown similar result of variation of yield in time and space due to soil and other climatic factors (Bhatti *et al*., 1991; Di Virgilio *et al*., 2007; Vieira and Paz Gonzalez, 2003). Characterization of spatial heterogeneity of landscape vegetation cover from the modeling of the variogram of high spatial resolution NDVI data showed that land use is a major factor for variability (Garrigues *et al*., 2006). In our study differences in the NDVI values could be as result of differences in soil property (particularly, EC, and SAR) that ultimately resulted in differences in 2014 corn yield and NDVI values.
Figure 3.3 Corn (*Zea mays*) yield (2014) interpolated surface map of the study area (Pierpont, SD) using the Inverse Distance Weighting interpolation method.

Pierpont GPS: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

Figure 3.4 Corn (*Zea mays*) yield (2014) interpolated surface map of the study area (Pierpont, SD) using Trend Surface interpolation method.

Pierpont GPS: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).
Figure 3.5 Corn (*Zea mays*) yield (2014) interpolated surface map of the study area (Pierpont, SD) using the Ordinary Kriging interpolation method.

Pierpont GPS: 44°55’30” to 45°28’30”N and 97°50’9” to 98°28’34”W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

Figure 3.6 Normalized Difference Vegetation Index (NDVI bare soil) interpolated surface map (2014) of the study area (Pierpont, SD) using the Ordinary Kriging interpolation method.

Pierpont GPS: 44°55’30” to 45°28’30”N and 97°50’9” to 98°28’34”W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).
Figure 3.7 Normalized Difference Vegetation Index (NDVI V1) interpolated surface map (2014) of the study area (Pierpont, SD) using the Ordinary Kriging interpolation method.

Pierpont GPS: 44°55′30″ to 45°28′30″ N and 97°50′9″ to 98°28′34″ W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

Figure 3.8 Normalized Difference Vegetation Index (NDVI V4) interpolated surface map (2014) of the study area (Pierpont, SD) using the Ordinary Kriging interpolation method.

Pierpont GPS: 44°55′30″ to 45°28′30″ N and 97°50′9″ to 98°28′34″ W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).
Figure 3.9 Normalized Difference Vegetation Index (NDVI V6) interpolated surface map (2014) of the study area (Pierpont, SD) using the Ordinary Kriging interpolation method.

Pierpont GPS: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls [USDA-NRCS, 2016b]).

3.4 Conclusions

Geospatial models coupled with remote sensing methods, including MSR, were used to analyze and predict the spatial dependence of NDVI values and corn yield and gave insight about for spatial prediction of unknown spatial variables. However, detailed analysis of other soil attributes are needed to give a better understanding of spatial variability at different scales. In future studies, unmanned aircraft should be tested with their high resolution image capability. In addition, testing more and relevant interpolation methods and other geospatial approaches, including multivariable and spatial classification techniques, should be done to determine if they would be more helpful in understanding the relationship of the different attributes. The study of reflectance signatures at different crop growth stages as an indicator of plant stress and salt level could also be another area of future research.
3.5 Literature Cited


4. CHAPTER IV

WATER INFILTRATION AND SOIL DISPERSION AS AFFECTED BY AMMENDEMENTS

Abstract

Soils with sodic properties significantly affect water infiltration by altering soil physical and chemical properties leading to runoff and loss of topsoil through erosion. Surface amendments (SA) and cropping systems (CS) are used to reduce the sodium level in the soil and improve soil physical properties. The objectives of this study were 1) compare different soil remediation strategies particularly the influence of SA (gypsum, calcium chloride, and elemental sulfur) and CS in a corn (Zea mays) soybean (Glycine max) rotation system on water infiltration by double-ring (ponded) and Cornell sprinkler infiltrometer, and 2) evaluate the effect of variable cation concentrations on the dispersion of bentonite clay and selected soil samples. A field study was conducted in three locations: White Lake (2013-2015), Redfield (2014-2015), and Pierpont (2014-2015) in Eastern South Dakota. Infiltration rates (IR) and runoff rates (ROT) were computed. A randomized complete block design with 4 replications was used. The treatments were: cover crop and surface amendments. The cover crop was a mixture of barley (Hordeum vulgare L.) and sugar beet (Beta vulgaris) seeded at the rate of 34 kg ha\(^{-1}\) and 4.5 kg ha\(^{-1}\), respectively. There were significant differences among the chemical amendments in 2013 in White Lake and 2014 and 2015 in Redfield. Cover crop treatments significantly improved ponded infiltration at Pierpont in 2014. The infiltration rate and runoff rate measurements using Cornell infiltrometer showed no significant differences among treatments in all locations. The results of this study suggest that chemical amendments influenced double-ring water infiltration...
more than the cover crop treatments in White Lake and Redfield, whereas, cover crop influenced infiltration more at Pierpont. Monitoring of the experiment in the long-term could be useful. Significantly higher turbidity was measured in NaCl solutions at different concentrations when compared with similar concentrations of CaCl₂ or MgCl₂ solutions. There was no significant difference in CaCl₂ and MgCl₂ solutions at variable concentrations. Therefore, effect of Mg²⁺ and Ca²⁺ solutions on clay dispersion demonstrates that the two ions have more flocculating effect than dispersion at the concentrations tested. Turbidity can be used as an indicator/measure of clay dispersion potential in salt-affected soils.

**Keywords:** Bentonite clay, Cornell sprinkler infiltrometer, dispersion, double-ring infiltration, flocculation, sodic properties, turbidity, saline, sodic, saline-sodic.
4.1 Introduction

Saline-sodic soil genesis is a major form of soil degradation resulting in the decline of agricultural productivity and environmental quality. Millions of hectares of these soils have formed worldwide. With improved management these soils could produce more food, fiber, and energy to feed the ever increasing world population (Qadir et al., 2007). In addition, above average precipitation and changes in land use and management in the last few decades coupled with extensive tile drainage installation have aggravated saline-sodic soil formation (Franzen, 2007).

Previous reports have identified factors that affect water infiltration into the soil including: soil structure, texture, pores (size, distribution, and orientation), slope, and organic matter content (Bronick and Lal, 2005; Tisdall and Oades, 1982); soil vegetative cover (Meek et al., 1992); antecedent water content and rainfall intensity (Radke and Berry, 1993); and water management (Agassi et al., 1986). Soils with sodic properties affect water infiltration into soil by altering soil physical properties (structure, porosity, and bulk density) that ultimately lead to increased runoff and loss of topsoil (Chi et al., 2012; Hulugalle et al., 2010; Rengasamy and Olsson, 1991). Clay-size fraction dispersion caused by high exchangeable Na$^+$ levels causes soil structural degradation and poor permeability (Amezketa, 1999; Sumner, 1993).

Water turbidity is a measure of water clarity and measured by nephelometric turbidity units (NTU) (Davies-Colley and Smith, 2001). Sediments from surface erosion are a major source of turbidity (Alexander et al., 1998; Lettenmaier et al., 1991; Wong et al., 2010). Sodic conditions can cause soil organic matter loss by increasing dispersion of aggregates and, increasing bulk density (Wong et al., 2010).
Reclamation of sodic soils using tillage has been found to be effective in improving water infiltration and reducing runoff (Hulugalle et al., 2010), however the interactive effect of different chemical amendments and cropping systems on Northern Great Plains (NGP) saline-sodic soils has not been tested. The objectives of this study were: to evaluate the effectiveness of surface chemical amendments and cover crops in improving water infiltration measured using the ponded infiltration method in saline-sodic soils; and to evaluate the effect of selected cation concentrations on the dispersion and flocculation of bentonite clay and selected NGP soils.

4.2 Materials and Methods

4.2.1 Sites description and experimental set up

A field study was conducted in three locations: White Lake (43°40′31″N, -98°45′50″W), Redfield (44°58′10″N, -98°27′52″W), and Pierpont (45°30′31″N, -97°53′50″W) in Eastern South Dakota. Sites were selected in 2013 and three years of field study (2013-2015) were conducted in White Lake and in Redfield and a two years were conducted in Pierpont. Prior to treatment application the surface soil salt level of the sites were determined (Table 4.1). The area is known to have a corn (Zea mays), sorghum (Sorghum bicolor), and soybean (Glycine max) crop rotation. Occasionally, spring wheat (Triticum aestivum) and oats (Avena sativa) are planted as part of a 3-year rotation with corn and soybeans.

The dominant soils at the Redfield, Spink County study site were Harmony-Aberdeen silty clay loams (0-2 % slopes), Winship-Tonka silt loams (0-1 % slopes), and Great Bend-Beotia silt loams (0-2 % slopes). Whereas, the dominant soils at the White Lake, Aurora County study site were Beadle-Dudley complex (0-3 % slopes), Delmont-Talmo complex (6-15 %
slope), Houdek and Ethan loams (2-6 % slopes) (USDA-NRCS, 2016a; 2016b). Kranzburg-Brookings silt loams and Nahon-Aberdeen-Exline silt loams with slopes of 2 to 6 and 0 to 2, respectively, were the two dominant soil series at the Pierpont (Day County) research site.

The study used a randomized complete block design with 4 replications. The treatments were soil surface amendments and cover crop (cover crop and non-cover crop). Barley (*Hordeum vulgare* L.) and sugar beet (*Beta vulgaris*) were seeded at the rate of 34 kg ha$^{-1}$ and 4.5 kg ha$^{-1}$, respectively. Sugar beet and barely were mixed at their recommended rate and planted in 6 rows between the main crop (corn, soybean, and sorghum). The date of cover crop planting was based on the growth stage of the main crop and the soil conditions. For corn and sorghum the cover crop planting was done when the main crop growth stage was between V4 and V6. Whereas the cover crop planting in soybean field was conducted between V stage (unfolding of trifoliate leaves, the final number of trifoliate’s depends on the soybean variety and the environmental conditions) and R1-beginning flowering - plants have at least one flower on any node (Clark, 2008; Fehr *et al.*, 1971; Vaughan and Evanylo, 1998). Soil surface amendments application rates are summarized in Table 2.2.

### 4.2.2 Soil chemical analysis

Soil EC, pH, and soluble cation concentrations were determined from a saturated extract (Table 4.1). Electrical conductivity was determined using a conductivity probe (PC 2700, Oakton Instruments Vernon Hills, IL). Cation concentrations of Na$^+$, Ca$^{2+}$, and Mg$^{2+}$ were measured using flame atomic adsorption spectrophotometry (200 A, Buck Scientific, Norwalk, CT) (Rhoades, 1982). Sodium adsorption ratio (SAR) was calculated using Equation 4.1.
\[ SAR = \frac{[Na^+]}{\left(\frac{[Ca^{2+}] + [Mg^{2+}]}{2}\right)^{1/2}} \]  

(4.1)

Table 4.1 Initial soil properties mean values by soil depth and location

<table>
<thead>
<tr>
<th>Sites</th>
<th>Salt Composition</th>
<th>Electrical Conductivity (EC) (dS/m)</th>
<th>pH</th>
<th>Sodium Adsorption Ratio (SAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Depth (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-7.5</td>
<td>7.5-15</td>
<td>15-30</td>
</tr>
<tr>
<td>Redfield*</td>
<td>Saline</td>
<td>8.0</td>
<td>6.2</td>
<td>6.5</td>
</tr>
<tr>
<td>White Lake**</td>
<td>Saline-sodic</td>
<td>10.2</td>
<td>8.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Pierpont***</td>
<td>Saline-sodic</td>
<td>20.0</td>
<td>19.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

* 44°58'10"N, -98°27'52"W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
** 43°40'31"N, -98°45'50"W (Dominant soils: Argiustolls, Nattrustolls, Haplustolls, Calciustolls).
*** 45°30'31"N, -97°53'50"W (Dominant soils: Hapludolls, Natrudolls).
Source of soil information: USDA-NRCS, Soil Survey Division (2016b). n= 4 (Redfield); n=5 (White Lake); n=5 (Pierpont).

### 4.2.3 Ponded infiltration measurements

Water infiltration was measured at 32 points at each research site location using a double-ring with a 12 cm radius inner ring water infiltrometer (Figure 1). *In situ* soil moisture measurements of the surface soil were measured with a moisture probe (Table 4.2). The ring was driven into the soil to a depth of 4 cm and the infiltration measurements were conducted for about 60 minutes (Reynolds and Elrick, 1990). Field water infiltration measurements were done 5 months after application of the treatments (October 2013) and each consecutive year after harvest (2013 to 2015). Additional field infiltration and runoff measurements were taken with a Cornell Sprinkle Infiltrometer after harvest in 2015 (Ogden *et al*., 1997). Cornell infiltration measurement showed different values compared to double-ring water infiltration measurement.
due to surface structure breakdown, dispersion, and surface sealing due to water drops that occurred during field measurement.

**Infiltration Rate (IR)**

The infiltration rate (IR), reported in mm h$^{-1}$, was calculated as:

$$IR = \frac{\Delta Q}{A \times \Delta t}$$  \hspace{1cm} (4.1)

Where $\Delta Q$ is the volume of water collected during a given time period, $\Delta t$, and $A$ is the cross-sectional area of the soil columns.

![Figure 4.1 Infiltration measurement at White Lake, SD.](image)

**4.2.4 Bentonite clay and soil dispersion**

A laboratory experiment was conducted to evaluate the effect of variable concentrations of selected cations ($\text{Ca}^{2+}$, $\text{Mg}^{2+}$, $\text{Na}^+$) on the dispersion and flocculation of bentonite clay and selected NGP soils. Bentonite clay soil material (10 g) was placed in a 250 mL Erlenmeyer flask and 200 mL of 0.1, 0.2, or 0.3 $M$ $\text{CaCl}_2$, $\text{MgCl}_2$, or $\text{NaCl}$ were added. The suspension was shaken for 1 hr and allowed to settle for 24 hours. A 50 mL subsample of the suspension was taken. The
level of suspended soil materials was determined by measuring absorbance at 650 nm using a colorimeter to measure turbidity.

A second part of experiment was conducted to evaluate the effect of variable cation Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\)) concentrations on the dispersion of selected NGP saline-sodic and normal (non-saline, non-sodic) soils. Soil samples were collected from four locations (Pierpont, Andover, and White Lake in 2014; and Brookings in 2016). Forty g of soil was placed in a 250 mL Erlenmeyer flask and a 200 mL of 0.1, 0.2, or 0.3 \(M\) CaCl\(_2\), MgCl\(_2\), or NaCl were added. The experiment was replicated 4 times. The suspension was shaken for 1 hr and allowed to settle for 24 hr and a 50 mL subsample of the suspension was taken. The level of suspended soil materials was determined by measuring absorbance at 650 nm using a colorimeter to measure turbidity.

4.2.5 Statistical analysis

Infiltration rates variability and turbidity differences were tested for analysis of variance (ANOVA) using SAS version, SAS Institute, Cary, NC (SAS, 2007). Statistical differences were declared significant at \(\alpha = 0.05\) level.

4.3 Results and Discussion

4.3.1 Ponded Infiltration Measurements

Average precipitation and temperature of the research sites for the months of April to October and soil moisture content of the research plots are shown Table 4.2. Month by month precipitation and temperature is reported in chapter 2, Figures 2.1 to 2.5. The measured double-ring water infiltration rate was significantly different due to surface treatments in 2013 at White Lake, but treatments were not significantly different in consecutive years (2014 and 2015). The
sulfur treatment was significantly higher in 2013 when compared to the control and was numerically higher in 2014 and 2015. Cover crop did not significantly influence ponded water infiltration in all years at White Lake (Table 4.3).

Table 4.2 Mean annual precipitation, mean annual temperature, and % antecedent soil moisture at research sites.

<table>
<thead>
<tr>
<th>Research Sites</th>
<th>Soil Moisture (%)</th>
<th>Average April to October Precipitation (mm)</th>
<th>Average April to October Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redfield*</td>
<td>-</td>
<td>-</td>
<td>46</td>
</tr>
<tr>
<td>White Lake**</td>
<td>36.8</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>Pierpont***</td>
<td>29.5</td>
<td>66 (9 years average)</td>
<td>16 (9 years average)</td>
</tr>
</tbody>
</table>

Source: South Dakota Climate and Weather, 2016
*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls).

Table 4.3 Saturated water infiltration rates (double-ring) of surface amended soils and cover crop treatments from 2013-2015 at White Lake, SD.

<table>
<thead>
<tr>
<th>Treatments at White Lake</th>
<th>Infiltration rate (mm h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2013</td>
</tr>
<tr>
<td><strong>Surface Amendments (SA)</strong>†</td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td></td>
</tr>
<tr>
<td>No-treatment</td>
<td></td>
</tr>
<tr>
<td>Gypsum (CaSO₄·2H₂O)</td>
<td></td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td></td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong> ††</td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>NCC</td>
<td></td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td></td>
</tr>
<tr>
<td>SA*CS</td>
<td></td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡CC = cover crop (sugar beet and barley); NCC = non-cover crop.
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
The measured water infiltration rates for the treatments tested were significantly different at Redfield in 2014 at the 0.05 level. Both gypsum and sulfur significantly increased infiltration rates in 2014 with no significant difference in 2015 when compared to the control. Similar to White Lake (2013 and 2014) the cover crop treatments did not show a significant difference in Redfield plots (Table 4.4). Water infiltration measurements were also done at Pierpont in 2014 and 2015. There were no significant differences in both years for the chemical amendments. However, there was a significant difference for cover crop treatment in 2014 (Table 4.5). The results of the double-ring water infiltration study suggest that chemical amendments influenced water infiltration more than cover crop treatments in White Lake and Redfield. Whereas cover crop influenced ponded infiltration more in the Pierpont study site. Because soil and parent materials differ at the three locations more studies on different soils and parent materials are needed. The water infiltration variation could be attributed to soil differences among sites, changes in soil properties as a result of surface amendment application (mainly sulfur and gypsum), and cover crop. The influence of the treatments is site specific. The infiltration rate and runoff rate measurements using Cornell infiltrometer showed no significant difference among treatments (amendment and cover crop) in all locations (Table 4.6). The differences in results obtained from each study sites is attributed to the differences in soil properties, salinity levels, sodicity, parent materials, and precipitation. Similar results were found in previous findings on the effects of amendments and salt concentration on infiltration of sodic soils (Agassi et al., 1981; Robbins, 1986). However, research on the impact of cover crop in salt affected soil is very limited. The recorded values of double-ring water infiltration were much higher when compared to the Cornell infiltration due to soil dispersion (breakdown of soil structure) and surface sealing of soil pores when using Cornell infiltration process when compared to the seepage with the
double-ring water infiltration measurement (Ben-Hur et al., 1987; van Es, 2015). This could be part of the reason that higher infiltration rates were recorded in double-ring when compared to Cornell infiltration measurements.

Table 4.4 Saturated water infiltration rates (double-ring) of surface amended soils and cover crop treatments from 2014-2015 at Redfield, SD.

<table>
<thead>
<tr>
<th>Treatments at Redfield</th>
<th>Infiltration rate (mm h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
</tr>
<tr>
<td><strong>Surface Amendments (SA)</strong>†</td>
<td></td>
</tr>
<tr>
<td>CaCl(_2)</td>
<td>144(^{bc})</td>
</tr>
<tr>
<td>No-treatment</td>
<td>42(^c)</td>
</tr>
<tr>
<td>Gypsum (CaSO(_4)·2H(_2)O)</td>
<td>362(^{ab})</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>535(^a)</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong>††</td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>230(^\circ)</td>
</tr>
<tr>
<td>NCC</td>
<td>311(^a)</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>0.013</td>
</tr>
<tr>
<td>CS</td>
<td>0.445</td>
</tr>
<tr>
<td>SA*CS</td>
<td>0.861</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at \(P < 0.05\).
‡CC = cover crop [barley (Hordeum vulgare L.) and sugar beet (Beta vulgaris)]; NCC = non-cover crop.
*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).

Table 4.5 Saturated water infiltration rates (double-ring) of surface amended soils and cover crop treatments from 2014-2015 at Pierpont, SD.

<table>
<thead>
<tr>
<th>Treatments at Pierpont</th>
<th>Infiltration rate (mm h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
</tr>
<tr>
<td><strong>Surface Amendments (SA)</strong>†</td>
<td></td>
</tr>
<tr>
<td>CaCl(_2)</td>
<td>223(^{ab})</td>
</tr>
<tr>
<td>No-treatment</td>
<td>116(^a)</td>
</tr>
<tr>
<td>Gypsum (CaSO(_4)·2H(_2)O)</td>
<td>195(^a)</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>163(^a)</td>
</tr>
<tr>
<td><strong>Cropping System (CS)</strong>††</td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>247(^\circ)</td>
</tr>
<tr>
<td>NCC</td>
<td>101(^a)</td>
</tr>
<tr>
<td><strong>ANOVA P&gt;F</strong></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>0.5243</td>
</tr>
<tr>
<td>CS</td>
<td>0.0114</td>
</tr>
<tr>
<td>SA*CS</td>
<td>0.3723</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at \(P < 0.05\).
‡CC = cover crop [barley (Hordeum vulgare L.) and sugar beet (Beta vulgaris)]; NCC = non-cover crop.
***45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls).
Table 4.6 Comparison of infiltration rate and runoff rate (using Cornell sprinkle infiltrometer) two years after surface amendment and cover crop treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th><strong>White Lake</strong></th>
<th><em>Redfield</em></th>
<th>**<em>Pierpont</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infiltration</td>
<td>Runoff</td>
<td>Infiltration</td>
</tr>
<tr>
<td></td>
<td>rate (mm h⁻¹)</td>
<td>rate (mm h⁻¹)</td>
<td>rate (mm h⁻¹)</td>
</tr>
<tr>
<td>Surface Amendments (SA) †</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-treatment</td>
<td>5.3 a†</td>
<td>0.40 a</td>
<td>8</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>5.3 a</td>
<td>0.45 a</td>
<td>8</td>
</tr>
<tr>
<td>Cropping System (CS) ‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC</td>
<td>5.3 a</td>
<td>0.43 a</td>
<td>8</td>
</tr>
<tr>
<td>NCC</td>
<td>5.3 a</td>
<td>0.41 a</td>
<td>8</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>0.337</td>
<td>0.337</td>
<td>0.383</td>
</tr>
<tr>
<td>CS</td>
<td>0.688</td>
<td>0.688</td>
<td>0.173</td>
</tr>
<tr>
<td>SA*CS</td>
<td>0.298</td>
<td>0.298</td>
<td>0.348</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatment are significantly different at P < 0.05.
‡CC, cover crop; NCC, non cover crop.
*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls);
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls);
***45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls), Soil Survey Division, 2016b.
4.3.2 Turbidity as a measure of dispersion

Table 4.7 Soil chemical properties of the tested soils.

<table>
<thead>
<tr>
<th>Locations</th>
<th>EC (dS/m)</th>
<th>pH</th>
<th>SAR</th>
<th>soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Lake*</td>
<td>13</td>
<td>7.6</td>
<td>17</td>
<td>Saline Sodic</td>
</tr>
<tr>
<td>Pierpont**</td>
<td>20</td>
<td>8.0</td>
<td>19</td>
<td>Saline Sodic</td>
</tr>
<tr>
<td>Andover***</td>
<td>18</td>
<td>7.7</td>
<td>8</td>
<td>Saline</td>
</tr>
<tr>
<td>Brookings***</td>
<td>3.9</td>
<td>7.8</td>
<td>-</td>
<td>None saline, none sodic</td>
</tr>
<tr>
<td>Bentonite</td>
<td>-</td>
<td>8.2</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*44°58′10″N, -98°27′52″W (Dominant soils: Hapludolls, Natrudolls, Argiudolls).
**43°40′31″N, -98°45′50″W (Dominant soils: Argiustolls, Natrustolls, Haplustolls, Calciustolls).
***45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls).
**** 44° 19′ 7″N,-96° 46′ 56″W (Dominant soil: Hapludolls).

Selected soil chemical properties of the tested soils and bentonite clay are presented in Table 4.7. Results of the lab study showed significant differences for the chemical treatments and the different salt concentrations for all selected soils and bentonite clay. There was significantly higher turbidity in NaCl solutions at different concentrations when compared to similar concentrations of CaCl₂ and MgCl₂ solutions (see Tables 4.8 and 4.9) for the saline, sodic and saline-sodic soils studied (except for 0.1 M on the White Lake soil). The turbidity measurements of CaCl₂ and MgCl₂ solutions at variable concentrations were not significantly different from each other (except for 0.3 M on the White Lake soil) and were less turbid than NaCl solutions (See Figure 4.2, Table 4.8, and Table 4.9). The highest turbidity was recorded in NaCl treated soil for saline, sodic and saline-sodic soils while the highest turbidity measurements in the bentonite clay and Brookings soils were with distilled water. This increased turbidity could be attributed to higher dissolved organic matter level in the Brookings soil and the fine clay particles of the bentonite clay. In previous studies, smaller particle sizes have contributed the higher turbidity reading (Cuker et al., 1990; Cuker and Hudson Jr, 1992). In other studies similar results of dispersion of organic matter being increased with dispersion of clay was reported (Fitzpatrick et al., 1994; Naidu et al., 1993).
Figure 4. 2 Bentonite clay and selected soils turbidity measurement after treated with variable concentration of salts (Logarithmic scale of base 10).
Table 4.8 Effect of salt concentration on soil dispersion (turbidity as an indicator) of three different salt affected soils, a normal soil and bentonite clay.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Soil Sampling Locations</th>
<th>n=12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Andover (Saline)</td>
<td>Pierpont (Sodic)</td>
</tr>
<tr>
<td>Salts (S)</td>
<td>Turbidity in (NTU)</td>
<td>Turbidity in (NTU)</td>
</tr>
<tr>
<td>NaCl‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 M</td>
<td>44.3 a†</td>
<td>23.3 a</td>
</tr>
<tr>
<td>0.2 M</td>
<td>31.5 a</td>
<td>24.3 a</td>
</tr>
<tr>
<td>0.3 M</td>
<td>40.8 a</td>
<td>20.3 ab</td>
</tr>
<tr>
<td>Distilled H2O</td>
<td>7.5 b</td>
<td>10.5 b</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>0.001</td>
<td>0.040</td>
</tr>
<tr>
<td>CaCl2·2H2O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 M</td>
<td>20.3 a</td>
<td>18.0 a</td>
</tr>
<tr>
<td>0.2 M</td>
<td>14.0 a</td>
<td>21.0 a</td>
</tr>
<tr>
<td>0.3 M</td>
<td>18.5 a</td>
<td>15.0 ab</td>
</tr>
<tr>
<td>Distilled H2O</td>
<td>7.5 a</td>
<td>10.5 b</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>0.312</td>
<td>0.047</td>
</tr>
<tr>
<td>MgCl2·6H2O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 M</td>
<td>13.0 b</td>
<td>12.8 a</td>
</tr>
<tr>
<td>0.2 M</td>
<td>14.8 ab</td>
<td>14.3 a</td>
</tr>
<tr>
<td>0.3 M</td>
<td>27.0 a</td>
<td>13.0 a</td>
</tr>
<tr>
<td>Distilled H2O</td>
<td>7.5 b</td>
<td>10.5 a</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>0.033</td>
<td>0.137</td>
</tr>
</tbody>
</table>

†Means with different letters within a column, treatments are significantly different at $P < 0.05$.
‡S=Salt type; NaCl=sodium Chloride; CaCl2·6H2O= Calcium Chloride Hexahydrate;
MgCl2·2H2O= Magnesium Chloride Dehydrate;
C=Concentration in molarity; 0.1, 0.2, and 0.3 M
NTU=Nephelometric Turbidity Unit.
Table 4.9 Effect of salt type on soil dispersion (turbidity as an indicator) of three different salt affected soils, a normal soil and bentonite clay.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Soil Sampling Locations</th>
<th>n=12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salts Concentration</td>
<td>Andover (Saline)</td>
<td>Pierpont (Sodic)</td>
</tr>
<tr>
<td></td>
<td>Turbidity in (NTU)</td>
<td>Turbidity in (NTU)</td>
</tr>
<tr>
<td>(0.1 , M) ‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>44.3 (^a)</td>
<td>23.3 (^a)</td>
</tr>
<tr>
<td>CaCl(_2)-2H(_2)O</td>
<td>20.3 (^b)</td>
<td>18.0 (^{ab})</td>
</tr>
<tr>
<td>MgCl(_2)-6H(_2)O</td>
<td>13.0 (^b)</td>
<td>12.8 (^{bc})</td>
</tr>
<tr>
<td>Distilled H(_2)O</td>
<td>7.5 (^b)</td>
<td>10.5 (^c)</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>0.003</td>
<td>0.007</td>
</tr>
<tr>
<td>(0.2 , M) ‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>31.5 (^a)</td>
<td>24.3 (^a)</td>
</tr>
<tr>
<td>CaCl(_2)-2H(_2)O</td>
<td>14.0 (^b)</td>
<td>21.0 (^{ab})</td>
</tr>
<tr>
<td>MgCl(_2)-6H(_2)O</td>
<td>14.8 (^b)</td>
<td>14.3 (^{bc})</td>
</tr>
<tr>
<td>Distilled H(_2)O</td>
<td>7.5 (^b)</td>
<td>10.5 (^c)</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>&lt;.0001</td>
<td>0.015</td>
</tr>
<tr>
<td>(0.3 , M) ‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>40.8 (^a)</td>
<td>20.3 (^a)</td>
</tr>
<tr>
<td>CaCl(_2)-2H(_2)O</td>
<td>18.5 (^{bc})</td>
<td>15.0 (^{ab})</td>
</tr>
<tr>
<td>MgCl(_2)-6H(_2)O</td>
<td>27.0 (^{ab})</td>
<td>13.0 (^b)</td>
</tr>
<tr>
<td>Distilled H(_2)O</td>
<td>7.5 (^c)</td>
<td>10.5 (^b)</td>
</tr>
<tr>
<td>ANOVA P&gt;F</td>
<td>0.007</td>
<td>0.049</td>
</tr>
</tbody>
</table>

† Means with different letters within a column, treatments are significantly different at \(P < 0.05\).

‡ S=Salt type; NaCl=sodium Chloride; CaCl\(_2\)-2H\(_2\)O= Calcium Chloride Hexahydrate; MgCl\(_2\)-2H\(_2\)O= Magnesium Chloride Dehydrate;
C=Concentration in molarity; 0.1, 0.2, and 0.3 \(M\)
NTU=Nephelometric Turbidity Unit.
4.4 Conclusions

Sulfur appeared to improve double-ring water infiltration in all years and locations (although values were not always statistically significant). However, significant differences among the chemical amendments were observed in year 2013 in White Lake and 2014 in Redfield. A cover crop treatment seems to have a positive effect at Pierpont soil in terms of improving double-ring water infiltration. The infiltration rate and runoff rate measurements using Cornell infiltrometer showed no significant differences among the treatments in all locations. The experiment needs to be monitored longer (5 years or more) as a permanent plot trial since soil physical property change often requires time to obtain the anticipated result.

The effect of Mg\(^{2+}\) and Ca\(^{2+}\) solutions on clay dispersion suggest that the two ions have more flocculating effect than dispersion for the concentrations studied on the soils tested. Na\(^+\) had more dispersion effect (increased turbidity) as seen in many previous studies. However, additional experiments are needed to be conducted at higher ion concentrations on a wider variety of salinity and sodicity levels in various parent materials soils under field conditions. Turbidity can be used as an indicator of clay dispersion in salt affected soils.
4.5 Literature Cited


5. CHAPTER V

SPATIAL VARIABILITY ANALYSIS OF SELECTED SOIL ATTRIBUTES IN SALINE-SODIC SOIL

Abstract

Soil spatial variability in the northern Great Plains of USA is related to natural (topographic, vegetation, time, parent material, and climate) and anthropogenic (management and landuse change) factors. The objective of this study was to describe the spatial variability of selected soil properties at a landscape scale and define spatial class. The study was conducted at Pierpont, SD with dominant soils of Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls. A total of 169 grid points (62 x 62 m grid) were laid out in the field in 2014. The field was planted with corn (*Zea mays*). Soil pH, electrical conductivity (EC) and sodium adsorption ratio (SAR) were analyzed. Mollic depth and lime depth were measured at each grid points. Semivariograms fit for exponential, spherical, and Gaussian models were tested. Spatial class was developed using nugget to sill ratio. Analysis of variance for soil attributes were made to test if there is variation due to differences in soil series. Global *Moran’s I* and local *Moran’s I* statistics were performed. The exponential model was the optimum fit for mollic depth, lime depth, pH, EC, and SAR with nugget to sill ratio of 0, 0, 45, 17, and 49, respectively. EC and SAR showed moderate spatial dependence whereas the other parameters showed strong spatial dependence. At the V1, V4, and V6 growth stages the exponential model was the optimum fit for NDVI with a value of nugget to sill ratio of 23, 0, and 25, respectively. At all plant growth stages the NDVI had showed strong spatial dependence. Analyses of variance of all the parameters measured were significantly different at P < 0.05.
Mollic depth, lime depth, and EC showed slight positive spatial autocorrelation with Moran’s statistic value of 0.193, 0.106, and 0.337 and significantly small p-values at alpha 0.05. So the null hypothesis of random distribution was rejected for these variables. Whereas the Global Moran’s I statistics value and the z-score of SAR was very small and p-value was insignificant. SAR showed random distribution. Patterns of local spatial autocorrelation were assessed from a generated map using Local Moran’s I. Semivariogram modelling and Moran’s I of soil attributes and NDVI data can help to quantify spatial heterogeneity in saline-sodic soils.

**Key words:** Semivariogram, clustering, dispersion, soil spatial variability, northern Great Plains, NDVI, saline-sodic soil, Argiudolls, Calciaquolls, Endoaquolls, Hapludolls, interpolation, Natrudolls, Calciudolls, mollic depth, lime depth, EC, SAR, and soil moisture.
5.1 Introduction

Soil properties distribution in a field or landscape are variable in terms of time and space (Corwin et al., 2003). In-depth understanding of the spatial and temporal distribution of these properties at all levels (field, landscape, or watershed) is useful to make sound management decisions in natural resource conservation and agriculture (Cambardella et al., 1994).

Several methods have been used to estimate spatial variability of soil physical and chemical properties (Cambardella et al., 1994; Goovaerts, 1998), soil apparent electrical conductivity (Corwin and Lesch, 2005), soil moisture (Vinnikov et al., 1996), infiltration (Sharma et al., 1980), and several other properties. Several attempts were also made to estimate variability at various scales (Cambardella et al., 1994; Nielsen et al., 1973).

Semivariogram models are used to characterize the spatial variability of soil attributes (Goovaerts, 1998). Spatial dependence can be expressed as a percentage ratio of nugget semivariance to the sill semivariance with a value < 25 % (strong spatial dependence), 26-75 % (moderate spatial dependence), and > 75 % (weak spatial dependence) (Schlesinger et al., 1996).

However, soil spatial variability studies in saline sodic soils of the Northern Great Plains have not been well studied in the past and there is very little information available as to the spatial variability of properties in saline-sodic soils.

Therefore, this study was conducted to describe the spatial variability of selected soil properties at a landscape scale and define spatial class for measured soil variables in selected Northern Great Plains (NGP) soils.
Objectives

i. To assess the global and local spatial autocorrelation and variability of selected soil attributes

ii. Evaluate the differences in soil properties due to soil series.

5.2 Materials and Methods

A field measurement was conducted in Pierpont in Day County, South Dakota (44°55′30″N to 45°28′30″N and 97°50′9″ to 98°28′34″W) in April 2014. The dominant soils in the study area were Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls (USDA-NRCS, 2016a; 2016b).

A total of 169 grid points (62 x 62 m) were laid out in the field. Multispectral Radiometer (MSR) readings were taken by holding the MSR 2 m above the surface and 1 m diameter data was collected at each grid point in corn (Zea mays) field in April 2014. The readings were taken between 10 am to 3 pm.

Soil samples were taken from each grid point. Mollic depth, till depth (glacial till parent materials), and lime depth were measured at each grid point after sampling soil using soil sampling probe. Soil samples from 0-7.5 cm consisted of 10 subsamples collected with a 1.9 cm diameter soil probe. Each sample was dried at 40°C, ground, sieved (<2 mm), stored in plastic bags and analyzed for pH, electrical conductivity (EC), water soluble cations, sodium adsorption ratio (SAR) (Page, 1982).

Water soluble cation concentrations (Na+, Ca2+, and Mg2+), EC, and pH and were determined from a saturated extract. One hundred and fifty grams of air-dry soil was weighed and mixed with distilled water until saturated. The mixture was covered and allowed to
equilibrate for 24 hours. After 24 hours, the soil solution was extracted using a Böchner funnel apparatus and vacuum. All extracts were stored at 4°C until they were analyzed for pH, EC, Ca, Mg, and Na (Rhoades, 1982). Sodium adsorption ratio (SAR) was calculated using the following equation.

\[
SAR = \frac{[Na^+]}{\left(\frac{[Ca^{2+}]}{2} + [Mg^{2+}]\right)^{1/2}}
\]

Data exploration was made to evaluate the normality of the data. Exponential, spherical, and gaussian semivariograms were fitted for the selected variables (see Appendix V and Figures 5.1 to 5.5). The details (nugget, sill, and range) of the models were determined. Spatial class was developed for selected soil variables using the nugget to sill ratio as an indicator. Generally, semivariograms with higher range indicates spatial autocorrelation, whereas, higher sill values indicates more variation between neighbors samples.

The normalized difference vegetation indices (NDVI) were computed using the following equation:

\[
NDVI = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}
\]

Semi-variances were calculated using equation below, where \(\gamma(h)\) is the semi-variance for lag distance \(h\), \(N\) is the number of samples, \(A\) is the test value for sample \(i\), \(X\) is the location of sample \(i\). and \(X_i + h\) represents the distance between two sample locations (Nielsen and Wendroth, 2003).

\[
\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [A_i(X_i) - A_i(X_i + h)]^2
\]
Analysis of variance (ANOVA) was performed for selected soil attributes (EC, SAR, lime depth, mollic depth, till depth and soil moisture) and NDVI was computed for the crop growth stage (V1, V4, and V6) of corn (Zea mays). Spatial autocorrelation was tested for selected soil attributes using Global Moran’s I statistics and clustering and dispersion was detected using local Moran’s I statistics (Anselin, 1995). The test was applied for selected soil attributes including mollic depth, lime depth, electrical conductivity, and sodium adsorption ratio.

5.3 Results and Discussion

5.3.1 Correlation of soil properties

The soil properties selected at each grid point were correlated with each parameter. The raw correlation matrix is based on Appendix V, Table 3. A summary of the significant correlations from this matrix is given in Table 5.1.

Yield was positively correlated with elevation and lime depth content while negatively correlations were seen with salinity, sodicity and soil moisture properties. Elevation was positively correlated with yield and chlorophyll negatively correlated with salinity, sodicity, moisture level, mollic depth, redox depth and depth to till. This demonstrates how erosion and water interact on the landscape to affect yield and soil properties studied.
Table 5.1 Summary of significant correlation relationship for selected soil properties.

<table>
<thead>
<tr>
<th>Soil Property (n=169)</th>
<th>Significantly positively correlated*</th>
<th>Significantly negatively correlated*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil moisture E (SME)</td>
<td>SMV1, ECV1, EC, SAR, MD</td>
<td>Yld, Elev</td>
</tr>
<tr>
<td>Soil moisture V1 (SMV1)</td>
<td>EC V1, EC, SAR, MD, SME</td>
<td>Yld, Elev</td>
</tr>
<tr>
<td>EC V1 (EC V1)</td>
<td>EC, SAR, MD, RD, TD, SME, SME V1</td>
<td>Yld, Elev</td>
</tr>
<tr>
<td>Chlorophyll V4 (CV4)</td>
<td>Elev, pH</td>
<td>MD</td>
</tr>
<tr>
<td>Yield (Yld)</td>
<td>Elev, LD</td>
<td>EC, pH, SAR, SME, SMV1, ECV1</td>
</tr>
<tr>
<td>Elevation (Elev)</td>
<td>CV4, Yld</td>
<td>EC, SAR, MD, RD, TD, SME, SMV1, ECV1</td>
</tr>
<tr>
<td>EC 0-3 inch depth</td>
<td>SAR, MD, RD, SME, SMV1, ECV1</td>
<td>Yld, Elev</td>
</tr>
<tr>
<td>pH 0-3 inch depth</td>
<td>RD, CV4</td>
<td>LD, Yld</td>
</tr>
<tr>
<td>SAR 0-3 inch depth</td>
<td>MD, RD, SME, SMV1, ECV1, EC</td>
<td>Yld, Elev</td>
</tr>
<tr>
<td>Lime depth (LD)</td>
<td>MD, RD, TD, Yld</td>
<td>pH</td>
</tr>
<tr>
<td>Mollic depth</td>
<td>RD, TD, SME, SMV1, ECV1, EC, SAR, LD</td>
<td>Elev, CV4</td>
</tr>
<tr>
<td>Redox depth (RD)</td>
<td>TD, ECV1, EC, pH, SAR, LD, MD</td>
<td>Elev</td>
</tr>
<tr>
<td>Till depth (TD)</td>
<td>ECV1, LD, RD, MD</td>
<td>Elev</td>
</tr>
</tbody>
</table>

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.

E= Emergence (crop), EC = electrical conductivity, SAR = sodium adsorption ratio, V1=one leaf with collar visible, V4=four leaves with collar visible

*significant at 0.05 alpha level.
5.3.2 Data Exploration

Detailed statistics of the data exploration are summarized in Table 5.2. All the measured soil data (mollic depth, lime depth, EC, and SAR) have showed a distribution of positive skewness. Whereas, all the calculated NDVI value were negatively skewed. The transformed data was not improved when compared to the raw data (original).

Table 5.2 Descriptive statistics showing data distribution for the variables measured at Pierpont.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Skewness</th>
<th>Median</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollic Depth</td>
<td>168</td>
<td>0.00</td>
<td>49.0</td>
<td>21</td>
<td>10.88</td>
<td>0.61</td>
<td>18.00</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Lime Depth</td>
<td>168</td>
<td>0.00</td>
<td>40.0</td>
<td>17</td>
<td>9.18</td>
<td>0.08</td>
<td>16.00</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>EC</td>
<td>168</td>
<td>0.00</td>
<td>25.8</td>
<td>2.0</td>
<td>3.84</td>
<td>3.79</td>
<td>0.07</td>
<td>0.0140</td>
</tr>
<tr>
<td>SAR</td>
<td>168</td>
<td>0.00</td>
<td>21.3</td>
<td>1.5</td>
<td>2.67</td>
<td>3.74</td>
<td>0.58</td>
<td>0.0008</td>
</tr>
<tr>
<td>NDVI E</td>
<td>168</td>
<td>0.14</td>
<td>0.23</td>
<td>0.2</td>
<td>0.02</td>
<td>0.25</td>
<td>0.18</td>
<td>0.0012</td>
</tr>
<tr>
<td>NDVI V1</td>
<td>168</td>
<td>0.00</td>
<td>0.27</td>
<td>0.8</td>
<td>0.06</td>
<td>-2.35</td>
<td>0.19</td>
<td>0.1125</td>
</tr>
<tr>
<td>NDVI V4</td>
<td>168</td>
<td>0.00</td>
<td>0.31</td>
<td>0.1</td>
<td>0.11</td>
<td>-2.58</td>
<td>0.20</td>
<td>0.2553</td>
</tr>
<tr>
<td>NDVI V6</td>
<td>168</td>
<td>0.09</td>
<td>0.79</td>
<td>0.5</td>
<td>0.16</td>
<td>-0.81</td>
<td>0.55</td>
<td>0.0077</td>
</tr>
</tbody>
</table>

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Arguidolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.

E= Emergence (crop), EC = electrical conductivity, SAR = sodium adsorption ratio, NDVI=normalized difference vegetation indices, V1=one leaf with collar visible, V4= four leaves with collar visible, V6=six leaves with collar visible.
5.3.3 Semivariogram model fitting

Spatial variability of the different soil attributes measured is summarized in Table 5.3. Mollic depth had a strong spatial dependence and fitted well all the models tested (with the exponential model being the optimum fit with 0 nugget to sill ratio and RMS=10.15).

Similarly, the exponential model was the optimal fit for lime depth, pH, EC, and SAR with nugget to sill ratio of 0, 45, 17, and 49, respectively. EC and SAR showed moderate dependence whereas the other parameters showed strong spatial dependence. Spatial variability of the NDVI values are summarized in Table 5.4. The exponential model was the optimum fit for NDVI at V1, V4, and V6 stage with a value of nugget to sill ratio of 23, 0, and 25, respectively. At all stages the NDVI showed a strong spatial dependence. Similar results of spatial variability and model fitting were reported in earlier research (Burrough, 1983; Gessler et al., 1995; Goovaerts, 1998). Semivariogram fit for all other soil properties and NDVI values are presented in Appendix V (Figures 3 to 12).
Table 5.3 Variogram models for selected soil parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>Nugget</th>
<th>Sill</th>
<th>Range</th>
<th>Nugget/Sill Ratio</th>
<th>Root-Mean-Square</th>
<th>Spatial Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollic depth</td>
<td>Exponential</td>
<td>0.0000</td>
<td>133.5</td>
<td>0.001</td>
<td>0</td>
<td>10.15</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>0.0000</td>
<td>121.0</td>
<td>0.001</td>
<td>0</td>
<td>10.03</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.1228</td>
<td>122.9</td>
<td>0.001</td>
<td>0.1</td>
<td>10.06</td>
<td>S</td>
</tr>
<tr>
<td>Lime depth</td>
<td>Exponential</td>
<td>0.0000</td>
<td>91.7</td>
<td>0.001</td>
<td>0</td>
<td>9.64</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>4.0179</td>
<td>87.0</td>
<td>0.001</td>
<td>5</td>
<td>9.67</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>34.3257</td>
<td>88.6</td>
<td>0.001</td>
<td>39</td>
<td>9.66</td>
<td>M</td>
</tr>
<tr>
<td>EC</td>
<td>Exponential</td>
<td>8.0082</td>
<td>17.9</td>
<td>0.010</td>
<td>45</td>
<td>3.54</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>9.1545</td>
<td>17.3</td>
<td>0.008</td>
<td>53</td>
<td>3.50</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>10.5491</td>
<td>17.6</td>
<td>0.007</td>
<td>60</td>
<td>3.47</td>
<td>M</td>
</tr>
<tr>
<td>pH</td>
<td>Exponential</td>
<td>1.4332</td>
<td>8.4</td>
<td>0.001</td>
<td>17</td>
<td>2.87</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>6.0567</td>
<td>8.4</td>
<td>0.001</td>
<td>72</td>
<td>2.89</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>6.4498</td>
<td>8.4</td>
<td>0.001</td>
<td>77</td>
<td>2.84</td>
<td>W</td>
</tr>
<tr>
<td>SAR</td>
<td>Exponential</td>
<td>4.1089</td>
<td>8.4</td>
<td>0.009</td>
<td>49</td>
<td>2.55</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>4.5440</td>
<td>8.0</td>
<td>0.007</td>
<td>57</td>
<td>2.53</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>5.1224</td>
<td>8.1</td>
<td>0.006</td>
<td>63</td>
<td>2.50</td>
<td>M</td>
</tr>
</tbody>
</table>

S= strong, M=moderate, W=weak, EC= electrical conductivity, SAR=sodium adsorption ratio.

Table 5.4 Variogram models for NDVI at different crop growth stage.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>Nugget</th>
<th>Sill</th>
<th>Range</th>
<th>Nugget/Sill Ratio</th>
<th>Root-Mean-Square</th>
<th>Spatial Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI V1</td>
<td>Exponential</td>
<td>0.0010</td>
<td>0.004</td>
<td>0.012</td>
<td>23</td>
<td>0.04</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>0.0014</td>
<td>0.004</td>
<td>0.012</td>
<td>33</td>
<td>0.04</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.0016</td>
<td>0.005</td>
<td>0.012</td>
<td>30</td>
<td>0.04</td>
<td>M</td>
</tr>
<tr>
<td>NDVI V4</td>
<td>Exponential</td>
<td>0.0000</td>
<td>0.018</td>
<td>0.012</td>
<td>0</td>
<td>0.03</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>0.0000</td>
<td>0.022</td>
<td>0.012</td>
<td>0</td>
<td>0.03</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.0015</td>
<td>0.031</td>
<td>0.012</td>
<td>5</td>
<td>0.04</td>
<td>S</td>
</tr>
<tr>
<td>NDVIV6</td>
<td>Exponential</td>
<td>0.0074</td>
<td>0.030</td>
<td>0.007</td>
<td>25</td>
<td>0.11</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>Spherical</td>
<td>0.0116</td>
<td>0.029</td>
<td>0.007</td>
<td>40</td>
<td>0.12</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Gaussian</td>
<td>0.0141</td>
<td>0.029</td>
<td>0.005</td>
<td>49</td>
<td>0.12</td>
<td>M</td>
</tr>
</tbody>
</table>

Pierpont coordinate: (44°55’30″ to 45°28’30”N and 97°50’9″ to 98°28’34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b. S= strong, M=moderate, W=weak NDVI=normalized difference vegetation indices, V1=one leaf with collar visible, V4= four leaves with collar visible, V6=six leaves with collar visible.
Table 5.5 Analysis of Variance for selected soil parameters as affected by soil series.

<table>
<thead>
<tr>
<th>Soil Series†</th>
<th>Mollic Depth (inches)</th>
<th>n</th>
<th>Lime Depth (inches)</th>
<th>n</th>
<th>EC (dS/m)</th>
<th>n</th>
<th>SAR</th>
<th>n</th>
<th>Till depth(inches)</th>
<th>n</th>
<th>SM (%)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookings</td>
<td>26 ± 6.1bc</td>
<td>55</td>
<td>24 ± 6ab</td>
<td>55</td>
<td>3.0 ± 2.9b</td>
<td>37</td>
<td>2 ± 2.1b</td>
<td>37</td>
<td>36 ± 8.6abc</td>
<td>53</td>
<td>30 ± 4.7abc</td>
<td>29</td>
</tr>
<tr>
<td>McKranz</td>
<td>15 ± 10.5d</td>
<td>19</td>
<td>8 ± 5.7d</td>
<td>19</td>
<td>6.0 ± 7.0b</td>
<td>15</td>
<td>4 ± 4.0b</td>
<td>15</td>
<td>32 ± 11.4bcd</td>
<td>19</td>
<td>30 ± 3.6ab</td>
<td>18</td>
</tr>
<tr>
<td>Deposition</td>
<td>41 ± 3.9a</td>
<td>7</td>
<td>25 ± 4.4ab</td>
<td>4</td>
<td>4.0 ± 3.2b</td>
<td>5</td>
<td>3 ± 2.5b</td>
<td>5</td>
<td>43 ± 4.2abc</td>
<td>4</td>
<td>34 ± 3.9ab</td>
<td>7</td>
</tr>
<tr>
<td>Beotia</td>
<td>35 ± 7.5a</td>
<td>4</td>
<td>24 ± 23.3ab</td>
<td>2</td>
<td>5.0 ± 1.8b</td>
<td>2</td>
<td>3 ± 1.4b</td>
<td>2</td>
<td>42 ± 6.9abc</td>
<td>4</td>
<td>32 ± 2.4ab</td>
<td>4</td>
</tr>
<tr>
<td>Kranzburg</td>
<td>14 ± 2.3d</td>
<td>32</td>
<td>15 ± 3.2bcd</td>
<td>32</td>
<td>2 ± 3.5b</td>
<td>28</td>
<td>1 ± 2.0b</td>
<td>28</td>
<td>29 ± 6.0cd</td>
<td>32</td>
<td>28 ± 4.2abc</td>
<td>18</td>
</tr>
<tr>
<td>Harmony</td>
<td>42 ± 4.8a</td>
<td>4</td>
<td>25 ± 7.6ab</td>
<td>4</td>
<td>2.0 ± 0.8b</td>
<td>2</td>
<td>1 ± 0.6b</td>
<td>2</td>
<td>50 ± 5.5a</td>
<td>3</td>
<td>31 ± 1.3ab</td>
<td>4</td>
</tr>
<tr>
<td>Buse</td>
<td>9 ± 5.8d</td>
<td>5</td>
<td>6 ± 7.8de</td>
<td>5</td>
<td>2.0 ± 0.0b</td>
<td>1</td>
<td>1 ± 0.0b</td>
<td>1</td>
<td>19 ± 0.0de</td>
<td>1</td>
<td>30 ± 2.6abc</td>
<td>3</td>
</tr>
<tr>
<td>Vienna</td>
<td>10 ± 2.2d</td>
<td>7</td>
<td>14 ± 3.1bcd</td>
<td>7</td>
<td>1.0 ± 0.6b</td>
<td>5</td>
<td>1 ± 0.2b</td>
<td>5</td>
<td>16 ± 2.6e</td>
<td>7</td>
<td>28 ± 6.5abc</td>
<td>3</td>
</tr>
<tr>
<td>Barnes</td>
<td>11 ± 2.6d</td>
<td>13</td>
<td>13 ± 5.0cd</td>
<td>13</td>
<td>1.0 ± 0.8b</td>
<td>9</td>
<td>1 ± 0.6b</td>
<td>9</td>
<td>12 ± 0.0e</td>
<td>1</td>
<td>23 ± 2.6cd</td>
<td>4</td>
</tr>
<tr>
<td>Hamerly</td>
<td>13 ± 2.1d</td>
<td>4</td>
<td>0 ± 0.0e</td>
<td>4</td>
<td>1.0 ± 0.0b</td>
<td>1</td>
<td>1 ± 0.0b</td>
<td>1</td>
<td>nd</td>
<td>1</td>
<td>27 ± 0.0abc</td>
<td>1</td>
</tr>
<tr>
<td>Svea.like</td>
<td>29 ± 6.9abc</td>
<td>6</td>
<td>29 ± 6.9a</td>
<td>6</td>
<td>1.0 ± 0.1b</td>
<td>3</td>
<td>1 ± 0.3b</td>
<td>3</td>
<td>36 ± 0.0abcd</td>
<td>1</td>
<td>14 ± 0.0d</td>
<td>1</td>
</tr>
<tr>
<td>Aastad</td>
<td>18 ± 0bcd</td>
<td>1</td>
<td>18 ± 0bcd</td>
<td>1</td>
<td>0.4 ± 0.0b</td>
<td>1</td>
<td>1 ± 0.0b</td>
<td>1</td>
<td>nd</td>
<td>-</td>
<td>nd</td>
<td>-</td>
</tr>
<tr>
<td>Aberdeen</td>
<td>33 ± 0ab</td>
<td>1</td>
<td>21 ± 0.0abc</td>
<td>1</td>
<td>2 ± 0.0b</td>
<td>1</td>
<td>3 ± 0.0b</td>
<td>1</td>
<td>36 ± 0.0abcd</td>
<td>1</td>
<td>32 ± 0.0ab</td>
<td>1</td>
</tr>
<tr>
<td>Bearden</td>
<td>17 ± 3.1bcd</td>
<td>3</td>
<td>12 ± 3.8cd</td>
<td>3</td>
<td>1.0 ± 0.4b</td>
<td>3</td>
<td>2 ± 1.5b</td>
<td>3</td>
<td>45 ± 3.8</td>
<td>3</td>
<td>28 ± 1.1abc</td>
<td>3</td>
</tr>
<tr>
<td>Putney</td>
<td>42 ± 0a</td>
<td>1</td>
<td>15 ± 0.0bcd</td>
<td>1</td>
<td>nd</td>
<td>Nd</td>
<td>nd</td>
<td>-</td>
<td>48 ± 0.0ab</td>
<td>1</td>
<td>30 ± 0.0abc</td>
<td>1</td>
</tr>
<tr>
<td>Nahon</td>
<td>42± 0a</td>
<td>1</td>
<td>16 ± 0.7bcd</td>
<td>2</td>
<td>3.0 ± 1.3b</td>
<td>2</td>
<td>3 ± 0.2b</td>
<td>2</td>
<td>48 ± 0.0ab</td>
<td>1</td>
<td>34 ± 2.0ab</td>
<td>2</td>
</tr>
<tr>
<td>Huffton</td>
<td>30 ± 0abc</td>
<td>1</td>
<td>13 ± 0.0bcd</td>
<td>1</td>
<td>1.0 ± 0.0b</td>
<td>1</td>
<td>1 ± 0.0b</td>
<td>1</td>
<td>42 ± 0.0abc</td>
<td>1</td>
<td>25 ± 0.0bcd</td>
<td>1</td>
</tr>
<tr>
<td>Heil</td>
<td>29 ± 0abc</td>
<td>1</td>
<td>21 ± 0.0abc</td>
<td>1</td>
<td>0.3 ± 0.0b</td>
<td>1</td>
<td>1 ± 0.0b</td>
<td>1</td>
<td>nd</td>
<td>-</td>
<td>37 ± 0.0a</td>
<td>1</td>
</tr>
<tr>
<td>Badger</td>
<td>32 ± 0ab</td>
<td>1</td>
<td>15 ± 0.0bcd</td>
<td>1</td>
<td>4.0 ± 0.0b</td>
<td>1</td>
<td>7 ± 0.0ab</td>
<td>1</td>
<td>nd</td>
<td>-</td>
<td>24 ± 0.0bcd</td>
<td>1</td>
</tr>
<tr>
<td>Saline</td>
<td>40 ± 5.7a</td>
<td>2</td>
<td>14 ± 8.5bcd</td>
<td>2</td>
<td>14 ± 16.5a</td>
<td>2</td>
<td>12 ± 13.6a</td>
<td>2</td>
<td>44 ± 0.0abc</td>
<td>1</td>
<td>36 ± 2.3a</td>
<td>2</td>
</tr>
</tbody>
</table>

ANOVA P>F: <.0001 <.0001 0.0314 0.0018 <.0001 0.0002

†Means with different letters within a column, treatments are significantly different at P < 0.05.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Arguidolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.

EC= electrical conductivity, SAR=sodium adsorption ratio, SM= soil moisture, dS/m= deciSiemens per meter, n=number of samples, nd= not determined
5.3.4 **Analysis of variance and Moran’s I statistics**

Analysis of variance was performed to test if there is variation in soil series for selected soil attributes. Accordingly, all the parameters (mollic depth, lime depth, till depth, EC, SAR, and SM) measured were significantly different at P < 0.05. The selected soil properties are used in South Dakota to classify and organize soils into management groups. The thickest mollic depths were recorded for the following series, Beotia, Putney, Nahon, Harmony Deposition (unidentified), and saline (unidentified) soil series (see Table 5.5).

Svea soil series had the greatest lime depth whereas; the Hamerly series had lime at soil surface. Saline (unidentified) had the highest EC (14 dS/m). Aastad and Heil had the lowest EC value of 0.3 and 0.4 dS/m, respectively. Harmony had the highest till depth (50). Heil and Saline (unidentified) soil series had the highest moisture content (37 and 36%, respectively). Svea like soil series had the lowest (14%).

**Moran’s I** statistics measure of the degree of spatial correlation present in a spatial data set. In Moran’s I statistics, a value closer to one indicates presence of positive spatial autocorrelation. Any value close to zero indicates the absence of spatial auto correlation (Anselin, 1995). Results of the Global Moran’s I test are presented in Table 5.6. Maps of the local Moran’s I are shown in Figures 5.1 to 5.5. Mollic depth, lime depth, and EC showed slight positive spatial autocorrelation with Moran’s statistic value of 0.193, 0.106, and 0.337, respectively, and significantly small p-values at alpha 0.05 (Table 5.6). So the null hypothesis of random distribution was rejected for these variables. Whereas the Moran’s I statistics value and the z-score of SAR and pH were very small the p-values were insignificant and showed random distribution. Patterns of local spatial autocorrelation were assessed from a generated map using Local Moran’s I.
Mollic depth shows a pattern of high-high and low-low correlation. That means areas of high mollic depth values are surrounded by areas of high mollic depth and vice versa (see Figure 5.1). Similar results were found for lime depth and EC (see Figures 5.2 and 5.3, respectively).

Table 5.6 Summary of spatial autocorrelation of selected soil attributes using Global Moran’s I.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Moran's Index</th>
<th>Expected Index</th>
<th>Variance</th>
<th>z-score</th>
<th>p-value</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollic depth</td>
<td>0.193</td>
<td>-0.00595</td>
<td>0.0042</td>
<td>3.0637</td>
<td>0.0022</td>
<td>Clustered</td>
</tr>
<tr>
<td>Lime Depth</td>
<td>0.106</td>
<td>-0.00595</td>
<td>0.0042</td>
<td>1.7286</td>
<td>0.0839</td>
<td>Clustered</td>
</tr>
<tr>
<td>EC</td>
<td>0.337</td>
<td>-0.00595</td>
<td>0.0040</td>
<td>5.4154</td>
<td>0.0001</td>
<td>Clustered</td>
</tr>
<tr>
<td>SAR</td>
<td>0.088</td>
<td>-0.00595</td>
<td>0.0037</td>
<td>1.5390</td>
<td>0.1238</td>
<td>Random</td>
</tr>
<tr>
<td>pH</td>
<td>0.094</td>
<td>-0.00595</td>
<td>0.0041</td>
<td>1.5533</td>
<td>0.1203</td>
<td>Random</td>
</tr>
</tbody>
</table>

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b. EC= electrical conductivity, SAR=sodium adsorption ratio. A significance level of 0.05, a z score would have to be less than −1.96 or greater than 1.96 to be statistically significant. Global Moran's I evaluates whether the pattern expressed is clustered, dispersed, or random. When the Z score indicates statistical significance, a Moran's I value near +1.0 indicates clustering while a value near −1.0 indicates dispersion.
Figure 5.1 Interpolated map showing the clustering of mollic depth using local Moran’s I test.

Pierpont, SD coordinates: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).

Figure 5.2 Interpolated map showing the clustering of lime depth using local Moran’s I test.

Pierpont, SD coordinates: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 5.3 Interpolated map showing the clustering of EC using local Moran’s I test.

Pierpont, SD coordinates: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiidolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).

Figure 5.4 Interpolated map showing the clustering of SAR using local Moran’s I test.

Pierpont, SD coordinates: 44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiidolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Pierpont, SD coordinates: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.

5.4 Conclusions

This study clearly showed using geospatial statistics particularly, local Moran’s I, semivariogram modelling of soil attributes, and NDVI data, could help to quantify spatial heterogeneity in saline-sodic soils. Thus, a better understanding of the spatial pattern of the measured soil variables in saline sodic soils can easily be captured. It also showed soil series variation for all the measured soil attributes and demonstrates the need to further explore and examine other soil attributes not covered in this study. Integrating high resolution imagery for NDVI and other indices could be an area of future research in saline-sodic soil.
5.5 Literature Cited


Appendix I: SAS and R codes

SAS Code for ANOVA

```sas
data one;
input CCT$ SA$ Rep VAR1;
cards;

Run;

proc glimmix;
class CCT SA Rep;
model VAR1 = CCT SA CCT*SA ;
random Rep;
lsmeans SA CCT*SA / diff;
lsmeans CCT / bylevel lines;
lsmeans SA/ bylevel lines;
run;

proc sort data=one out=one1;
by CCT;
run;

proc means data=one1 n mean std;
var VAR1;
by CCT;
run;

proc sort data=one out=one2;
by SA;
run;

proc means data=one2 n mean std;
var VAR1;
by SA;
run;
```

SAS codes used for ANOVA

```sas
Data;
Input TRT$ REP NDVI;
cards;

proc glm;
class TRT REP ;
model NDVI = TRT REP*TRT ;
test h=TRT e=REP*TRT;
means TRT/duncan alpha=0.01 e=REP*TRT;
PROC PRINT;
RUN;
```
R Code used for spatial analysis

Pierpont data - semivariograms and kriging
# Before starting, we need to have both the gstat package loaded
load libraries
library(rgdal)
library(sp)
library(gstat)
library(lattice)
library(RColorBrewer)
library(raster)
#library(tiff)
install.packages (tiff)
setwd("C:/Users/Girma/Desktop/girma")
ppt <- read.csv("data.csv")

dem.grid <- readGDAL("dem2.tif")
names(dem.grid) <- "elevation"
image(dem.grid)

# Generate an empty grid for spatial interpolation
library(sp)
# Specify the min and max coordinates and cell size in the E-W direction
xcoords <- seq(586050, 586900, 10)
# Specify the min and max coordinates and cell size in the N-S direction
ycoords <- seq(5040000, 5040800, 10)
# Expand to all possible combinations of these coordinates
gridcoords.sp <- expand.grid(xcoords, ycoords)
# Use same coordinate names as in your point file
names(gridcoords.sp) <- c("x", "y")
# Make into a spatial points object
coordinates(gridcoords.sp) <- ~ x + y
# Make gridded
gridded(gridcoords.sp) <- TRUE
# Look at the grid
plot(gridcoords.sp)
write.csv(gridcoords.sp, "datagrid.csv")

# Read in two datasets – the sample points and the prediction grid
# These are two gstat sample datasets – can be accessed by typing data(meuse)
# and data(meuse.grid). Here, we read them from text files as an example
data.sdf <- read.csv("data.csv")
data.grid <- read.csv("datagrid.csv")
data <- read.csv("data.csv")
class(data.sdf)
names(data.sdf)
# Make the data frame into a spatial data object for use with gstat
coordinates(data.sdf) <- c("x", "y")
class(data.sdf)
summary(data.sdf)

# We can access spatial locations directly with the coordinates() function
coordinates(data.sdf)[1:5,]

# Plot the spatial pattern of ACSA concentrations
bubble(data.sdf, zcol="E")

# Examine the distribution of E concentrations
attach(data.sdf@data)
hist(E)
qqnorm(E)
hist(sqrt(E))
qqnorm(sqrt(E))
hist(log(E))
qqnorm(log(E))

# Plot the semivariogram cloud
E.cl1 <- variogram(log(E) ~ 1, data=data.sdf, cloud=TRUE)
plot(E.cl1)

# Generate an empirical semivariogram for the sqrt of E concentrations
E.vgm <- variogram(log(E) ~ 1, data=data.sdf, width = 70, cutoff=350)
plot(E.vgm)
E.vgm

# Explicitly specify the width of the “bins”
E.vgm2 <- variogram(log(E) ~ 1, data=data.sdf, width = 70, cutoff=350)
plot(E.vgm2)
E.vgm2

# Explicitly specify width of bins and maximum lag distance
E.vgm3 <- variogram(log(E) ~ 1, data=data.sdf, width = 70, cutoff=350)
plot(E.vgm3)
E.vgm3

# Generate an anisotropic semivariogram with four direction classes
E.vgma <- variogram(log(E) ~ 1, data=data.sdf, alpha=c(0, 45, 90, 135))
plot(E.vgma)
E.vgma

# Fit a spherical semivariogram function
# Need to specify starting values for the fit
plot(E.vgm3)
E.fit <- fit.variogram(E.vgm3, model=vgm(psill=0.0005, model="Sph", range=350, nugget=0.0001))
E.fit
plot(E.vgm3, E.fit)

# Fit an exponential semivariogram function
E.fit2 <- fit.variogram(E.vgm3, model=vgm(psill=0.0005, model="Exp", range=350, nugget=0.0001))
E.fit2
plot(E.vgm3, E.fit2)

# Fit a Gaussian semivariogram function
E.fit3 <- fit.variogram(E.vgm3, model=vgm(psill=0.0005, model="Gau", range=350, nugget=0.0001))
E.fit3
plot(E.vgm3, E.fit3)

# Examine the prediction grid
class(data.grid)
names(data.grid)
coordinates(data.grid) <- c("x", "y")
class(data.grid)
gridded(data.grid) = TRUE
class(data.grid)
summary(data.grid)

# Fit first- and second-order trend surface models
# Specify trend-surface modeling using the degree argument
predict.tr1 <- krig(log(E) ~ 1, locations=data.sdf, newdata=data.grid, degree=1)
predict.tr2 <- krig(log(E) ~ 1, locations=data.sdf, newdata=data.grid, degree=2)

# Set blue-pink-yellow as default color ramp for trellis graphics (including spplot)
trellis.par.set(sp.theme())

# Generate maps of trend-surface predictions
spplot(predict.tr1, zcol="var1.pred")
spplot(predict.tr2, zcol="var1.pred")

# Cross-validate the trend surface models
crossval.tr1 <- krig.cv(log(E) ~ 1, locations=data.sdf, degree=1)
crossval.tr2 <- krig.cv(log(E) ~ 1, locations=data.sdf, degree=2)
# Mean absolute error
mean(crossval.tr1$residual)
mean(crossval.tr2$residual)
# Root mean squared error
sqrt(mean(crossval.tr1$residual^2))
sqrt(mean(crossval.tr2$residual^2))

# Correlation between predicted/observed
cor(crossval.tr1$observed, crossval.tr1$var1.pred)
cor(crossval.tr2$observed, crossval.tr2$var1.pred)

# Visually assess predicted versus observed
plot(crossval.tr1$observed, crossval.tr1$var1.pred)
# add the 1:1 line
abline(0, 1, lty=2)
plot(crossval.tr2$observed, crossval.tr2$var1.pred)
abline(0, 1, lty=2)

# Generate inverse distance weighting prediction for k=1
# Call the idw function and specify the idp parameter
predict.idw1 <- idw(log(E) ~ 1, locations=data.sdf, newdata=data.grid, idp=1)

# Generate inverse distance weighting prediction for k=2
predict.idw2 <- idw(log(E) ~ 1, locations=data.sdf, newdata=data.grid, idp=2)

# Generate maps of inverse distance weighting predictions
spplot(predict.idw1, zcol="var1.pred")
spplot(predict.idw2, zcol="var1.pred")

# Assess prediction accuracy using cross-validation
# Supply idp as a list element to the set argument
crossval.idw1 <- krig.cv(log(E) ~ 1, set=list(idp=1), data.sdf)
crossval.idw2 <- krig.cv(log(E) ~ 1, set=list(idp=2), data.sdf)
cor(crossval.idw1$observed, crossval.idw1$var1.pred)
cor(crossval.idw2$observed, crossval.idw2$var1.pred)
sqrt(mean(crossval.idw1$residual^2))
sqrt(mean(crossval.idw2$residual^2))
plot(crossval.idw1$observed, crossval.idw1$var1.pred)
abline(0, 1, lty=2)
plot(crossval.idw2$observed, crossval.idw2$var1.pred)
abline(0, 1, lty=2)

# Ordinary kriging
# Include a fitted semivariogram as the model argument
E.krige <- krig(log(E) ~ 1, locations=data.sdf, newdata=data.grid, model=E.fit)
spplot(E.krige, zcol="var1.pred")
names(E.krige)
spplot(E.krige, zcol="var1.var")
crossval.krige <- krig.cv(log(E) ~ 1, locations=data.sdf, model=E.fit)
cor(crossval.krige$observed, crossval.krige$var1.pred)
sqrt(mean(crossval.krige$residual^2))
plot(crossval.krige$observed, crossval.krige$var1.pred)
abline(0, 1, lty=2)

# Linear regression using elevation as an independent variable
predict.iv <- krig(log(E) ~ elevation, locations=data.sdf, newdata=dem.grid)
spplot(predict.iv, zcol="var1.pred")
# Root mean squared error
sqrt(mean(crossval.iv$residual^2))
# Correlation between predicted/observed
cor(crossval.iv$observed, crossval.iv$var1.pred)

# Kriging with external drift using elevation as an independent variable
E.vgm2 <- variogram(log(E) ~ elevation, data=data.sdf)
E.fit2 <- fit.variogram(E.vgm, model=vgm(psill=0.0005, model="Sph", range=350, nugget=0.0001))
predict.ed <- krig(log(E) ~ elevation, locations=data.sdf, newdata=dem.grid, model=E.fit2)
spplot(predict.ed, zcol="var1.pred")
crossval.ed <- krig.cv(log(E) ~ elevation, locations=data.sdf, model=E.fit2)
accuracy.ed <- accstats(crossval.ed$observed, crossval.ed$var1.pred, "ED")

# Kriging with external drift using elevation as an independent variable
E.vgm2 <- variogram(log(E) ~ elevation, data=data.sdf)
E.fit2 <- fit.variogram(E.vgm, model=vgm(psill=0.0005, model="Sph", range=350, nugget=0.0001))
predict.ed <- krig(log(E) ~ elevation, locations=data.sdf, newdata=dem.grid, model=E.fit2)
spplot(predict.ed, zcol="var1.pred")
crossval.ed <- krig.cv(log(E) ~ elevation, locations=data.sdf, model=E.fit2)
accuracy.ed <- accstats(crossval.ed$observed, crossval.ed$var1.pred, "ED")

# Extract elevation points from DEM
file<- list.files("C:\Users\Girma\Desktop\girma", "*.tif")
a<-raster(file[1])
plot(a)
elevation<-extract(a, data.sdf)
elevation
cbind(data.sdf@data,elevation)

projection(data.sdf) <- "+proj=utm +zone=14 +datum=WGS84 +units=m +no_defs +ellps=WGS84 +towgs84=0,0,0"
proj4string(data.sdf)<-"+proj=utm +zone=14 +datum=WGS84 +units=m +no_defs +ellps=WGS84 +towgs84=0,0,0"
install.packages("plotKML")
library(plotKML)
plotKML(data.sdf["yield"])
Appendix II: Soils of the study sites

Table 1 Soil of the research site with area of coverage.

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Dominant soils</th>
<th>Soil Classification</th>
<th>US Soil Mapping units containing named soil (ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redfield*, SD</td>
<td>Harmony</td>
<td>Fine, smectitic, frigid Pachic Argiudolls</td>
<td>1,189,440</td>
</tr>
<tr>
<td></td>
<td>Aberdeen</td>
<td>Fine, smectitic, frigid Glossic Argiudolls</td>
<td>2,062,270</td>
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<tr>
<td></td>
<td>Winship</td>
<td>Fine-silty, mixed, superactive, frigid Pachic Argiudolls</td>
<td>202,190</td>
</tr>
<tr>
<td></td>
<td>Tonka</td>
<td>Fine, smectitic, frigid Argiaquic Argiudolls</td>
<td>13,902,240</td>
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<tr>
<td></td>
<td>Bend</td>
<td>Fine-silty, mixed, superactive, mesic Typic Haplustolls</td>
<td>44,600</td>
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<tr>
<td></td>
<td>Beotia</td>
<td>Fine-silty, mixed, superactive, frigid Pachic Haplustolls</td>
<td>1,448,060</td>
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<tr>
<td>White Lake** SD</td>
<td>Beadle</td>
<td>Fine, smectitic, mesic Typic Argiustolls</td>
<td>1,869,900</td>
</tr>
<tr>
<td></td>
<td>Dudley</td>
<td>Fine, smectitic, mesic Typic Natrustolls</td>
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<tr>
<td></td>
<td>Delmont</td>
<td>Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Haplustolls</td>
<td>1,029,770</td>
</tr>
<tr>
<td></td>
<td>Talmo</td>
<td>Sand skeletal, mixed, mesic, udorthentic Haplustolls</td>
<td>472,420</td>
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<tr>
<td></td>
<td>Houdek</td>
<td>Fine-loamy, mixed, superactive, mesic Typic Argiustolls</td>
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<td></td>
<td>Ethan</td>
<td>Fine-loamy, mixed, superactive, mesic Typic Calciustolls</td>
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<tr>
<td>Pierpont*** SD</td>
<td>Kranzburg</td>
<td>Fine-silty, mixed, superactive, frigid Calcic Haplustolls</td>
<td>2,665,320</td>
</tr>
<tr>
<td></td>
<td>Brookings</td>
<td>Fine-silty, mixed, superactive, frigid Pachic Haplustolls</td>
<td>1,752,790</td>
</tr>
<tr>
<td></td>
<td>Nahon</td>
<td>Fine, smectitic, frigid Calcic Natrudolls</td>
<td>1,000,250</td>
</tr>
<tr>
<td></td>
<td>Aberdeen</td>
<td>Fine, smectitic, frigid Glossic Natrudolls</td>
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<tr>
<td></td>
<td>Exline</td>
<td>Fine, smectitic, frigid Leptic Natrudolls</td>
<td>1,095,090</td>
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<tr>
<td>Brookings****SD</td>
<td>Brookings</td>
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<tr>
<td></td>
<td>Vienna</td>
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</table>

*44°58′10″N, -98°27′52″W, **43°40′31″N, -98°45′50″W, ***45°30′31″N, -97°53′50″W, **** 44° 19′ 7″N,-96° 46′ 56″W

Appendix III: Interpolated maps of selected soil attributes using different interpolation methods.

Figure 1 Interpolated electrical conductivity (EC) measured at V1 (first leaf) stage of corn (*Zea mays*) overlaid on soil series at Pierpont, SD saline sodic soils.

Pierpont, SD coordinates: (44°55’30” to 45°28’30”N and 97°50’9” to 98°28’34”W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).

Figure 2 Interpolated soil moisture measured at V1 (first leaf) stage of corn (*Zea mays*) overlaid on soil series at Pierpont, SD saline sodic soils

Pierpont, SD coordinates: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.
Appendix IV: ANOVA tables

Table 2 ANOVA summary of soil attributes and NDVI values, soil series as independent variable at Pierpont.

<table>
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<tr>
<th></th>
<th>F-value</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI E</td>
<td>0.0012**</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>NDVI V1</td>
<td>0.1125</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>NDVI V4</td>
<td>0.2553</td>
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<td></td>
</tr>
<tr>
<td>NDVI V6</td>
<td>&lt;.0001***</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Soil Moisture E</td>
<td>0.0055**</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>Soil Moisture V1</td>
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<td>155</td>
<td></td>
</tr>
<tr>
<td>Soil Moisture V4</td>
<td>0.1262</td>
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<td></td>
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<tr>
<td>Soil Moisture V6</td>
<td>0.4364</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>EC V1</td>
<td>&lt;.0001***</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>EC V4</td>
<td>0.0012**</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>EC V6</td>
<td>&lt;.0001***</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Chlorophyll V4</td>
<td>0.5424</td>
<td>139</td>
<td></td>
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<tr>
<td>Chlorophyll V6</td>
<td>0.0077**</td>
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<tr>
<td>EC 0-3</td>
<td>0.0140*</td>
<td>112</td>
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<tr>
<td>pH 0-3</td>
<td>0.6894</td>
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<td></td>
</tr>
<tr>
<td>SAR 0-3</td>
<td>0.0008***</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Lime depth</td>
<td>&lt;.0001***</td>
<td>154</td>
<td></td>
</tr>
<tr>
<td>Mollic depth</td>
<td>&lt;.0001***</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Redox depth</td>
<td>&lt;.0001***</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Till depth</td>
<td>&lt;.0001***</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Yield</td>
<td>&lt;.0001***</td>
<td>156</td>
<td></td>
</tr>
</tbody>
</table>

Pierpont coordinate: 45°30′31″N, -97°53′50″W (Dominant soils: Hapludolls, Natrudolls).
NDVI= Normalized Difference Vegetation Index, E=emergence, V1= first leaf, V4=four leaves, V6=six leaves, EC= electrical conductivity, SAR=sodium adsorption ratio.
*Significant at P < 0.05.
** Significant at P < 0.01.
*** Significant at P < 0.001.
Appendix V: Soil variability

Figure 3 Semivariograms fit for NDVI at V1 stage of corn (Zea mays) at Pierpont, SD field: stable (a), exponential (b), Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 4 Semivariograms for NDVI at V4 stage of corn (*Zea mays*) at Pierpont, SD field: (a) stable, (b) exponential, Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).

Figure 5 Semivariograms for NDVI at V6 stage of corn (Zea mays) at Pierpont, SD field: (a) stable, (b) exponential, Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.
Figure 6 Semivariograms for mollic depth at Pierpont, SD field: (a) stable, (b) exponential), Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 7 Semivariograms for lime depth at Pierpont, SD field: (a) stable, (b) exponential), Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 8 Semivariograms for pH at Pierpont field: (a) stable, (b) exponential), Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 9 Semivariograms for EC at Pierpont field: stable, exponential), Spherical and Guassian models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.
Figure 10 Semivariograms for SAR at Pierpont field: (a) stable, (b) exponential, Spherical (c) and Guassian (d) models.

Pierpont coordinate: (44°55′30″ to 45°28′30″N and 97°50′9″ to 98°28′34″W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Figure 11 Semivariograms fit for NDVI at bare soil/emergence stage of corn (*Zea mays*) at Pierpont field: stable, (b) exponential), Spherical and Guassian models.

Pierpont coordinate: (44°55'30" to 45°28'30"N and 97°50'9" to 98°28'34"W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls). Source of soil information: USDA-NRCS, Soil Survey Division, 2016b.
Figure 12 Semivariograms fit for corn (*Zea mays*) yield at Pierpont, SD field: stable, (b) exponential, Spherical and Guassian models.

Pierpont coordinate: (44°55’30” to 45°28’30”N and 97°50’9” to 98°28’34”W (Dominant soils: Calciaquolls, Argiudolls, Calciudolls, Endoaquolls, Hapludolls, and Natrudolls).
Table 3 Correlation matrix of soil attributes

<table>
<thead>
<tr>
<th>Properties</th>
<th>SM E</th>
<th>SM V1</th>
<th>EC V1</th>
<th>Chlorophyll V4</th>
<th>Yield</th>
<th>Elevation</th>
<th>EC 0-3 inch depth</th>
<th>pH 0-3 inch depth</th>
<th>SAR 0-3 inch depth</th>
<th>Lime depth</th>
<th>Mollic depth</th>
<th>Redox depth</th>
<th>Till depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil moisture E</td>
<td>1.00</td>
<td>0.17**</td>
<td>0.24**</td>
<td>-0.02</td>
<td>-0.31**</td>
<td>-0.50**</td>
<td>0.20**</td>
<td>0.01</td>
<td>0.24**</td>
<td>0.06</td>
<td>0.35**</td>
<td>0.12</td>
<td>0.05</td>
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<tr>
<td>Soil moisture V1</td>
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<td>0.45**</td>
<td>-0.02</td>
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<td>0.34**</td>
<td>0.05</td>
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<td>-0.01</td>
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<td>0.18**</td>
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<td>0.16*</td>
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<td>Chlorophyll V4</td>
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<td>0.27**</td>
<td>-0.05</td>
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<td>-0.01</td>
<td>0.15**</td>
<td>-0.13</td>
<td>-0.05</td>
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<tr>
<td>Yield</td>
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<td>0.37**</td>
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<td>Elevation</td>
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<td>-0.06</td>
<td>-0.33**</td>
<td>-0.01</td>
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<td>-0.07</td>
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<td>0.66**</td>
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<td>Redox depth</td>
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</tr>
</tbody>
</table>

Pierpont coordinate: 45°30’31”N, -97°53’50”W (Dominant soils: Hapludolls, Natrudolls).


NDVI= Normalized Difference Vegetation Index, E=emergence, V1= first leaf, V4=four leaves, V6=six leaves, EC= electrical conductivity, SAR=sodium adsorption ratio.* Significant at 0.05, **significant at 0.01
VITA

Girma A. Birru was born on October 10, 1973 in Kebri Dehar from Almaze Mengesha and Abebe Birru. He received his Diploma and BSc from Addis Ababa University (Plant Science) in 1992 and 1998, respectively, and MSc from University of Jordan (Agricultural Resources and Environment) in 2002. For his PhD study he joined South Dakota State University in 2013 and received the PhD in Plant Science in 2016 under the supervision of Dr. Douglas Malo.