IMPACTS OF ROTATIONAL COVER CROPS ON SOIL QUALITY PARAMETERS, SOIL WATER HOLDING CAPACITY, AND FIELD-SCALE SOIL-WATER AND SURFACE ENERGY BALANCE DYNAMICS

NRCS-CIG Project Number: 69-3A75-12-207

FINAL REPORT

As the project leader, Dr. Suat Irmak express his most sincere appreciation to the USDA-NRCS Conservation and Innovation Grant Program, technical contact, and associated other leadership for sponsoring, supporting as well as providing financial support for this project.

Principal Investigator:
Suat Irmak, Ph.D., Harold W. Eberhard Distinguished Professor
University of Nebraska–Lincoln
239 L. W. Chase Hall, P.O. Box 830726, Lincoln, NE 68583-0726
402-472-4865 (Phone)| 402-472-6338 (FAX)
E-mail: sirmak2@unl.edu
http://engineering.unl.edu/bse/faculty/suat-irmak-0/
http://water.unl.edu/cropswater/nawmn

Technical Contacts:
Kerry Goodrich
USDA-Natural Resources Conservation Service
Central National Technology Support Center
Central Region Agronomist
501 W. Felix St., Bldg. 23
Fort Worth, Texas 76115
Work Phone: (817) 509-3363
Work Cell: (682) 404-0127

Philip J. Barbour, Ph.D.
Certified Wildlife Biologist ®|Central Region Biologist
ND, SD, NE, KS, OK, TX, LA, AR, MO, IA, MN, WI, IL, IN, MI
USDA Natural Resources Conservation Service|Central National Technology Support Center
501 West Felix Street, Building 23|Fort Worth, Texas 76115
☎ (817) 509-3225| Fax (817) 509-3336| iPhone (817) 320-2095|
✉ philip.barbour@ftw.usda.gov

BACKGROUND

The benefits of cover crops have been widely documented and can be seen through decreased field crop input requirements, improved soil quality, and better functioning ecosystems. Cover crops are frequently recommended to improve soil health for field crop production, since they have the potential to increase residue cover, increase soil organic matter content, improve soil structure and reduce compaction, increase or reduce loss of soil nitrogen and other nutrients through biological fixation and redistribution in the soil profile, increase water infiltration rate, decrease run-off and wind and water erosion, reduce weed and pest pressure and promote biological diversity, and provide supplemental grazing. In Nebraska, cover crops have supported no-till fields, organic farming, and suppression of wind and water erosion from highly erodible areas. Cover crop seed costs have been offset by the rising cost of fertilizer, making nitrogen-fixation and nutrient redistribution of cover crop types and mixes more attractive. Additionally, with over 1.8 million head beef cattle in Nebraska and 32.8 million head in the United States, cover crops can provide substantial forage opportunities and reduce the impact of grazing on compaction and soil water availability (USDA-NASS, 2007).

The benefits of cover cropping systems can vary significantly depending on soil properties, climate and weather, and management practices. There is a pressing need to quantify such impacts through field projects. Focusing on the relationship between cover crops and surface water balance, there is a complex feedback system where cover crops, as a water user, have demonstrated direct and indirect modifications of soil water holding capacity and soil water availability for field crop production. Directly, cover crops remove water from the soil profile. Indirectly, they can increase infiltration and water holding capacity of the soil through deposition of residue cover and subsurface root proliferation and decomposition, especially in conjunction with minimal tillage systems, which will increase organic matter, soil organic carbon, and soil aggregates and reduce compaction. The efficiency of cover crops in positively affecting soil water holding capacity and soil water availability for future field crop seasons is dependent on the cover crop water consumption during their growing season, which has not been studied sufficiently. Producers utilizing cover crops could benefit, via updated sources, from accurate quantification of cover crop feedbacks with soil healthy and water availability.

The overall goal of this project was to determine the impact(s) of cover crop mixes on soil-water balance under different land use categories and quantify the impacts of cover crops on soil quality parameters, including soil physical and chemical properties. The results, discussions, and interpretation of several different subtopics that address the project goals and objectives are presented in this final report in different sections. Each section is designed to present the data, information, analyses, and interpretation in a manuscript format, which provides in depth information and analyses. Each section has its own introduction, materials and methods, results and discussion, and references section.

EXECUTIVE SUMMARY

SECTION 1: SOIL-WATER DYNAMICS, EVAPOTRANSPIRATION, AND CROP COEFFICIENTS OF COVER CROP MIXTURES IN SEED MAIZE-COVER CROP ROTATION FIELDS: SOIL-WATER DYNAMICS AND EVAPOTRANSPIRATION

Cover crops are incorporated into the row crop production systems as rotational crops because of their potential contributions to soil and water conservation. However, extremely limited data and information exist in the literature in terms of their water use (evapotranspiration, ET) rates, especially in the Midwestern states. The main objective of the Section 1 of this project was to investigate the impact of cover crop mixtures on soil-water dynamics and measure, analyze and compare the magnitude and trend of weekly, monthly and seasonal ET rates from different surface covers, including: (i) mixture of cover crops (CC) without maize residue, (ii) bare soil, (iii) cover crops with maize residue (SCCC), and (iv) only seed maize residue (SC) without cover crops. Extensive field research was conducted in three cover crop growing seasons (2012-2013, 2013-2014 and 2014-2015) on three center pivot-irrigated large scale seed maize-cover crop rotation production fields (F1, F2 and F3) near Beaver Crossing, Nebraska, U.S.A. Soil-water balance approach was used to quantify actual evapotranspiration rates (ET_a) from different surface cover treatments. Results for 2012-2013, 2013-2014 and 2014-2015 cover crop growing season indicate high values of cover crop ET_a at the beginning (fall) and end of the season (spring), while low values were observed during winter months in December, January, and February, when the surface was covered with snow and/or ice. The cumulative growing season precipitation varied from 183 mm in 2012-2013 growing season to 262 mm in 2013-2014 and 437 mm in 2014-2015. ET_a during 2012-2013 (dry year) was lower in the CC treatment than

bare soil and was significantly higher ($P<0.05$) in 2013-2014 and 2014-2015 growing season (above average years). In 2013-2014 and 2014-2015, SCCC ET_a was significantly lower ($P<0.05$) than those in the CC only treatment. Cumulative ET_a for CC only and SCCC treatments for 2012 – 2013 cover crop growing season was 135 mm and 142 mm, respectively, while it was 267 and 237 mm, respectively, in 2013-2014 season; and 417 mm and 381 mm, respectively, in 2014-2015. The SCCC and SC only treatments were compared to quantify the potential impact of cover crops on water use. While there were cases when SCCC treatment had lower ET_a values than SC only treatment, when the values from all three fields (F1, F2, and F3) are averaged, results indicated that cover crops did not have positive or negative impact on reducing or increasing evaporative losses when incorporated as a rotational crop in the soil, climate and management conditions presented in this research. For example, in, 2012-2013 season the three field average ET_a values for the SCCC and SC only were essentially the same (142 and 145 mm, respectively); in 2013-2014 season they were exactly the same (237 mm); and in 2014-2015 season they were 381 and 367 mm respectively (SCCC treatment had significantly greater ETa (14 mm than the SC only treatment)], indicating that the cover crops did not have impact in reducing evaporative losses. Substantial inter-seasonal variations were observed in terms of impact of the same surface covers on ET_a in the field. Soil-water storage (SWS) was significantly lower ($P<0.05$) in CC treatment than the bare soil during the 2013-2014 and 2014-2015 cover crop growing seasons and significantly higher in 2012-2013. Surface cover's influence on SWS for the next season's crop and ET rates in a maize-cover crop rotation system can vary substantially, depending on the current year's climatic conditions, especially air temperature (influence on evaporative losses), precipitation (influence on soil-water availability), growth, and water use of the cover crops.

SECTION 2: SOIL-WATER DYNAMICS, EVAPOTRANSPIRATION AND CROP COEFFICIENTS OF COVER CROP MIXTURES IN SEED MAIZE-COVER CROP ROTATION FIELDS: GRASS- AND ALFALFA-REFERENCE SINGLE (NORMAL) AND BASAL CROP COEFFICIENTS

Cover crops have been gaining attraction in agriculture as rotational crops due to their "potential" benefits in various soil characteristics and soil-water functions. The knowledge about cover crop water use in terms of examining the water availability for the next field crop is very important for developing and implementing sustainable agricultural management strategies. Crop coefficients for estimating water use for cover crops are among the least available coefficients of any cropping systems. In the Section II of this project, single (normal) and basal grass-reference (K_{co} and K_{cbo}) and alfalfa-reference (K_{cr} and K_{cbr}) crop coefficients were developed as a function of cumulative growing degree days (CGDD) for: (i) cover crop mixes (CC) only, (ii) seed maize-cover crop rotation (SCCC), (iii) seed maize residue without cover crop (SC), and (iv) bare soil. The research was conducted for three cover crop growing seasons (2012-2013, 2013-2014, and 2014-2015) on three center pivot-irrigated seed maize-cover crop rotation fields (F1, F2 and F3) near Beaver Crossing, Nebraska, U.S.A. Single and basal crop coefficients were developed from the ET_a data and estimated grass- and alfalfa-reference evapotranspiration (ET_o and ET_r). K_{co} and K_{cr} values exhibited inter-annual variability for the same months and treatments between the years. K_{co} and K_{cr} varied from 0.0 to 1.8 and from 0.0 to 1.2, respectively, in 2012-2013 season; from 0.0 to 2.3 and from 0.0 to 1.7, respectively, in 2013-2014 season; and from 0.0 to 2.3 and from 0.0 to 1.7 in 2014-2015 cover crop growing season. The bare soil treatment K_c values were higher than the values for cover crops in the winter months (mid-December to March). However, from October until mid-December cover crop treatments had higher K_c values. On average, the cover crop K_{cbo} and K_{cbr} values fluctuated between 0.0 to 1.6 and 0.0 to 1.5, respectively. The K_c and K_{cb} curves exhibited a bell-shaped trend from the emergence till mid-December that is the peak growing period for the winter cover crops in Midwest that peaked in September and October. Depending on the treatment, maximum K_c and K_{cb} values, in general, occurred at CGDD between approximately 980 and 1,300^{o}C (end of October) which then gradually decreased in the winter months. Minimum K_c values usually occurred at CGDD of approximately 200^{o}C. The K_c and K_{cb} curves presented in this study are among first cover crop K_c values and can be used to estimate cover crop ET_a for particular cover crop mixtures that are similar to those used in this research and grown under climatic conditions similar to the research area.

SECTION 3: EFFECT OF COVER CROPS ON SOIL QUALITY: SOIL CHEMICAL PROPERTIES – ORGANIC C, TOTAL N, PH, EC, ORGANIC MATTER CONTENT, NO_3-N, AND P

Winter cover crops in association with no tillage and crop rotation appear to be the most promising conservation practice in improving the soil physical and chemical characteristics.

Cover crops cover soil during fallow season, thereby reducing soil erosion, improving soil organic matter, aggregation, and water holding capacity, and influencing crop yields; however, the effect of inclusion of cover crops in no-till farming system on soil chemical properties is largely unknown. The main objective of the Section III of this project was to investigate the short term effects of growing cover crops under conservation tillage on soil Organic C, Total N, pH, EC, SOM, NO_3-N and P from different surface covers i.e. (i) cover crop only without seed maize or soybean residue (CC), (ii) cover crop mixtures planted in seed maize or soybean residue (SCCC), (iii) seed maize or soybean residue (SC) only without cover crops and (iv) bare soil (Bare soil). Extensive field research was conducted from 2012 to 2015 on three center pivot-irrigated seed maize/soybean cover crop rotation fields near Beaver crossing, Nebraska, U.S.A. Continuous cover cropping since 2012 resulted in small increase of organic C in SCCC treatment for 0-40 cm layer and total N in all soil layers. Compared to the beginning of the experiment in spring 2014, there was an increase in N concentration in all treatments, with maximum increase in SCCC treatment at all depths expect 0-5 cm, ranging from 38% to 95% increase in 2015 fall. For 20-40 cm soil depth, plots with cover crops (CC and SCCC) had increased the C concentration by 9.1% and 22%, respectively, from 2014 spring to 2015 fall. Cover crops rapidly increase the top soil SOM by residue decomposition. Although, cover crops are highly decomposable, increase in SOM levels following cover crops was limited to the top soil (5-20 cm) only. SOM under cover cropped plots in 0-5 cm soil was 28% higher than the bare soil plot. Cover crops significantly reduced the P and NO_3-N quantities in the soil when they are alive and actively growing, however, they also helped in providing N and P to the next cash crop by residue decomposition in the winters. There was no significant change in soil pH due to treatments. Though not significant, pH in SCCC treatment at the end of the experiment in 2015 fall was higher than that of SC treatments by 0.1 to 0.3 units. On the other hand, cover cropped treatments had decreased the soil EC at all depths of soil ranging from 7.3% decrease to 74% decrease in fall 2015. This study shows that SOM, NO_3-N, P, C and N can be conserved or maintained by cover crops, thus improving the soil quality and crop productivity. Further research should investigate the long term impacts of cover crops on these selected soil properties. The results of this study are beneficial to the producers in Mid-west for better management of soil and water resources in cover crop production.

SECTION IV: EFFECT OF COVER CROPS ON SOIL QUALITY: SOIL EXCHANGEABLE BASES (K, Mg, Na, Ca) AND SOIL MICRONUTRIENTS (Zn, Mn, Fe, Cu and B)

Maintaining and conserving essential soil nutrients using soil management practices like cover cropping and no tillage can improve soil quality and fertility as well soil productivity. For the Section IV of this project, we examined the effect of cover crops in no till seed maize production system on soil exchangeable bases and soil micronutrients from spring 2014 to fall 2015 in Beaver Crossing (Seward County), Nebraska, U.S.A. The main objective of the study was to investigate the short term effects of growing cover crops under conservation tillage on soil exchangeable bases (K, Mg, Ca and Na), cation exchange capacity (CEC) and soil micronutrients (Zn, Cu, B, Fe and Mn). Extensive field research was conducted in four cover crop growing seasons (2012-2013, 2013-2014, 2014-2015 and 2015-2016) on three center pivot-irrigated seed maize/soybean cover crop rotation fields (BREBS field, west field and east field) near Beaver crossing, Nebraska, U.S.A. Cover crops in seed maize/soybean (SCCC) had a significant effect on soil exchangeable K in 0-5 cm soil profile. Cover crops did not affect exchangeable K concentration below the 5 cm. Exchangeable Ca concentrations were unaffected by any land cover treatment imposed in this study. Our finding suggests that incorporating cover crops in no till seed maize/soybean cropping system (SCCC), might help in maintaining the exchangeable Mg concentration better than no cover crop treatment (SC), especially in 20-40 cm soil profile. Cover cropping has significant effects on CEC at 5-40 cm soil depth. At 5-20 cm soil depth, SCCC treatment had increased the CEC by 8.4% as compared to study inception whereas, bare soil, CC and SC treatment had reduced it by 10% 4.1% and 21%, respectively. Cover cropping in seed maize (SCCC) reduced the concentration of micronutrients in top 0-5 cm soil. Overall, cover crops (SCCC) have the potential in maintaining the optimum levels of Zn, B, Fe and Mn in 0-5 cm soil profile as compared to SC treatment. The results of this study suggest that cover cropping altered several very important soil properties even in a very short period, however, further research is required to investigate the long term effects of cover cropping on soil chemical properties.

SECTION V: EFFECT OF COVER CROPS ON SOIL QUALITY. SOIL PHYSICAL PROPERTIES – FIELD CAPACITY, PERMANENT WILTING POINT, SOIL WATER HOLDING CAPACITY, INFILTRATION, BULK DENSITY, AND HYDRAULIC CONDUCTIVITY

Winter annual cover crops in conservation tillage represent a different soil physical environment as compared to conventional tillage systems. For the Section V of this project, a field experiment was conducted in southeastern Nebraska to assess the effects of cover cropping on soil physical properties. Field capacity (FC), permanent wilting point (PWP), soil water holding capacity (SWHC), bulk density and hydraulic conductivity (K_{fs}) were measured and compared for four land cover treatments [CC (cover crop without seed maize); SCCC (seed maize followed by cover crop); bare soil (bare soil without any residue cover); and SC (seed maize without cover crop)]. Comparison of field measured soil properties in SCCC treatment was also made with natural resource conservation service (NRCS) web soil survey data. In general, soil properties were unaffected by cover cropping. However, not significant, but there was slight increase in bulk density (0.02 g cm^{-3}) in bare soil from 2013 to 2016, yet SCCC treatment maintained the bulk density of soil to same level as it was at the beginning of the experiment. Hydraulic conductivity for SCCC treatment Kfs has increased by 50% from 2013 to 2015. In 2015 fall, PWP at 5-20 and 20-40 cm and FC at 20-40 cm in SC treatment was significant lower than bare soil treatment ($P<0.05$). At the end of the experiment in 2015 fall, maximum SWHC in 0.6m soil profile was observed in SCCC treatment (92.16 mm). Comparing field measured data with NRCS data on three field average, there was 5% increase in FC and 20% increase in PWP. Also, a decrease of 0.06 g/cc in bulk density was observed when compare to NRCS values for 0-15 cm soil depth. From the above results, we concluded that cover cropping altered several very important soil physical properties even in a very short period (though not significantly). Further research is required with longer durations of experimentation to investigate the long-erm effects of cover cropping on soil physical properties.

SECTION 1: SOIL-WATER DYNAMICS, EVAPOTRANSPIRATION, AND CROP COEFFICIENTS OF COVER CROP MIXTURES IN SEED MAIZE-COVER CROP ROTATION FIELDS: SOIL-WATER DYNAMICS AND EVAPOTRANSPIRATION

INTRODUCTION

Cover crop farming practices have been gaining increasing attention in recent years due to their *potential* contributions to the crop productivity of subsequent cash crop and ameliorating the soil degenerating impact caused by agricultural practices (Joyce et al., 2002; Lal et al., 1991). It is suggested that cover crops can be used for variety of purposes, including improving soil structure, fixing nitrogen, managing soil moisture, enhancing soil biological functions, and erosion control. Studies conducted in Midwestern United States have suggested that changes in vegetative covers and land use affects plant water uptake patterns and may influence the hydrological balances (Asbjornsen et al., 2007; Qi et al., 2011). Hydrologic balances influence how water is managed in agricultural production fields and since water management (primarily conservation) is one of the intended applications of cover crops, these can vary significantly with different climatic conditions. Cover crop water use estimates, in most cases, can be site-specific and depend on many factors such as management practices of differences in cover crop species and their specific growth characteristics as well as local factors, which contribute to actual evapotranspiration (ET_a) demand during the cover crop growth and development period (Tanner and Sinclair, 1983; Unger and Vigil, 1998).

Incorporating cover crops into the agronomic row crop rotation (i.e., maize-soybean cropping system) may have positive, neutral, or negative impacts on soil-water storage, depending on environmental and climatic conditions as well as management practices. Cover crops may enhance recharging of soil-water through their potential influence on increased soil infiltration rates. Comparative studies have shown that soil-water storage (SWS) under cover crop and fallow vary widely. Cover crops increase soil infiltration (McVay et al., 1989), soil-water retention (Colla et al., 2000), reduce soil evaporation, and increase solar energy harvest (radiation use efficiency) and carbon flux into the soil. Colla et al. (2000) studied the impact of alternative cropping systems on the soil physical properties and tomato yields in Sacramento Valley, California. They observed that cover crops (oat and purple vetch) increased both soil-water holding capacity and soil permeability as compared to the conventional cropping system of 4-yr rotation and showed 0.028 m^3 m^{-1} infiltration during 3-h of irrigation event in conventional treatment and a greater infiltration rate of 0.062 m^3 m^{-1} in cover-cropped systems. Moschler et al. (1967) reported elevated soil-water content with winter rye cover crop from the upper 0-60 cm soil layers. In a study conducted at British Columbia, Canada, Odhiambo and Bomke (2007) compared soil-water content in the winter cover crops with bare soil plots in the early spring. They found that the soil water content in the cover crop treatment was significantly higher in the top soil (0 - 20 cm) possibly due to cover crops reducing soil evaporation and increasing infiltration rate. In a 3-yr study conducted in Iowa, Qi et al. (2011) showed that winter rye planted in maize and soybean maintained higher soil-water storage when compared to the plots with only maize and soybean with no cover crop. They also reported that during the period of no-rainfall, soil-water storage in the plots with cover crops decreased significantly than bare soil plots. Also, ET_a during this period was significantly higher in cover crop plots. They reported a 1.90 mm d^{-1} of ET_a from the plots with cover crops in maize and soybean fields and an ET_a of 0.60 mm d^{-1} from the bare soil plots with no cover crops. This might suggest that infiltration could be increased for subsequent rainfall events, which would result in reduced run-off from cover crop plots. A field research conducted by Islam et al. (2006) in the Central Valley of California, investigated the effect of cover cropping systems on water balance variables (recharge and ET) and found a generally higher rye cover crop ET_a (140 mm from November to March) as compared to fallow (110 mm during same period). This may indicate that higher ET_a consumption from the rye cover crop may reduce the SWS due to high rate of transpiration and lead to water stress for the following main crop.

In a long-term (1999-2014) field experiments in San Joaquin Valley, California, Mitchell et al. (2015) found that net soil-water storage increased during the period January to March (the primary growing period for cover crops in California) by 48 and 43 mm in 2013 and 2014, respectively, for the fallow system, but in the cover crop mixture plots, there was no additional water storage. Instead, water use by the cover crop mixes resulted in a negative water balance over the cover crop growth period on an average of 4.7 and 2.6 mm in 2013 and 2014, respectively. Thus, compared to the fallow system, cover crops depleted 53 and 6.7 mm, or more, of water from the 0 to 0.90 m soil profile in 2013 and 2014, respectively. They concluded that while vigorous growth of winter cover crops in the Central Valley of California may not be possible in all years due to low and erratic precipitation patterns, there may be benefits in terms of providing ground cover, residue, and photosynthetic energy capture in many years. However, the authors concluded that cover crop biomass production may come at a cost of soil-water depletion in this semiarid, drought-prone region. Joyce et al. (2002) conducted research in winters of 1998-1999 and 1999-2000 to determine the ability of cover crops to conserve soil-water for subsequent crops in Davis, California. They found improved rainfall infiltration in cover cropped fields as compared to fallow. They also found higher run-off on fallow treatment than on cover-cropped treatment. However, Ewing et al. (1991) reported that crimson clover cover crop depleted the soil-water in the upper 0.15 m by 28% more in 1985 and 55% more in 1986 than the fallow treatments. They reported a reduction in maize grain yield in the presence of crimson clover by 0.5 Mg ha^{-1} and 0.9 Mg ha^{-1} in 1985 and 1986, respectively. In arid and semi-arid regions, it was reported that cover crops can deplete the soil-water availability for the following cash crops and also reduce the yield (Mitchell et. al, 1999; Nielsen and Vigil, 2005). The aforementioned studies indicate that the effectiveness of cover crops in conserving soil moisture as well as their effect on soil properties varies substantially with the climatic conditions. Even though the cover crop adoption in Midwestern states, including Nebraska, has been increasing in the last several years; data, information or knowledge of ET rates and impact(s) of various cover crop mixtures on soil-water are essentially not known. Nebraska is represented by two major climate zones: the eastern half of the state has sub-humid continental climate and the western half, a semi-arid climate, thus is susceptible to both excess and shortage of rainfall (Sharma and Irmak, 2012). This makes it a challenging decision for producers to incorporate cover crops into the cropping rotation without knowing the water demand of the cover crops. Hardly any research has been conducted on the effects of cover crops on water management in this region and very little is known about the impact of various cover crop mixtures on soil-water dynamics, including cover crop water use vs. their impact(s) to the next cash crop. Therefore, knowledge about the cover crop water use for sound water management decisions for the subsequent cash crop requires accurate quantification of cover crops water use.

The specific objective of this research was to measure, document and compare weekly, monthly, and seasonal ET$_a$ and soil-water dynamics from different surface covers: (i) mixture of cover crops only (CC), (ii) bare soil only, (iii) cover crops planted in seed maize residue (SCCC), and (iv) only seed maize (SC) without cover crops in large production fields in south central Nebraska climatic, soil and management conditions.

MATERIALS AND METHODS

Research sites

The research was conducted in three consecutive (2012- 2013, 2013-2014, and 2014-2015) cover crop growing (dormant) seasons in three large scale farmer production fields (F1-BREBS field, F2-West Field and F3- East field) all located in the same area in Seward County near Beaver Crossing, Nebraska, USA. The research fields are located in the transition zone between the wetter Vegetative Zone IV and drier Zone III (http://efotg.sc.egov.usda.gov/references/public/NE/NebraskaVegetativeZones.pdf) (Figure 1). One of these three fields (F1) with approximately 48.5 ha of area was equipped with a Bowen Ratio Energy Balance System (BREBS) (Figure 2), which is a part of the Nebraska Water and Energy Flux Measurement, Modeling, and Research Network (NEBFLUX) (Irmak, 2010). The other two research fields (F2 and F3) are located within 2.5-3.0 km south of F1 field (Figure 1). All three research fields are center-pivot irrigated seed maize-cover crop rotation fields with different cover crop mixes and no-till practice. All fields have very similar topography and soil properties. Predominant soil at the F1 field is Hasting silt loam, which is a well-drained loamy upland soil with available water capacity of 126 mm m^{-1} in the top 0.90 m (average field capacity: 32% vol and permanent wilting point: 20% vol) (Table 1). The other two fields have very similar silt loam soils (Butler and Muir silt loam) with a very similar available water holding capacity of 142 mm m^{-1} in top 0.90 m (Table 1). Table 1 shows detailed description of field measured physical and chemical soil properties in all three fields at various depths.

Experimental design and cover crop management practices

Four land cover treatments were created and evaluated in each individual year in all three fields: (i) cover crop only without seed maize residue (CC), (ii) cover crop mixtures planted in seed maize residue (SCCC), (iii) seed maize residue (SC) only without cover crops and (iv) bare soil (Bare soil) without any considerable seed maize residue. The cover crop treatment (CC) in this research represented the conditions when there is only cover crop in the field without any seed maize residue from the previous crop. The SCCC treatment represented the conditions where cover crops are planted in the seed-maize residue after harvest or broadcasted within the maize plants around physiological maturity before harvest. The SCCC treatment represents the actual production system that growers typically practice in the Midwest. The SC treatment corresponds to condition where there is no cover crop after seed maize harvest and only seed maize residue existed in the plot. Bare soil treatment refers to the bare soil plot in the field with no seed maize, cover crop or any other crop cultivated for several years. All research plots in three fields were maintained throughout the research period. It was made sure that during the seed maize planting, the CC and bare soil plots did not get any seed maize seeds. In addition, bare soil and SC plots were covered with tarp whenever cover crop seeds were broadcasted so that these plots do not get any cover crop seeds. Weeds and other unwanted plants like volunteer corn were manually removed on regular basis from all plots.

Cross-pollination method was used in the seed maize production, which consists of de-tasseling of female seed maize plant rows to prevent their self-pollination and get pollinated from the male plant's pollens. After pollination of female rows, male rows were chopped and the same process was practiced every year. The cover crops were then planted (drilled or broadcasted), usually, close to the physiological maturity of the seed maize. This research focuses only on cover crops growing season, which is generally from August through April when used as a rotation with seed maize. Cover crop mixes (more than one cover crop) were used in all fields over three years, except F2 field in 2012-2013 and F1 field in 2013-2014, where only single cover crop species was grown. Cover crop mixtures were used to ensure good soil cover across variety of conditions as different cover crops may respond differently to varying soil, management and weather conditions. Information about cover crop mixtures, cover crop planting dates, seed maize planting and harvesting dates, cover crop termination dates, and some of the other agronomic management practices and dates for three fields for three growing seasons is presented in Table 2. Different winter cover crops used in this research and detailed information about their types, winter-kill temperature (USDA-NRCS: Plant Material Program), and other crop-specific functions are presented in Table 3. Also, cover crops were planted either into the existing seed maize or after harvest of seed-maize before the next crop was planted the following spring. The reason of incorporating the cover crops before seed-maize harvesting was to ensure the maximum cover crop emergence rate and plant growth and development before the winter season (dormancy) (Clark, 2007). In the research, a randomized complete block design with three fields described in the study (F1, F2 and F3) as three replications or blocks was implemented. Each block had four treatments/plots (CC, SCCC, SC and bare soil; 6.5 m X 4.5 m each) throughout the research years. Data for average soil water storage (SWS) over the cover crop growing season from each treatment, seasonal total ET_a, wet period ET_a and dry period ET_a was analyzed using Proc Glimmix Procedure in SAS program. Data from each year were analyzed separately.

Soil-water measurements

Soil water status was measured continuously using Watermark Granular Matrix sensors (WGMS, Irrometer, Co., Riverside, CA). WGMS were used to monitor soil matric potential (SMP, kPa) on an hourly basis, which was then subsequently converted to volumetric soil-water content using pre-determined soil-water retention curves for the research site using the equation developed by Irmak (2006; unpublished research data), Irmak et al. (2010), Irmak et al. (2012) and Irmak et al. (2014) at Clay Center NE, having the same soil series:

$$\Theta v = (0.0003\psi^2) - (0.1302\ \psi) + 37.635 \qquad (R^2 = 0.98) \tag{1}$$

where, θ_v is the volumetric soil water content ($m^3\ m^{-3}$) and ψ is the soil matric potential (kPa). WGMSs were installed every 0.15 m down to 0.75 m (0.15, 0.30, 0.45, 0.60 and 0.75 m) soil profile at two locations in each treatment (plot) in all the three fields every year. The sensors were connected to a Watermark Monitor datalogger (Irrometer Co., Riverside, CA) and hourly readings were recorded throughout the cover crop growing season. Soil temperature sensors were installed in each plot and were also recorded with each datalogger to automatically adjust the SMP values for measured soil temperature using the procedures outlined by Irmak et al. (2014). The volumetric soil water content data were then multiplied by the representative depth intervals to determine the soil water storage (SWS) for each depth and then summed up to obtain SWS for the 0-0.75 m soil profile for each treatment. From hourly soil-water moisture data (two values from each plot), an hour of the day was selected to represent the soil moisture present in the profile in that particular day. Then, the cover crop growing season was divided into weekly or 10-day periods such that all the days with precipitation events present in these periods. There was no precipitation at the start of the period and this period ends 1-2 days after the precipitation. This was done because on the day of precipitation, the soil-water content in the profile is very dynamic and it is impossible to calculate the storage on an hourly or daily basis as water needs time to move down to the root zone and be stored in this zone. After this, change in soil-water storage (ΔSWS) was calculated by subtracting SWS at the beginning of the period from SWS value at the end of the 7 to 10 days' period. These ΔSWS calculations were then used to calculate the ET_a using the soil-water balance approach for each treatment for each field, including the bare soil plots. The seasonal SWS was calculated by averaging all the SWS values over the cover crop growing season for each year. In 2012-2013 growing season, SWS for only 0-0.30 m of profile was measured for field F1 due to some missing data. In 2013-2014 cover crop growing season, data from 20 December to 19 March could not be recorded due to technical issues.

Evapotranspiration calculations using soil-water balance approach

Seasonal ET_a was calculated using a general soil-water balance equation. This method consists of accounting for the incoming and outgoing water amounts into and from the crop root-zone over time as:

$$\mathrm{ET_a} = \mathrm{I} + \mathrm{P} - \mathrm{RO} - \mathrm{DP} + \mathrm{CR} \pm \Delta\mathrm{SWS} \tag{2}$$

where, ET_a is actual evapotranspiration (mm), I is irrigation (mm), P is precipitation (mm), RO is surface run-off (mm), DP is deep percolation (mm), CR is capillary rise (mm), and ΔSWS is change in soil-water storage (mm). Precipitation data were taken from the BREBS station installed in the F1 field. There was no irrigation application for cover crops in any of the season in any of the fields. Deep percolation is assumed negligible and capillary rise from the water table was also considered negligible as the depth to the water table in the area is below 30 m. The deep percolation is one of the most difficult variables to estimate (or measure) in soil-water balance analyses. In our analyses, we had several primary reasons or justifications to assume zero deep percolation: (i) the silt-loam soil in which all there research conducted have very high water holding capacity (~200/1.20 m), thus the research fields have less potential for deep percolation than other coarse-textured soils; (ii) because there can be substantial uncertainty associated with deep percolation estimations, if deep percolation is not estimated with sufficient accuracy, this uncertainty and error can be lumped into the ET_a estimates, resulting in even larger errors in the final ET_a estimates as compared to zero deep percolation assumption; and (iii) all four treatments in all three fields were treated the same as zero deep percolation and that the zero deep percolation assumption should impact all treatments similarly, and (iv) currently there are not robust and accurate methods available to estimate deep percolation with sufficient accuracy using only soil-water and precipitation measurements. Deep percolation method(s) require the accurate knowledge of crop rooting depth, which is an extremely difficult task to obtain and accurately account for mixed cover cropping systems in deep percolation analyses; (v) winter period (November-March) in Nebraska is extremely severe and estimating deep percolation for frozen and/or snow-covered soil profile is an extremely difficult task and we are not sure if there are any method that can accurately estimate deep percolation during these severe periods; (v) the low values of estimated run-off (presented in the next section) indicated a low potential for deep percolation in the research plots, supporting our zero deep percolation assumption.

The surface run-off (RO) was estimated using the USDA Natural Resources Conservation Service (NRCS, formerly called as the Soil Conservation Service, SCS) curve number procedure (USDA-SCS, 1972). The run-off was determined for each day over the cover crop growing season and then summed up for each period (week or 10 days) for individual treatments each year. The SCS curve number method relates run-off curve number (CN) to run-off, accounting for initial abstraction losses and the soil infiltration rate. The following equation was used to estimate run-off from each treatment:

$$\mathrm{RO} = \frac{(\mathrm{P} - \mathrm{I_a})^2}{(\mathrm{P} - \mathrm{I_a}) + \mathrm{S}} \text{ for } \mathrm{P} > 0.2\ \mathrm{S} \tag{3}$$

where, I_a is initial abstraction (mm) and S is the potential maximum retention after run-off begins (mm) given by:

$$\mathrm{S} = \frac{25400}{(\mathrm{CN})} - 254 \tag{4}$$

Initial abstraction (I_a) represents the water loss before run-off begins and includes water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. The Ia value is usually strongly correlated with soil and surface residue cover parameters. From many small agricultural watersheds studies (USDA-SCS, 1972), Ia is approximated by the following empirical equation:

$$\mathrm{I_a} = 0.2\mathrm{S} \tag{5}$$

The Curve Number used in this method is dependent on surface cover type, hydrological soil group, treatment and hydrologic condition. According to the silt loam soil at the site and known land covers, curve numbers were determined as 72, 77.5, 83 and 86 for average antecedent run-off condition for CC, SCCC, SC, and bare soil treatment, respectively, from the USDA-NRCS (1985) tables. Run-off is affected by soil-water before a precipitation event, which is also known as the antecedent moisture condition (AMC), prior to estimating precipitation excess for a storm, the curve number was adjusted based on the five-day antecedent precipitation. The curve number, as mentioned above, may also be termed as AMC II, or average soil moisture. The other moisture conditions are dry (AMC I) and moist (AMC III). The curve number can be adjusted by AMC II factors, where AMC I factors are less than 1 (reducing CN and potential runoff) and AMC III factors are greater than 1 (increasing CN and potential runoff). Zero run-off occurred in 2012-2013 growing season from all treatments in three fields. On a three field average basis, run-off from CC, bare soil, SCCC and SC treatment was 0.2 mm, 8 mm, 0.8 mm and 4 mm, respectively in 2013-2014 season; and was 10.3 mm, 39 mm 17.8 mm and 28.6 mm, respectively in 2014-2015 season.

RESULTS AND DISCUSSION

Weather conditions

Three cover crop growing seasons (2012-2013, 2013-2014 and 2014-2015) had contrasting climatic conditions. The long-term (1996-2015), 2012–2013, 2013–2014 and 2014-2015 cover crop growing season monthly averages of maximum, minimum and average air temperature (T_{max}, T_{min} and T_{avg}); relative humidity (RH); vapor pressure deficit (VPD), incoming shortwave radiation (R_s) and wind speed (u_2) obtained from the nearest High Plains Regional Climate Center weather station at York, NE are presented in Table 4. The long-term (1996–2015) cover crop growing season (August-April) average precipitation in the area is 340 mm, with a significant monthly variability in the cover crop growing season. Figure 3 represents the cumulative and daily precipitation of the research site in three growing seasons. The 2012-2013 growing season had 3 and 17 fewer precipitation events than 2013-2014 and 2014-2015 seasons, respectively. In 2012-2013 season, the precipitation events were more evenly distributed throughout the season than in 2013-2014 and 2014-2015 season (figure 3). The cumulative growing season precipitation varied from 183 mm in 2012-2013 growing season to 262 mm in

2013-2014 and 437 mm in 2014-2015. The 2012-2013 and 2013-2014 cover crop growing seasons received less than the normal precipitation with 2012 being the driest year in Nebraska's recorded climate history. The 2012-2013 season had 54% (183 mm) of normal precipitation and 2013-2014 cover crop growing season precipitation was 79% (262 mm) of the normal. However, the 2014-2015 cover crop growing season precipitation was 28.5% (437 mm) more than the long-term average. Due to the minimal precipitation amounts and events in 2012-2013 season compared to other two seasons, particularly in August and September, large differences in RH were observed. The monthly average RH in August was 64.5%, 79 and 82.5% in 2012-2013, 2013-2014 and 2014-2015 season. On a long-term basis, air temperature usually peaks in August (29.7^{o}C) and minimum air temperatures were observed from December to February. The monthly T_{avg} of 6.1^{o}C, (ranging from 22.6^{o}C to -4.8^{o}C), 6.0^{o}C (ranging from 23.8^{o}C to -5.6^{o}C) and – 0.29^{o}C (ranging from 16.5^{o}C to -12.9^{o}C) was observed in 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons, respectively. In 2012-2013 and 2013-2014 growing seasons, the average air temperature was less than the long-term average by about 0.8^{o}C; however, in 2014-2015 the average air temperature was 7^{o}C less than the long-term average. The 2013-2014 and 2014-2015 growing seasons were much colder in February, with an average air temperature of 4.2^{o}C and 11.5^{o}C, respectively, lower than those in 2012-2013. Wind speed was 8% higher and 2% lower in 2013-2014 and 2014-2015, respectively, as compared to 2012-2013 season. On average, R_s was 4, 8 and 2% higher than the long-term average values in 2012-2013, 2013-2014 and 2014-2015 seasons, respectively. Greater VPD values were observed in 2012-2013 than in 2013-2014 and 2014-2015 seasons.

Soil-water storage

The term "storage" is used to describe the amount of water temporarily retained in the soil profile (0 – 0.75 m) at any particular time period. Figures 4a, 4b, and 4c; 5a, 5b, and 5c and 6a, 6b and 6c show the trends in weekly SWS for 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons for fields F1, F2 and F3, respectively. Three fields' weekly average SWS values for each treatment for three research years are presented in Table 5. In 2012-2013, 29 weekly SWS values from F2 (west) and F3 (east) field, and 28 from F1 (BREBS) field were obtained. A total of 16 (F1) and 26 (F2 and F3), weekly SWS values were obtained in 2013-2014 cover crop growing season. In 2014-2015, a total of 33 weekly SWS values for all three fields were obtained.

Generally higher SWS values were observed in late fall (September and October) and in early spring (March and April). During the winter periods (November through January), when cover crops were in the dormant or semi-dormant state or killed due to low air temperatures, the SWS in all treatments was less than the rest of the growing season months. Because precipitation during this period was low (36 mm in 2012-2013; 34.5 mm in 2013-2014; and only 13 mm in 2014-2015), this resulted in low recharge and soil-water depletion and reduced storage. For instance, in 2012-2013, average weekly SWS for all treatments in April and September was 268 and 243 mm, respectively, while the average SWS in December was only 231 mm. Similar trends were found for other two seasons. Despite the fact that amount of precipitation in 2014-2015 season was highest (28.5% more than long-term average), the weekly average SWS was lower than in 2013-2014, because the precipitation was more evenly distributed. The lowest SWS (180 mm) across all the treatments and three growing seasons was observed on 13 December 2013 in CC treatment in F2 field while the highest SWS (279 mm) was observed on 18 September 2013 in bare soil treatment in F3 field.

The average weekly soil-water exhibited substantial inter-annual variation, which is attributed to the differences in the evaporation rates due to the differences in precipitation and other climate conditions. For each treatment, average SWS over one growing season was significantly different ($P<0.05$) from other growing seasons. For three-year average SWS, CC treatment had the lowest average weekly SWS (214 mm), which was significantly lower ($P<0.05$) than other treatments (Table 5). Average weekly SWS of bare soil plots was 25 mm and 21 mm higher than the CC plots in 2013-2014 and 2014-2015 seasons, respectively, but was 10 mm lower in 2012-2013 when there was below average precipitation.

2012-2013 Cover crop growing season

The temporal trends of SWS along with comparisons between four treatments for 2012-2013 growing season in all three fields are presented in Figure 4. In field F1, the weekly SWS (0-0.30 m) in CC and SCCC treatment was higher than those in bare soil and SC treatment from November 1, 2012 to March 28, 2013 (Figure 4a). However, at the beginning of the season from

September 27 to mid-October, bare soil treatment had the highest SWS among all treatments. This may be explained by the fact that in the early season, cover crops (mixture of seven cover crops) require more water for their root and shoot establishment, growth and development as well as their transpirative losses, resulting in less SWS in the profile. In spring, (March and April) when cover crops re-grew and were well established, they increased the SWS, which may be attributed to cover crops root growth which enhanced the infiltration and also the coverage of cover crop residue on the ground that resulted in reduced soil evaporation due to surface shading. In field F2, similar trends of SWS in the 0 – 0.75 m soil profile among different treatments were observed (Figure 4b). The SWS difference within the four treatments was very small, with average weekly SWS in CC and SCCC treatments being greater (238 mm) than those in bare soil (228 mm) and SC (233 mm) treatments. Slightly higher SWS was observed in SC (233 mm) treatment than the bare soil surface (228 mm) because of surface coverage in SC treatment. Throughout the cover crop growing season, SWS in the CC treatment was highest (average weekly SWS is 263 mm) among different surface cover treatments and bare soil in the F3 field, except between 18 October and 25 October, 2012 when bare soil treatment had slightly greater SWS (269 mm) than the CC treatment (264 mm) due to a heavy precipitation event of 21.6 mm during that week (Figure 4c). Higher SWS (267 mm) in the bare soil treatment than the SCCC treatment (256 mm) was observed from 20 December, 2012 to 21 February, 2013.

Overall, in 2012-2013 growing season, the average weekly SWS in the CC treatment was significantly higher ($P<0.05$) than the bare soil and SC treatment. This might be due to 2012 being an extremely dry year with an average precipitation over the cover crop growing season 46% less (182 mm) than the long-term average (340 mm). It is possible that due to lower precipitation, soil-water could not reach down to a depth of 0.75 m and the soil-water storage was limited to the topsoil layer, which was likely evaporated readily due to lack of residue cover in SC and bare soil treatments, resulting in reduced SWS. However, the CC and SCCC treatments reduce the soil surface evaporation due to presence of seed maize residue and cover crop vegetation, which reduces the impact of wind speed on evaporation and reducing the solar radiation reaching the soil surface by shading the surface, which in turn results in increased SWS.

2013-2014 Cover crop growing season

In 2013-2014 cover crop growing season, data from 20 December 2013 to 19 March 2014 were missing. As a result, soil water dynamics for different surface covers was quantified only in the period from planting of cover crop until mid-December (when cover crop growth terminated due to extreme cold temperatures) and from late-March until cover crop termination in spring. Also, in extremely cold, windy and icy surface conditions in Nebraska in winters, the growth of winter cover crops is usually not substantial from mid- to late-December to late-March. The SWS in this season showed an opposite trend as compared to 2012-2013 growing season. The average weekly SWS in CC treatment was significantly less ($P<0.05$) than the bare soil and SC treatments (Table 5). This might be because the transpiration losses by cover crops were higher than the evaporative losses from the bare soil surface. Also, the precipitation in this season (mostly in the start and the end of the season, which corresponds to maximum growth period of cover crops) was sufficient to replenish the soil water depleted by evaporation, thus increasing SWS in the bare soil treatments. In this season, cover crop (cereal rye) was planted in the F1 field on 13 October, 2013, ten days after the seed maize was harvested. Due to late planting of cover crop, it could not achieve a full canopy cover (visual observation) in fall season and became dormant in the winter season. Cereal rye re-grew in early spring in 2014 (Figure 5a). Thus, early in the season, the CC plot SWS with very little rye growth was very similar to the SWS in the bare soil treatment while the SCCC plot was covered with seed maize residue and with little rye growth as well, thus conserving more water than other treatments. In F2 and F3 fields, cover crops were planted on 14 August and 11 August, 2013, respectively, before the seed maize was harvested on 10 October 2013 in F2 field and on 9 October 2013 in F3 field. Therefore, there was a period from planting of cover crop until seed maize harvest when both cover crops and seed-maize were present in the SCCC treatment and seed maize in SC treatment, which would contribute to the soil water depletion. In this period, the bare soil treatment exhibited the maximum SWS among all treatments (266 mm). This might be due to the ET_a of seed maize in SCCC (135 mm in F2 field and 164.5 mm in F3 field) and SC treatment (128 mm in F2 and 114 mm in F3) being higher than the evaporation from the bare soil treatment (119 mm), resulting in more SWS in the bare soil treatment. Also, CC treatment showed higher SWS (261 mm in F2 and 262 mm in F3) than SCCC (252 mm in F2 and 260 mm in F3) and SC treatment (239 mm in F2 and 250 mm in F3) in the first two weeks as ET_a losses from seed maize were greater than the sparsely emerged cover crop in CC treatment during those two weeks (Figure 5b and 5c). The SWS during the winter season remained almost unchanged in all treatments because of very small amount of precipitation (35 mm in 2013-2014 season) during this period.

2014-2015 Cover crop growing season

In 2014-2015 growing season, SWS in the CC treatment is significantly less ($P<0.05$) than bare soil and SC treatments (table 5). The highest SWS was observed in the bare soil and SC treatments (237 mm). The SWS trend in this growing season (Figure 6) showed a similar trend as that of 2013-2014 season; however, showed an opposite trend as compared to 2012-2013 growing season. In all three fields, during the period of substantial precipitation from August through mid-October, SWS for each treatment was similar. In this season, mixture of radish, turnip and Ethiopian cabbage was broadcasted into the standing seed maize on 7 August, 10 August and 9 August 2014, in field F1, F2 and F3, respectively; and seed maize was harvested on 26 September, 25 September and 25 September, 2014 for the same fields, respectively. Similar to field F2 and F3 in 2013-2014 growing season, bare soil treatment had the maximum SWS during this period in all three fields in 2014-2015 growing season. In all three fields, from 12 October 2014 until the end of the growing season, CC treatment had the lowest SWS as compared to all other treatments. This might be because the transpiration losses of cover crops were higher than the evaporative losses from the bare soil surface and SC treatment. Precipitation in this season (437 mm) was sufficient to replenish the soil water depleted by evaporation, thus increasing SWS in the bare soil and SC treatments. However, in fields F1 and F2, the SCCC treatment exhibited SWS values that were similar to bare soil and SC treatments and were higher than the CC treatment.

Differences in the SWS between three cover crop growing seasons were highly dependent on the surface and environmental factors such as surface residue covers provided by different cover crop mixtures, and most importantly different climate conditions (precipitation, wind speed, air temperature, and solar radiation) that influence evaporation rates as well as residue cover decay rate. The 2013-2014 and 2014-2015 growing seasons were wetter with higher (262 mm and 437 mm, respectively) precipitation than the 2012-2013 season (183 mm). However, precipitation was more evenly distributed in 2012-2013 season (Figure 3). Based on the results from three cover crop growing seasons, it is evident that the SWS was improved by cover crops in a dry season (2012-2013) when compared to the bare soil treatment whereas the cover crop decreased the SWS in the wetter 2013-2014 and 2014-2015 seasons.

Seasonal actual evapotranspiration (ET_a)

The ET_a values for four surface cover treatments (CC, SCCC, bare soil and SC) on a weekly, monthly and seasonal basis in three growing seasons were evaluated using soil-water balance approach to infer information about the impact of different surface covers on soil-water dynamics and ET_a. Figures 7a, 7b, and 7c; 8a, 8b, 8c and 9a, 9b and 9c shows the monthly ET_a values of all surface cover treatments in three research fields for three growing seasons. The summary of the ET_a values for all treatments and all three fields for three seasons are presented in Table 6. Alfalfa- (ET_r) and grass-reference evapotranspiration (ET_o) outpaced ET_a for all treatments in 2012-2013, 2013-2014 and 2014-2015 seasons. In 2012-2013, cumulative ET_r was 498, 602 and 621 mm for F1, F2 and F3 fields, respectively; whereas cumulative ET_o was 334, 406 and 420 for the same fields, respectively. In 2013-2014, cumulative ET_r was 663, 970 and 995 mm; and cumulative ET_o was 442, 669, and 689 mm for the F1, F2 and F3 fields, respectively. Cumulative ET_r and ET_o for 2014-2015 cover growing season was 633 mm and 453 mm, respectively, for all three fields. The methods and other details of reference ET calculations are presented in Sharma and Irmak (2016) (companion Part II paper, this issue). Temporal trend of ET_a was similar among four treatments with higher ET_a values in the early season (September and October) and towards the end of the season (March and April), which corresponds to the general most extensive growth period of cover crops in the research area as well as high rainfall period (wet period). In 2012-2013, ET_a ranged from 135 mm in CC treatment to 146 mm in bare soil treatment. In 2013-2014, ET_a ranged from 237 mm in SCCC and SC treatments to 267 mm in CC treatment. The ET_a values for all treatments were higher in 2014-2015 season due to higher seasonal rainfall (especially in the early season) that resulted in greater evaporative loses. In 2014-2015, the highest seasonal total ET_a (in the top 0-0.75 m soil profile) was observed as 417 mm in the CC plot and a lowest value (367 mm) was in the SC plot. On a seasonal total basis, CC ET_a was 11 mm less than the bare soil treatment, though not significantly different ($P>0.05$), in the extremely dry 2012-2013 season, whereas it was significantly higher ($P<0.05$) than all other treatments in the wetter 2013-2014 season in all fields. In 2014-2015 growing season CC ET_a was 21 mm higher than bare soil treatment. However, there was not any significant difference between SCCC and bare soil and between SCCC and SC treatment in all three seasons. Also, in 2013-2014 and 2014-2015, SCCC ET_a was significantly less ($P<0.05$) than those in the CC treatment (Table 6). In 2013-2014 and 2014-2015 seasons, there was a significant difference in ET_a between CC and SC treatment.

In 2012-2013, in field F1, on a weekly basis, CC and SCCC ET_a ranged from 0.5 to 18 mm and from 0.2 to 19 mm, respectively, although considerable variations in weekly ET_a were observed. Bare soil and SC treatment ET_a ranged from 1 to 14 mm and from 0.1 to 15 mm, respectively. Similar seasonal total ET_a values were observed for CC and SCCC treatments (125 mm) and the bare soil treatment (129 mm) (Table 6). On average, CC monthly ET_a was 8% higher than bare soil ET_a in October and was 34% lower in winter months (December through February) in field F1. In field F2, temporal trends of ET_a among treatments followed the opposite pattern as that of F1 with bare soil ET_a being higher than CC ET_a in the start of the season and lower in the mid-season period (Figure 7b), although the difference in magnitudes of ET_a among treatments was very small. On average, CC monthly ET_a was 23% lower than the bare soil treatment ET_a in September and October. This difference in two fields might be due to the fact that in field F1, mixture of seven cover crops was grown, which reached their full growth potential in the early season (visual observation) while field F2 had only forage sorghum which died at the first frost (October 6 and October 7, 2012) (visual observation), resulting in higher ET_a for the bare soil treatment. Field F3 showed similar trend as that of F1 with higher monthly ET_a in CC plots than bare soil in October. Seasonal total ET_a value for CC treatment was 15% lower than the bare soil treatment in field F3. In 2013-2014 and 2014-2015 season, trends among the fields were consistent i.e., higher CC ET_a than bare soil in September and October and lower ET_a in CC plots than bare soil in winter season for all three fields. In 2013-2014, CC monthly ET_a was 9%, 42% and 32% higher than those in the bare soil treatment ET_a for F1, F2 and F3, respectively, at the start of the season (September and October). Also, in 2014-2015, CC monthly ET_a was 33%, 18% and 16% higher than the bare soil treatment ET_a for F1, F2 and F3 fields, respectively, during September and October.

Wet and dry period analyses

To better evaluate and understand the behavior of the surface cover treatments in wet period (high rainfall months; i.e., planting to November, and March and April) and dry period (zero to very little rainfall; i.e., December to February), separate analysis was done each year. Table 7 and 8 shows the ET_a values of wet period and dry period, respectively. Our analysis showed that the trend of total seasonal ET_a (table 6) was mostly driven by the wet period of that season and not the dry period. This is due to the fact that the wet period constitutes the most extensive growth period of cover crops in the research area with favorable weather conditions and high rainfall. Most part of the total seasonal ET_a comes from this wet period, because crop was active. In dry period, surface was mostly covered with snow and/or ice and cover crops were dead, so the surface conditions in all treatments in this period were approximately same. However, in CC and SCCC treatments, the surface below this snow cover had a thick layer of cover crop residue, which was not present in bare soil and SC treatment. During the times in dry period when there was no snow cover, this mulch can change the evaporation loses from the surface. Thus, it is equally important to study and understand the behavior of these surface covers in the winter season as well. We found no significant differences (or trends) among the treatments in the dry period. For the wet period, similar trends of ET_a as that of the total seasonal ET_a trends mentioned above were observed. No significant differences among the treatments was observed for 2012-2013 growing season. However, CC and SCCC ET_a was 6 mm and 8 mm lower than the bare soil treatment, respectively. In 2013-2014, significant difference was observed between CC and SC treatment with CC ET_a being 32 mm higher than SC treatment. Similar results were found for 2014-2015 growing season with CC ET_a being significantly higher than bare soil and SC treatment by 43 mm and 53 mm, respectively. SCCC treatment was also 9 mm and 19 mm higher than bare soil and SC treatment, respectively, but the difference was not significant ($P>0.05$).

SUMMARY AND CONCLUSIONS

Evapotranspiration (ET_a), soil-water dynamics and soil-water storage (SWS) for four land cover treatments [CC (cover crop without seed maize); SCCC (seed maize followed by cover crop); bare soil (bare soil without any residue cover); and SC (seed maize without cover crop)] were quantified and compared in three cover crops growing seasons (2012-2013, 2013-2014 and

2014-2015) near Beaver Crossing in eastern Nebraska, USA. Three research years differed substantially in terms of precipitation amount and distribution as well as other climatic variables during the cover crop growing period. The seasonal total (August through April) precipitation was 183 mm (46% below normal) in 2012-2013; 262 mm (21% below normal) in 2013-2014; and 437 mm (28.5% above normal) in 2014-2015. The SWS was significantly improved by cover crops in the dry 2012-2013 season, when compared to the bare soil treatment. However, SWS of bare soil plots were significantly higher than the CC plots during the wetter 2013-2014 and 2014-2015 seasons.

There was substantial inter-seasonal variation in ET_a trends for the same fields between the treatments. No significant differences were observed between the CC and bare soil treatments in drier 2012-2013 season and wetter 2014-2015 season with the CC ET_a 11 mm lower and 21 mm higher than bare soil, respectively. However, CC treatment had significantly higher ($P<0.05$) ET_a than bare soil treatment during 2013-2014 growing season. Planting cover crops without previous cash crop (CC only treatment) resulted in substantially more evaporative losses than planting cover crops after a cash crop (comparing CC vs. SCCC treatments) in wet years. For all three seasons, planting cover crops in seed maize residue (SCCC) reduced the evaporative losses when compared to bare soil. The SCCC and SC only treatments were compared to quantify the potential impact of cover crops on water use. While there were cases when SCCC treatment had lower ET_a values than SC only treatment, when the values from all three fields (F1, F2, and F3) are averaged, results indicated that cover crops did not have positive or negative impact on reducing or increasing evaporative losses when incorporated as a rotational crop in the soil, climate and management conditions presented in this research. For example, in, 2012-2013 season the three field average ET_a values for the SCCC and SC only were essentially the same (142 and 145 mm, respectively); in 2013-2014 season they were exactly the same (237 mm); and in 2014-2015 season they were 381 and 367 mm respectively (SCCC treatment had significantly greater ETa (14 mm than the SC only treatment)], indicating that the cover crops did not have impact in reducing evaporative losses.

Surface cover's influence on SWS for the next season's crop and ET_a rates in a maize-cover crop rotation system can vary substantially depending on the current year's climatic conditions, especially temperature (influence on evaporative losses) and precipitation (influence on soil water availability). In terms of SWS for the next cash crop after cover crop is terminated, our results indicated that cover crops performed poorly under wet conditions (i.e., with a cover crop growing season precipitation of 261 mm and 437 mm), but can be beneficial in terms of reducing evaporative losses in dry conditions that have 183 mm, or less, of precipitation. Since cover crop's ET_a and SWS are highly site-specific and are influenced by factors such a cover crop species, cover crop management practice (planting and termination date) and most importantly, the climatic conditions of the site, it is expected that the ET_a and SWS values reported in this research to vary substantially in other locations.

ACKNOWLEDGEMENT

This project was funded and supported by the United States Department of Agriculture-Natural Resources Conservation Service, National Conservation Innovation Grants Program under the project number: 69-3A75-12-207. As the project PI, Dr. Suat Irmak expresses his appreciation to the USDA-NRCS for collaboration and for providing financial support for this project. Dr. Irmak also expresses his appreciation to David Cast and Doug Cast in Beaver Crossing, NE, for allowing us to conduct these extensive projects in their production fields and for their excellent collaboration. We also thank Kari E. Skaggs for her contributions in field data collection.

REFERENCES

Asbjornsen, H., G. Mora and M. J. Helmers. 2007. Variation in water uptake dynamics among contrasting agricultural and native plant communities in the Midwestern US. *Agric., Ecosys. & Environ.* 121(4): 343-356.

Clark, A., 2007. Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network Handbook Series 9. Beltsville, MD.

Colla, G., J. P. Mitchell, B. A. Joyce, L. M. Huyck, W. W. Wallender, S. R. Temple, T. C. Hsiao and D. D. Poudel. 2000. Soil physical properties and tomato yield and quality in alternative cropping systems. *Agron. J.* 92(5): 924-932.

Ewing, R., M. Wagger and H. Denton. 1991. Tillage and cover crop management effects on soil water and maize yield. *J. Soil Sci. Soc. of Am.* 55(4): 1081-1085.

Irmak, S. 2010. Nebraska Water and Energy Flux Measurement, Modeling, and Research Network (NEBFLUX). *Trans. ASABE* 53(4): 1097-1115.

Irmak, S., J.O. Payero, B. VanDeWalle, J. Rees, G. Zoubek, D.L. Martin, W.L. Kranz, D.E. Eisenhauer and D. Leininger. 2016. Principles and operational characteristics of Watermark granular matrix sensor to measure soil water status and its practical applications for irrigation management in various soil textures. University of Nebraska-Lincoln Extension Circular EC783. 14 pp.

Irmak, S., M.J. Burgert, H.S. Yang, K.G. Cassman, D.T. Walters, W.R. Rathje, J.O. Payero, P. Grassini, M.S. Kuzila, K.J. Brunkhorst, B. VanDeWalle, J.M. Rees, W.L. Kranz, D.E. Eisenhauer, C.A. Shapiro, G.L. Zoubek and G.J. Teichmeier. 2012. Large scale on-farm implementation of soil moisture-based irrigation management strategies for increasing maize water productivity. *Trans. ASABE* 55(3): 881-894.

Irmak, S., J.O. Payero, B. VanDeWalle, J.M. Rees, and G.L. Zoubek. 2014. Principles and operational characteristics of Watermark granular matrix sensor to measure soil water status and its practical applications for irrigation management in various soil textures. University of Nebraska-Lincoln Extension Circular EC783.

Islam, N., W. W. Wallender, J. Mitchell, S. Wicks and R. E. Howitt. 2006. A comprehensive experimental study with mathematical modeling to investigate the affects of cropping practices on water balance variables. *Agric. Water Mgmt.* 82(1): 129-147.

Joyce, B., W. Wallender, J. Mitchell, L. Huyck, S. Temple, P. Brostrom and T. Hsiao. 2002. Infiltration and soil water storage under winter cover cropping in California's Sacramento Valley. *Trans. ASAE* 45(2): 315-326.

Lal, R., E. Regnier, D. Eckert, W. Edwards and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. Cover crops for clean water. Hargrove, W.L. (ed.). *Soil and water cons. Soc.* publication, Ankeny, USA. 1-11.

McVay, K., D. Radcliffe and W. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. *J. Soil Sci. Soc. of Am.* 53(6): 1856-1862.

Mitchell, J., D. Peters and C. Shennan. 1999. Changes in soil water storage in winter fallowed and cover cropped soils. *J. of Sustainable Agric.* 15(2-3): 19-31.

Mitchell, J.P., A. Shrestha and S. Irmak. 2015. Trade-offs between winter cover crop production and soil water depletion in California’s San Joaquin Valley. *J. Soil and Water Conservation* 70(6):430-440. doi:10.2489/jswc.70.6.430.

Moschler, W.W., Shear, G.M., Hallock, D.L., Sears, R.D., Jones, G.D., 1967. Winter cover crops for sod-planted corn: their selection and management. *Agron. J.* 59, 547–551.

Nielsen, D. C. and M. F. Vigil. 2005. Legume green fallow effect on soil water content at wheat planting and wheat yield. *Agron. J.* 97(3): 684-689.

Odhiambo, J.J.O., Bomke, A.A., 2007. Cover crop effects on spring soil water content and the implications for cover crop management in south coastal British Columbia. *Agric. Water Mgmt*. 88, 92–98.

Qi, Z., M. J. Helmers and A. L. Kaleita. 2011. Soil water dynamics under various agricultural land covers on a subsurface drained field in north-central Iowa, USA. Agric. Water Mgmt. 98(4): 665-674.

Sharma, V., and S. Irmak. 2016. Soil-water dynamics and evapotranspiration of cover crop mixtures in seed maize-cover crop rotation fields: Part II. Grass-and alfalfa-reference single (normal) and basal crop coefficients. *J. Irrig. and Drain. Eng., ASCE* (this issue, submitted).

Sharma, V. and Irmak, S. 2012. Mapping spatially interpolated precipitation, reference evapotranspiration, actual crop evapotranspiration, and net irrigation requirements in Nebraska: Part I. Precipitation and reference evapotranspiration. *Trans. ASABE.* 55(3): 907-921.

Tanner, C. and T. Sinclair. 1983. Efficient water use in crop production: research or re-search? In: Limitations to efficient water use in crop production, no. limitations to efficient, Madison, USA: 1-27.

Unger, P. W. and M. F. Vigil. 1998. Cover crop effects on soil water relationships. *J. of Soil and Water Cons.* 53(3): 200-207.

USDA-NRCS. Plant Material Program. A Comprehensive Guide to Cover Crop Species Used in the Northeast United States. http://www.nrcs.usda.gov.

USDA-NRCS. 1985. National Engineering Handbook (NEH) Section 4, Hydrology. Soil Conservation Service, USDA, Washington, D.C.

USDA-NRCS. 1972. Soil Conservation Service National Engineering Handbook. Section 4, Hydrology, USDA, Washington, DC.

Table 1. Some of the soil physical and chemical properties at the BREBS (F1), West (F2) and East (F3) cover crop research fields. F1: BREBS [NEBFLUX (Irmak, 2010) Bowen ratio energy balance system] field, F2: East Field, F3: West Field, D: Soil Depth; FC: Field Capacity; PWP: Permanent Wilting Point; OMC: Organic Matter Content.

Field	Latitude	Longitude	Elev. (m)	D (m)	pH	OMC (%)	FC (% vol)	PWP (% vol)	Sand (%)	Silt (%)	Clay (%)
F1	40^{o} 49' 09.44" N	97^{o} 18' 21.67 " W	478	0-0.15	7.2	2.8	31.2	17.2	21	68	11
				0.15-0.30	6.4	2.2	32.6	19.5	21	68	11
				0.30-0.45	6.7	1.0	33.5	21	23	54	23
				0.45-0.60	6.9	1.2	33.7	21.4	21	40	39
				0.60-0.75	7.3	1.2	33.7	21.4	33	38	29
F2	40^{o} 47' 31.2" N	97^{o} 19' 26.4 " W	448	0-0.15	7.3	2.4	30.6	16.2	21	60	19
				0.15-0.30	5.1	1.6	31.2	17.1	22	58	20
				0.30-0.45	5.7	2.4	31.3	17.3	21	60	19
				0.45-0.60	6.2	1.7	31.3	17.3	21	60	19
				0.60-0.75	6.3	1.6	31.3	17.3	21	58	21
F3	40^{o} 47' 31.2" N	97^{o} 18' 57.6 " W	447.5	0-0.15	6.6	2.4	30.6	16.2	21	60	19
				0.15-0.30	6.4	1.9	31.2	17.1	27	50	23
				0.30-0.45	6.5	1.7	31.3	17.3	23	54	23
				0.45-0.60	6.7	1.4	31.3	17.3	21	60	19
				0.60-0.75	6.7	2.2	31.3	17.3	21	60	19

Table 2. Management information for three research fields in three cover crop growing seasons in 2012-2013, 2013-2014, and 2014-2015.

2012-2013

Management	**F1**	**F2**	**F3**
Seed maize harvesting	21-Aug	28-Aug	28-Aug
CC planting	8-Sep	30-Aug	28-Aug
Method of CC planting	Drill	Drill	Broadcast
CC type	Winter pea, Common vetch, Hairy vetch, Cereal rye, Oats, Nitro-radish, and rapeseed	Forage sorghum	Turnip, Radish, and Ethiopian cabbage
CC termination date	30-Apr	Winter kill	Winter kill

2013-2014

Management	**F1**	**F2**	**F3**
Seed maize harvesting	2-Oct	10-Oct	9-Oct
CC planting	13-Oct	14-Aug	11-Aug
Method of CC planting	Drill	Broadcast	Broadcast
CC type	Cereal rye	Turnip, Radish	Turnip, Radish, millet, and Winter pea
CC termination date	6-May	Winter kill	Winter kill

2014-2015

Management	**F1**	**F2**	**F3**
Seed maize harvesting	26-Sep	25-Sep	25-Sep
CC planting	7-Aug	10-Aug	9-Aug
Method of CC planting	Broadcast	Broadcast	Broadcast
CC type	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage
CC termination date	Winter kill	Winter kill	Winter kill

F1: BREBS station field, F2: East Field, F3: West Field, CC: Cover Crop

Table 3. Cover crop type and suggested potential functions (USDA-NRCS: Plant Material Program).

Cover crop	Type	Winter kill temperature	Function
Turnip	Brassicas	Winter kill below -3.8°C	Improves soil structure, controls erosion, controls diseases
Radish	Brassicas	Winter kill at -6.6 to -3.8°C	Improves soil structure, controls erosion, controls diseases, quick forage for grazing
Ethiopian Cabbage	Brassicas	Winter kill	Improve soil structure and controls diseases
Winter Pea	Legume	Winter kill, but generally winter hardy (-12.2°C)	Reduce pest population, soil erosion and supplies N to soil
Common vetch	Legume	Usually survives winters	Organic matter generation, controls weeds, nitrogen source
Hairy vetch	Legume	Usually survives winters	Nitrogen source, controls weeds, improve soil tilth
Cereal rye	Grass	Usually survives winters	Erosion control, control weeds and quick forage grazing
Oats	Grass	-7.7°C	Erosion and weed control
Rapeseed	Brassicas	Low temp (-12.2°C)	Used as forage, controls diseases, weed suppression, erosion control, enhances soil properties
Forage Sorghum	Grass	Very frost sensitive	Excellent subsoiler and suppresses weeds
Millets	Grass	Winter kill	Controls nematodes

Table 4. Long-term (1996-2014), 2012-2013, 2013-2014 and 2014-2015 average cover crop growing season weather conditions near research sites at Beaver Crossing, NE (T_{max}, T_{min} and T_{avg} are: maximum, minimum, and average air temperature; RH: relative humidity; VPD: vapor pressure deficit; u_2: wind speed at 2 m above the ground; R_s: incoming shortwave radiation; and P: precipitation).

		T_{max}	T_{min}	T_{avg}	RH	VPD	u_2	R_s	P
		°C	°C	°C	%	kPa	m/s	MJ/m^2/day	mm
Long-Term (1996-2015) Average	August	29.68	16.53	23.10	77.37	0.72	2.18	19.48	84.02
	September	26.16	10.65	18.42	68.43	0.81	2.59	15.69	42.89
	October	18.88	3.92	11.41	66.02	0.58	3.21	11.11	51.76
	November	10.75	-3.35	3.71	69.17	0.33	3.45	7.71	29.40
	December	2.93	-9.19	-3.11	76.49	0.15	3.40	6.08	16.65
	January	2.02	-10.42	-4.17	74.72	0.16	3.47	7.22	10.32
	February	3.76	-8.47	-2.35	75.49	0.17	3.61	9.97	16.89
	March	11.29	-2.70	4.31	67.88	0.37	3.91	13.53	24.98
	April	17.73	3.24	10.49	63.83	0.59	4.28	16.68	63.50
2012-2013 Cover crop growing season	August	30.84	14.34	22.59	64.54	1.12	2.15	21.24	12.34
	September	28.06	7.63	17.84	51.38	1.21	2.09	17.41	12.85
	October	17.14	1.93	9.53	60.13	0.58	3.59	10.96	36.25
	November	13.22	-2.90	5.16	64.87	0.38	3.29	8.70	10.85
	December	3.53	-9.45	-2.96	75.63	0.19	3.03	6.00	20.42
	January	0.89	-10.50	-4.81	80.60	0.10	2.90	7.35	4.78
	February	4.30	-7.05	-1.37	76.76	0.16	3.92	9.67	1.01
	March	8.20	-5.05	1.57	71.22	0.26	3.96	14.27	27.86
	April	14.80	0.04	7.42	67.05	0.47	3.90	16.02	56.14
2013-2014 Cover crop growing season	August	30.00	17.53	23.76	78.97	0.69	2.25	19.61	29.97
	September	28.14	13.38	20.76	69.36	0.88	2.80	15.56	37.84
	October	18.02	3.53	10.78	68.24	0.51	3.38	11.88	93.22
	November	10.12	-4.89	2.61	66.27	0.31	3.48	9.29	34.54
	December	1.52	-12.19	-5.33	72.60	0.17	3.19	7.45	0.00
	January	2.50	-12.77	-5.13	62.60	0.22	4.10	8.08	0.00
	February	0.53	-11.76	-5.61	70.15	0.18	3.47	10.84	0.00
	March	10.35	-6.42	1.97	55.98	0.46	4.19	16.21	0.00
	April	18.00	2.99	10.49	59.52	0.67	4.67	18.02	66.29
2014-2015 Cover crop growing season	August	28.81	16.47	22.60	82.51	0.67	1.86	18.44	224.29
	September	24.57	10.87	18.01	79.11	0.75	2.23	15.09	98.41
	October	20.31	4.74	12.68	66.63	0.70	2.60	12.37	31.78
	November	7.62	-7.25	0.33	67.38	0.34	4.03	8.58	1.26
	December	2.58	-5.83	-1.31	84.72	0.11	3.48	4.29	9.08
	January	4.50	-9.97	-2.25	72.33	0.26	3.48	7.79	2.51
	February	1.01	-12.90	-5.76	75.42	0.13	3.50	9.88	3.78
	March	15.42	-3.30	6.38	53.53	0.73	3.21	16.05	9.06
	April	18.44	4.55	11.60	63.44	0.66	3.75	17.01	57.35

Table 5. Average weekly soil-water storage (SWS, mm) for each treatment in the 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons.

Treatment	3 -Year Average	2012-2013	2013-2014	2014-2015
CC	214 a	198 a	229 a	216 a
Bare	226 b	188 b	254 b	237 b
SCCC	222 b	192 ab	242 ab	232 ab
SC	222 b	184 b	246 b	237 b

The numbers within a column followed by same letter are not significantly different at the 10% significance level.

Table 6. Seasonal actual evapotranspiration (ETa) of four surface cover treatments (CC, Bare soil, SCCC and SC) determined using soil-water balance approach for 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons in F1, F2 and F3 fields. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

Year	Field	CC ET_a (mm)	Bare soil ET_a (mm)	SCCC ET_a (mm)	SC ET_a (mm)
2012-2013	F1 (BREBS)	126	129	125	117
	F2 (West)	142	152	141	157
	F3 (East)	137	157	162	161
Average of all fields (2012-2013)		135 a	146 a	142 a	145 a
2013-2014	F1 (BREBS)	171	158	158	167
	F2 (West)	305	280	270	281
	F3 (East)	323	299	284	264
Average of all fields (2013-2014)		267 a	246 b	237 b	237 b
2014-2015	F1 (BREBS)	436	390	369	374
	F2 (West)	399	404	388	352
	F3 (East)	418	393	387	374
Average of all fields (2014-2015)		417 a	396 ab	381 bc	367 c
Average of all fields and three years		273	262	254	250

The numbers followed by the same letter are not significantly different at α = 0.05.

Table 7. Wet period actual evapotranspiration (ETa) of four surface cover treatments (CC, Bare soil, SCCC and SC) determined using soil-water balance approach for 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons in F1, F2 and F3 fields. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

Year	Field	CC	Bare soil	SCCC	SC
2012-2013	F1 (BREBS)	91	83	78	76
	F2 (West)	98	110	98	110
	F3 (East)	98	113	105	111
Average of all fields (2012-2013)		96 a	102 a	94 a	99 a
2013-2014	F1 (BREBS)	137	130	130	134
	F2 (West)	299	251	260	247
	F3 (East)	281	270	270	240
Average of all fields (2013-2014)		239 a	217 ab	220 ab	207 b
2014-2015	F1 (BREBS)	390	336	318	329
	F2 (West)	354	323	333	313
	F3 (East)	361	316	351	304
Average of all fields (2014-2015)		368 a	325 b	334 b	315 b
The numbers followed by the same letter are not significantly different at α = 0.05.					

Table 8. Dry period actual evapotranspiration (ETa) of four surface cover treatments (CC, Bare soil, SCCC and SC) determined using soil-water balance approach for 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons in F1, F2 and F3 fields. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

Year	Field	CC	Bare	SCCC	SC
2012-2013	F1 (BREBS)	35	46	47	40
	F2 (West)	44	42	43	47
	F3 (East)	38	44	56	50
Average of all fields (2012-2013)		39 a	44 a	49 a	46 a
2013-2014	F1 (BREBS)	34	28	28	33
	F2 (West)	7	28	9	34
	F3 (East)	42	29	14	23
Average of all fields (2013-2014)		28 a	28 a	17 a	30 a
2014-2015	F1 (BREBS)	46	54	51	45
	F2 (West)	44	82	55	40
	F3 (East)	57	77	36	71
Average of all fields (2014-2015)		49 a	71 a	47 a	52 a

The numbers followed by the same letter are not significantly different at α = 0.05.

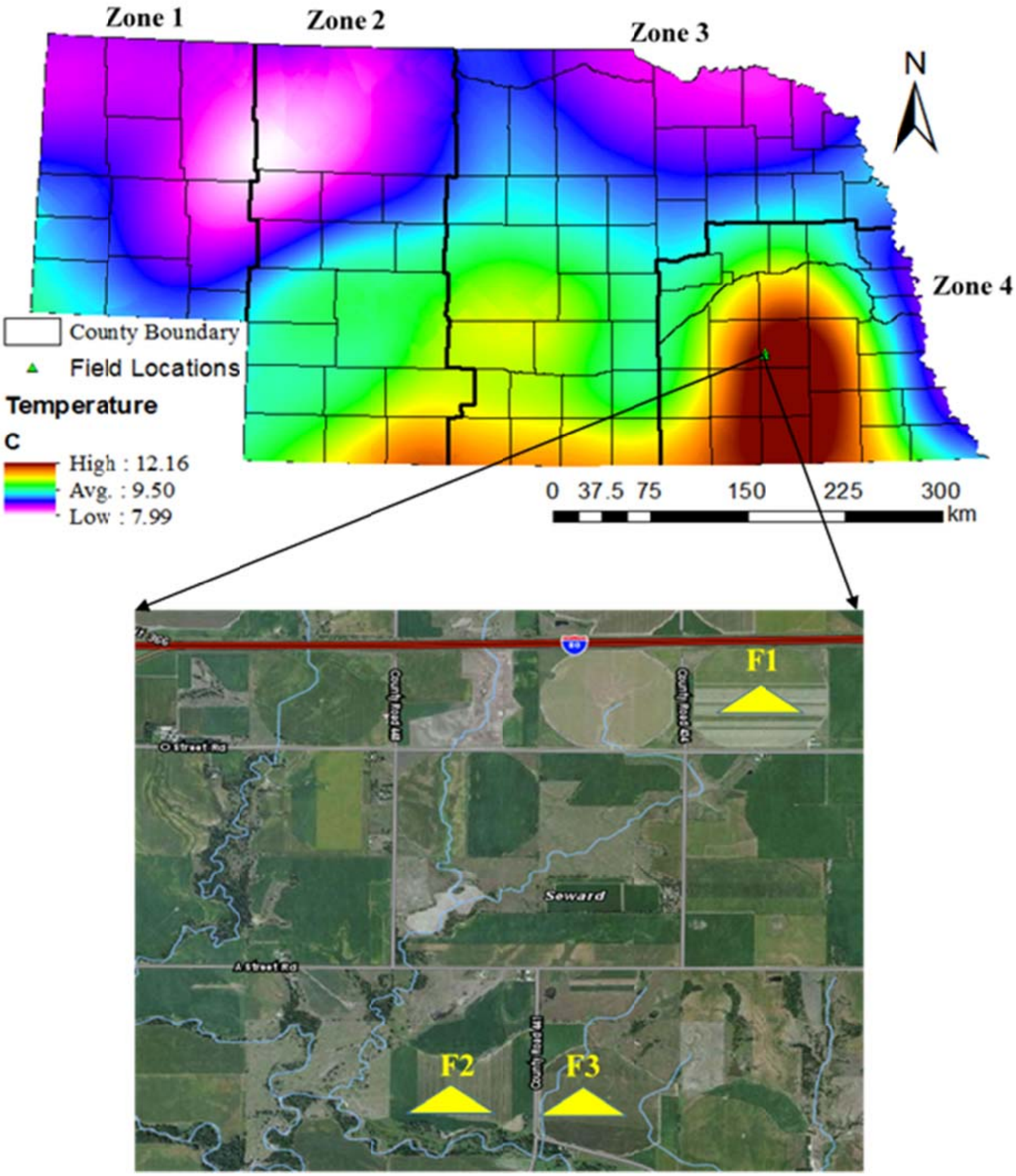


Figure 1. Location of three research fields (lower) with temperature variation along with four vegetative zones (upper) in the state of Nebraska, USA.

Figure 2. Bowen Ratio Energy Balance System (BREBS) at the F1 field and different treatments in seed maize-cover crop rotation fields.

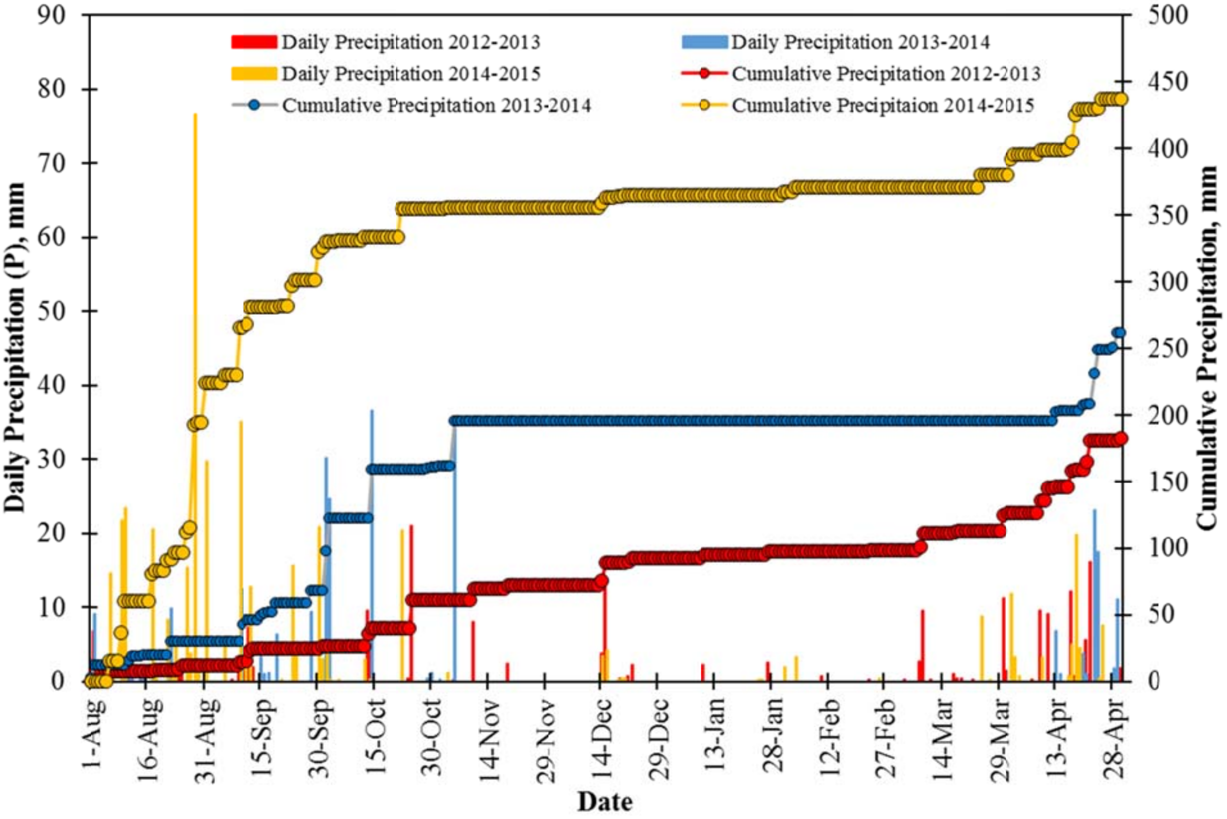
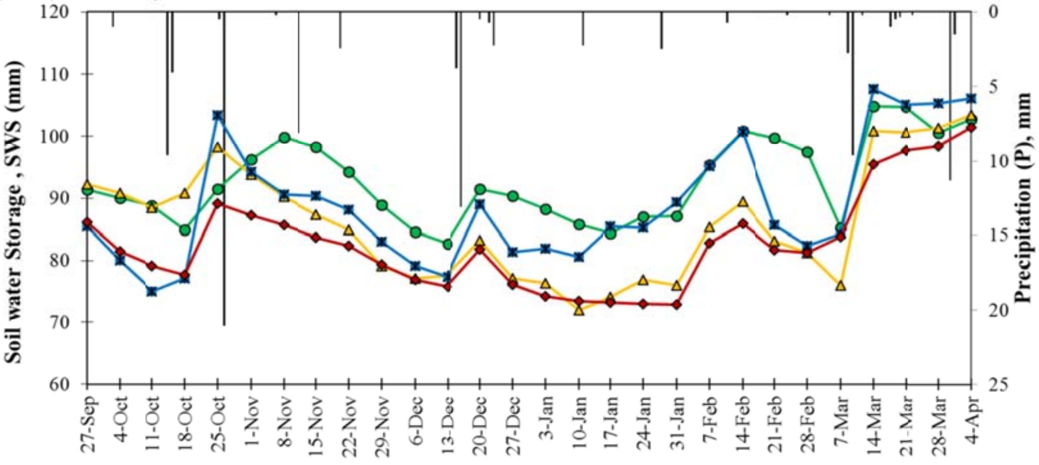
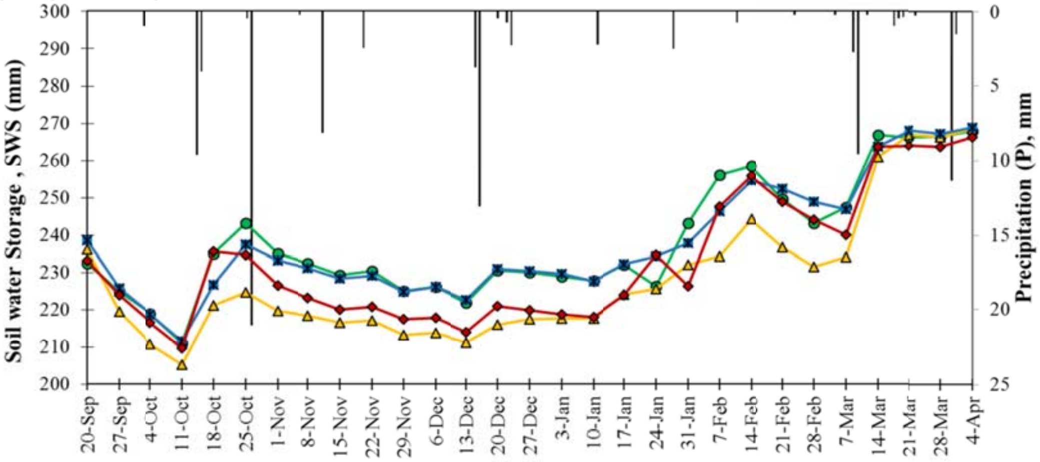


Figure 3. Daily and cumulative precipitation (mm) for 2012-2013, 2013-2014, and 2014-2015 cover crop growing seasons at Beaver Crossing, NE.

(a) F1 (2012-2013)



(b) F2 (2012-2013)



(c) F3 (2012-2013)

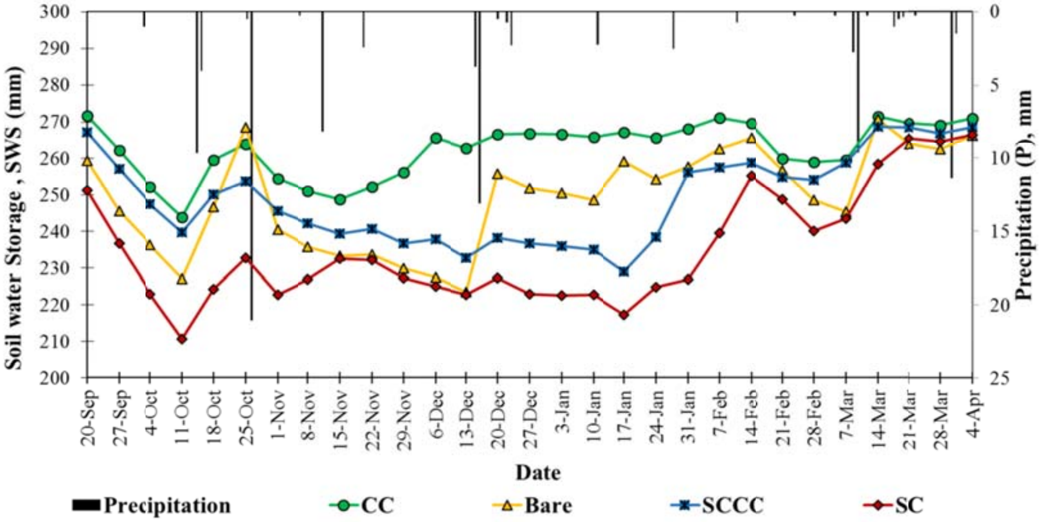


Figure 4. Seasonal soil-water storage (SWS, mm) of four treatments (CC, Bare soil, SCCC and SC) in 2012-2013 growing season in (a) field F1, (b) field F2 and (c) field F3. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

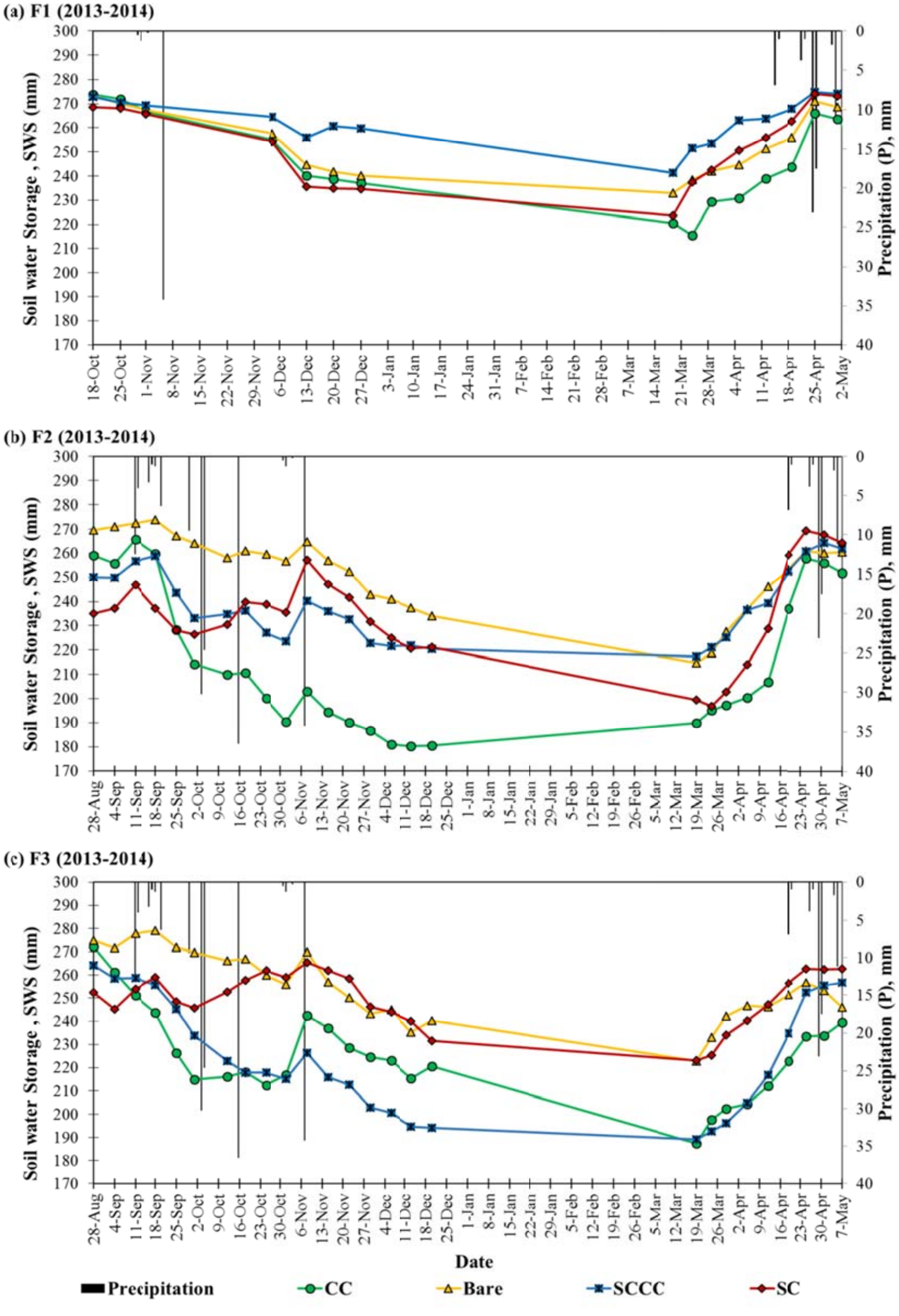
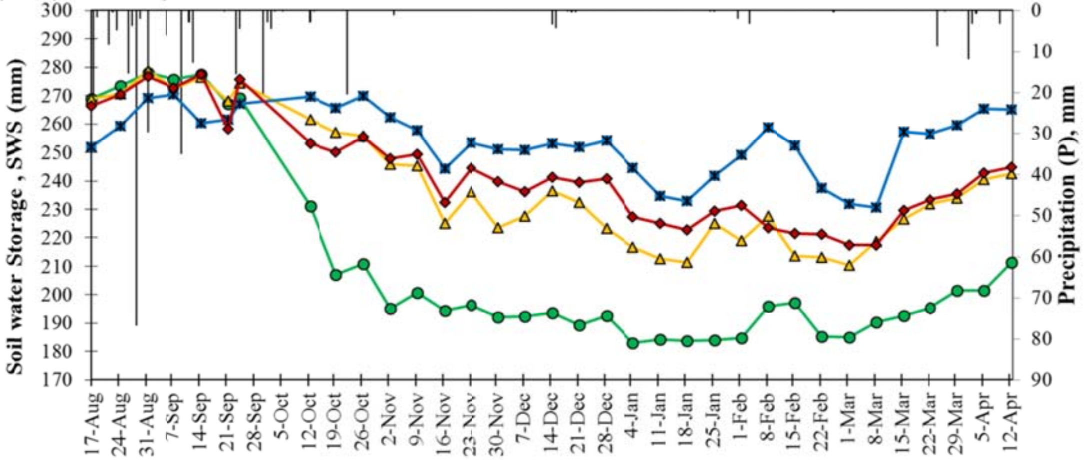
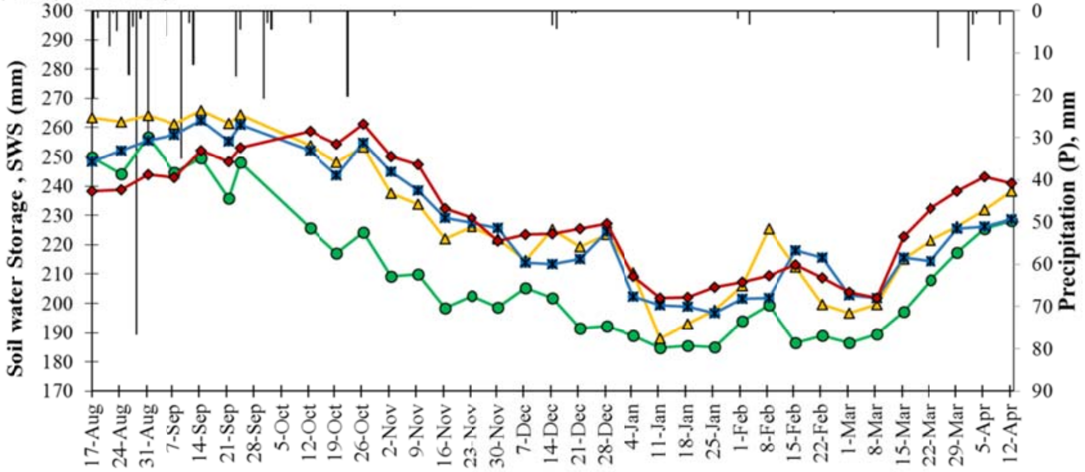


Figure 5. Seasonal soil-water storage (SWS, mm) of four treatments (CC, Bare soil, SCCC and SC) in 2013-2014 growing season in (a) field F1, (b) field F2 and (c) field F3. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

(a) F1 (2014-2015)



(b) F2 (2014-2015)



(c) F3 (2014-2015)

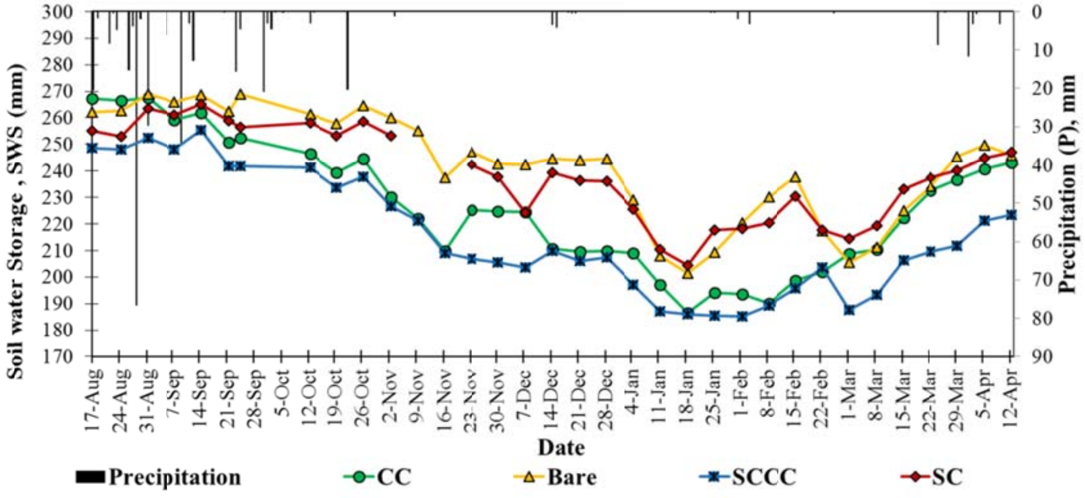


Figure 6. Seasonal soil-water storage (SWS, mm) of four treatments (CC, Bare soil, SCCC and SC) in 2014-2015 growing season in (a) field F1, (b) field F2, and (c) field F3. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

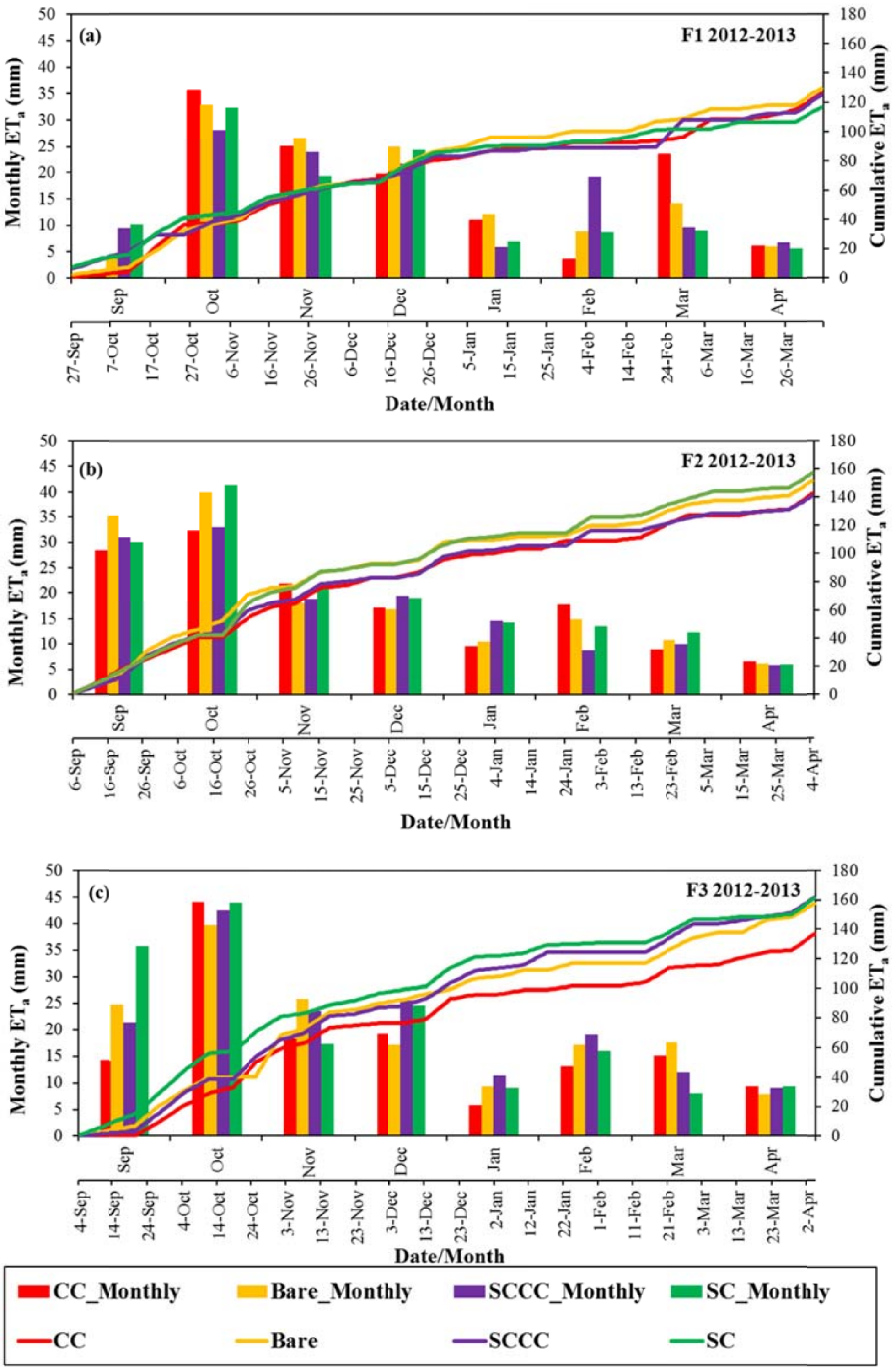


Figure 7. Cumulative soil-water balance-determined actual evapotranspiration (ET$_a$), and monthly total ET$_a$ in (a) F1 field, (b) F2 field and (c) F3 in 2012-2013 cover crop growing season. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

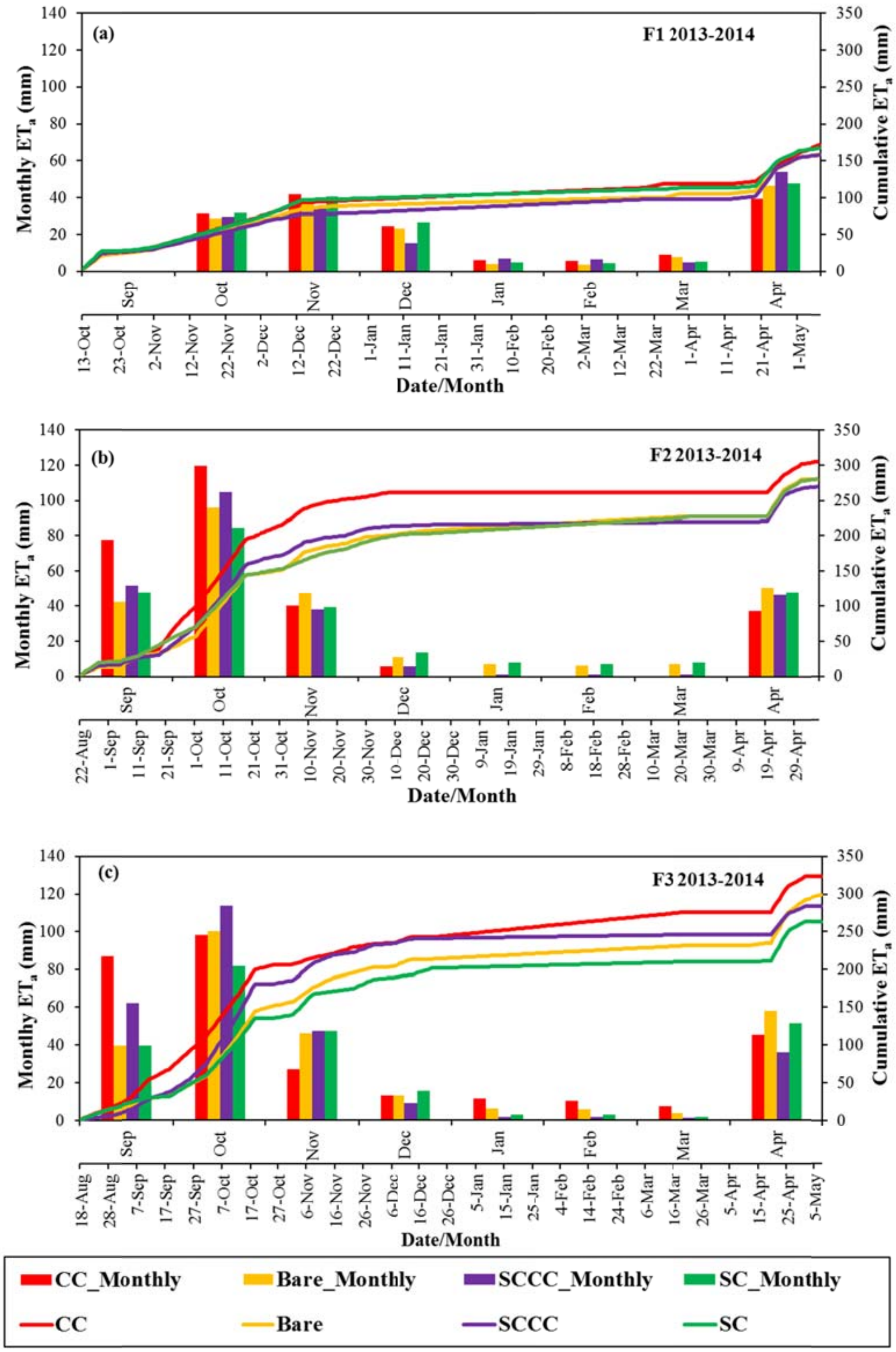


Figure 8. Cumulative soil-water balance-determined actual evapotranspiration (ET_a), and monthly total ET_a in (a) F1 field, (b) F2 field and (c) F3 in 2013-2014 cover crop growing season. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

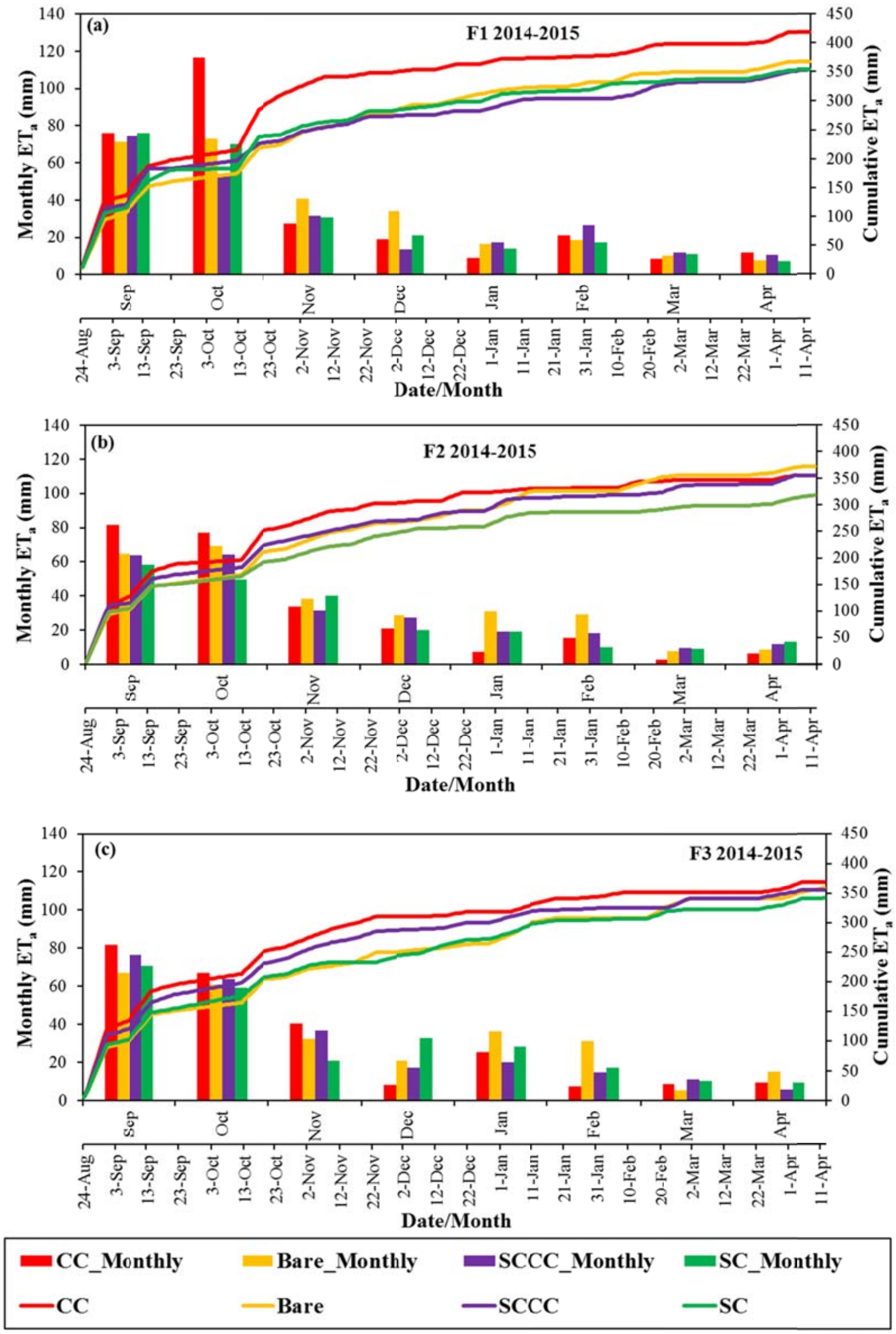


Figure 9. Cumulative soil-water balance-determined actual evapotranspiration (ET$_a$), and monthly total ET$_a$ in (a) F1 field, (b) F2 field and (c) F3 in 2014-2015 cover crop growing season. Treatments are: CC = Cover crop without seed maize; Bare soil = bare soil without any residue cover; SCCC = Seed maize followed by cover crop; and SC = seed maize without cover crop.

SECTION 2: SOIL-WATER DYNAMICS, EVAPOTRANSPIRATION AND CROP COEFFICIENTS OF COVER CROP MIXTURES IN SEED MAIZE-COVER CROP ROTATION FIELDS: GRASS- AND ALFALFA-REFERENCE SINGLE (NORMAL) AND BASAL CROP COEFFICIENTS

INTRODUCTION

Cover crops are incorporated into the cropping system rotation because of their "assumed potential" contributions to soil and water conservation. According to the 2012 Census of Agriculture (USDA, 2012), more than 4 million hectares of cover crops have been planted across the United States on 133,124 farms, which account for 2.6% of total cultivated crop acres. Historically, cover crops in Midwestern United States have been suggested to provide various benefits to the cropping systems, ranging from increasing organic matter content, nutrient and carbon sequestration to soil improvement, erosion control and water management (Dabney et al., 2001). Water management is one of the functions of cover crops that vary substantially with climatic conditions. The cover crop's impact on soil water storage and soil water availability for following cash crop could be positive, neutral, or negative, depending on the climatic, soil and management conditions of the area (Unger and Vigil, 1998). Unger and Vigil (1998) found that cover crops are more suited for use in sub-humid to humid regions because of more reliable precipitation than semi-arid or arid regions where precipitation is generally limited and highly erratic. Studies have presented the impact of cover crops on plant-soil water relationships (Smith et al., 1987; Frye et al., 1988; Wagger et al., 1988). These researchers studied the impact of legume and non-legume crops on soil water relationships and nitrogen cycling, but quantitative analyses of cover crop water consumption during cover crop growing season and crop coefficients that can be used to estimate evaporative losses from cover crop fields in comparison to other land covers have not been studied sufficiently. Among very limited studies, Islam et al. (2006) found higher cover crop evapotranspiration (ET_a) (140 mm from November to March) as compared to bare soil conditions (110 mm from November to March) independent of climatic characteristics and water table depth in central valley of California. Qi et al. (2011) reported 1.9 mm d^{-1} ET_a from cover crop plots in maize and soybean fields and 0.6 mm d^{-1} from the plots with conventional maize and soybean without cover crops in north-central Iowa due to increase in water infiltration and reduced surface run-off in cover crop plots. Bodner et al. (2007) compared the total ET_a losses from phacelia, vetch, rye, and mustard cover crops with fallow ET_a in 2004 and 2005 and observed higher ET_a values in cover crop plots than fallow in dry year and lower in wet year in Pannonic region of eastern Austria. They observed higher water use between 3.5 and 14.8 mm d^{-1} due to ET_a from cover crop plots as compared to fallow in the dry year in 2005, whereas highest ET_a was obtained in the fallow treatment in 2004.

Only a few studies have been reported on ET_a rates for cover crop mixtures in the United States and globally and virtually no data or information existed in Midwestern states, including Nebraska. Furthermore, crop coefficients for cover crops do not exist in Midwestern and extremely rare globally. Crop coefficients (K_c) can be used to assess crop water use of a particular crop from the measurements or estimates of reference evapotranspiration (ET_{ref}). They are defined as the empirical ratios between the ET_a and estimated or measured grass-reference (ET_o) or alfalfa-reference (ET_r) crop evapotranspiration. Cover crop ET_a and crop coefficients are highly dependent on climatic conditions and management practices. Since this current research site in southeast Nebraska is in the transitional zone between humid continental climate and semi-arid climate, it is susceptible to both excess and shortage of rainfall. Thus, it is critical to evaluate cover crop ET_a and develop crop coefficient under local climate conditions, soil properties and management practice to have more robust local data and information for various purposes. Moreover, in the Midwestern states, cover crops are grown in winter season (dormant season for cash crop) in which enhanced evaporation from the surface has a great impact on surface runoff, groundwater recharge and soil moisture storage for the next cash crop growing season (Hay and Irmak, 2009). Therefore, prediction of evaporative loses from the surface (crop residue or cover crops) in non-growing season would allow water managers to account for water use in agroecosystems over the entire year.

While, in most cases, the normal (classic) crop coefficients are reported and most commonly used in practice, basal crop coefficients (K_{cb}) represent the condition when soil evaporation is minimal, but the availability of soil water within the root zone does not limit plant growth and transpiration. They can be adjusted to depict higher proportion of evaporation from the wet soil following irrigation or precipitation events (Wright 1982). While K_c curves have been developed for variety of agronomic crops, fruit trees, vegetables, and other cropping systems, and has been practiced by irrigation community to approximate the complex process of ET_a since 1960s, literature review reveals that K_c curves for cover crop, especially for cover crop mixtures, are rare. In Nebraska and other Midwestern states, such K_c curves do not exist to estimate water use rates of either individual or mixed cover crop systems. Because of the need to estimate the water use of cover crops to evaluate water availability vs. demand for the next cash crop, through this research extensive field measurements have been conducted in southeast Nebraska to determine the cover crop evapotranspiration (ET_a) and develop associated crop coefficient curves. The specific goal of this research is to derive grass- and alfalfa-reference single (K_{co} and K_{cr}) and basal crop coefficients (K_{cbo} and K_{cbr}) that can be used in quantifying cover crop water use during the cover crop growing season.

MATERIALS AND METHODS

Site description and crop and soil management practices

Field research campaigns were conducted in 2012- 2013, 2013-2014, and 2014-2015 cover crop growing season in three large production fields (F1-BREBS field, F2-West Field and F3- East field) that all located within very close proximity (3 km) in Seward County near Beaver Crossing, Nebraska, USA (Figure 1). One of these three fields (F1) with approximately 48.6 ha of area equipped with an advanced Bowen Ratio Energy Balance System (BREBS), which is a part of the Nebraska Water and Energy Flux Measurement, Modeling, and Research Network (NEBFLUX) (Irmak, 2010). The other two study fields (F2 and F3) are located within about 3 km south of F1. The BREBS measure surface energy fluxes, including latent heat flux (actual evapotranspiration; ET_a), sensible heat flux (H), soil heat flux (G), incoming and outgoing shortwave and longwave radiation (R_{ns}, R_{nl}), net radiation (R_n), surface albedo, air temperature (T_{air}), relative humidity (RH), barometric pressure (P), precipitation, wind speed (u_3; measured at 3 m height) and direction, and soil water content (every 0.30 m down to 1.8 m) throughout the years on an hourly basis for vegetation surfaces. The description of the instruments used in BREBS and data quality is described in detail in Irmak, 2010.

The predominant soil at the F1 field is Hasting silt loam, which is a well-drained loamy upland soil with available water capacity of 126 mm m^{-1} in the top 0.90 m (average field capacity: 32% vol and permanent wilting point: 20% vol). The other two fields have similar silt loam soils, including Butler and Muir silt loam with a very similar available water holding capacity of 142 mm $m^{-}1$. The long term (1996 – 2015) cover crop growing season (August-April) average precipitation in the area is 340 mm with significant variability during the cover crop growing season. The cumulative growing season (August-April) precipitation varied from 183 mm in 2012-2013 growing season to 262 mm in 2013-2014 and 498 mm in 2014-2015.

To determine the impact(s) of cover crop mixes on ET_a and develop grass- and alfalfa-reference K_c, four land cover treatments were imposed in each individual cover crop growing season in all three fields in a center pivot-irrigated seed maize/cover crop rotation cropping system (cover crop was not irrigated in any of the cover crop growing seasons): (i) cover crop without seed maize (CC), (ii) cover crop planted in seed-maize (SCCC), (iii) seed-maize without cover crop (SC), and (iv) bare soil (Bare soil). Out of the four treatments, only SC and SCCC plots had seed-maize residue after the harvest of seed-maize. Four plots (approximately 6.5 m x 4.5 m) (one for each treatment) were maintained in all the three fields for all three cover crop growing seasons. The cover crop without seed-maize treatment (CC) in this study represented the condition when there is only cover crop in the field without any seed-maize residue from the previous crop. During the seed-maize growing season, no seed-maize was grown in these plots in order to maintain the plots without seed-maize residue in cover crops growing season. The SCCC treatment represented the condition where cover crop was grown in the seed-maize and the residue from seed-maize remains in the field after it was harvested. This treatment was included in order to represent the actual producer’s practices in the field. The SC treatment corresponds to condition where there is no cover crop, but only seed-maize residue existed in the field. Bare soil treatment refers to the bare soil plot in the field without any residue or crop cultivation. Since the research was conducted on large scale farmers’ production fields, which are dedicated to commercial seed maize production, all of the farm and crop management decisions were taken by the farm manager to maximize the profit, following all the local management guidelines and management practices inputs from the project director (Dr. S. Irmak). All research plots in three fields were maintained throughout the research period and a good canopy cover similar to the rest of the field was ensured in the plots with crops. It was also made sure that during the seed maize planting, the CC and bare soil plots did not get any seed maize seeds. In addition, bare soil and SC plots were covered with tarp whenever cover crop seeds were broadcasted so that these plots do not get any cover crop seeds. Weeds and other unwanted plants like volunteer corn were manually removed on regular basis from all plots.

Complete details about the research sites, management practices, planting dates, termination dates and types of cover crops planted in fields F1, F2, and F3 in 2012-2013, 2013-2014 and 2014-2015 seasons are provided in Sharma et al. (2016; Part I, companion paper, this issue), but specific procedures relevant to this research for Part II will be described in the next sections.

Reference ET (ET_{ref})

Alfalfa- and grass-reference evapotranspiration (ET_o and ET_r, respectively) were calculated using the standardized Penman-Monteith equation (ASCE-EWRI, 2005), which is a derivation of Penman-Monteith (1965) equation with a fixed canopy resistance (Irmak et al., 2012) on a daily time steps (equation 1). The BREBS-measured climate variables were used as input data to calculate ET_{ref}. Measured climatic data included T_{air}, RH, u_3, R_s, and precipitation. The standardized ET_{ref} equation is:

$$ET_{ref} = \frac{0.408\,\Delta\,(R_n - G) + \gamma\left(\frac{C_n}{T + 273}\right) u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \tag{1}$$

where, reference ET_{ref} is, grass-reference ET (ET_o) or alfalfa-reference ET (ET_r) (mm d^{-1}); Δ is slope of saturation vapor pressure vs. air temperature curve (kPa $^oC^{-1}$); R_n is net radiation at the surface (MJ m^{-2} d^{-1}); G is soil heat flux density (MJ m^{-2} d^{-1}) and assumed to be zero for daily time step; T is mean daily air temperature (^{o}C); u_2 is mean daily wind speed at 2 m height (m s^{-1}); e_s is saturation vapor pressure (kPa); e_a is actual vapor pressure (kPa); e_a-e_s is vapor pressure deficit (kPa); γ is psychrometric constant (kPa $^oC^{-1}$); C_n is numerator constant that changes with reference type and calculation time step; C_d is denominator constant that changes with reference type and calculation time step. Both C_n and C_d are functions of time step and aerodynamic roughness of the surface (i.e., reference type). The value of C_d depends on bulk surface resistance and daytime/nighttime. The values of C_d and C_n values on a daily time step for grass and alfalfa-reference surfaces were taken as 0.34 and 0.38; and 900 and 1600, respectively. (ASCE-EWRI, 2005).

Daily values of Δ, R_n, e_a and e_s were calculated (for albedo=0.23) using equations given in ASCE-EWRI (2005) and FAO-56 (1998). The e_a and e_s were calculated using BREBS measured RH_{max}, RH_{min}, T_{max} and T_{min} values. The R_n was calculated as the difference between the incoming net shortwave radiation R_{ns} and the net outgoing longwave R_{nl} radiation. The R_{ns} was estimated from net solar radiation R_s measured by the BREBS station. The Stefan-Boltzman constant (σ) to calculate R_{nl} was taken as 4.901×10^{-9} MJ K^{-4} m^{-2} d^{-1} (Irmak et al., 2003; Payero and Irmak, 2013). The wind speed was measured at 3 m height by the BREBS station installed in the field, which was then converted to 2 m height wind speed values using the equation given in FAO 56 to use it in the standardized Penman-Monteith equation (equation 1). The latent heat of vaporization (λ) was taken as 2.45 MJ kg^{-1}. The constant 0.408 in the equation 1 represents (1/ λ). The psychrometric constant (γ) was calculated as a function of atmospheric pressure (P), latent heat of vaporization (λ), specific heat (c_p) and ratio of molecular weight of water vapor to dry air (ε =0.622). The value of c_p was taken as 1.013×10^{-3} MJ kg^{-1} $^oC^{-1}$ for the calculations (Irmak et al., 2003). Atmospheric pressure (P) was calculated as function of elevation above sea level (z) following equation given in FAO-56 (FAO 56, 1998).

Quantification of actual evapotranspiration (ET_a)

The soil-water matric potential measurements were taken at depths of 0.15 m to 0.75 m with 0.15 m increments using Watermark Granular Matrix sensors (WGMS, Irrometer, Co., Riverside, CA). The sensors were installed in all three research fields at two locations in each treatment (plot). The soil matric potential on hourly basis measured with Watermark sensors was then converted to volumetric soil water content using a pre-determined soil water retention curves for the study site using the equation developed by Irmak (2006; unpublished research data) [$\Theta v = (0.0003\psi^2) - (0.1302\ \psi) + 37.635$ ($R^2 = 0.98$); where, θ_v is the volumetric soil water content (m^3 m^{-3}) and ψ is the soil matric potential (kPa)] at Clay Center NE, which has the same soil series. The soil water content data was then multiplied by the representative depth intervals to compute the soil water storage (SWS) for each depth and then summed up to obtain SWS for 0-0.75 m soil profile. The sensors were connected to a Watermark Monitor datalogger (Irrometer Co., Riverside, CA) and hourly readings were recorded throughout three cover crop growing seasons (2012-2013, 2013-2014 and 2014-2015). From hourly soil-water moisture data (two values from each plot), an hour of the day was selected to represent the soil moisture present in the profile in that particular day. Then, the cover crop growing season was divided into weekly or 10-day periods such that all the days with precipitation events present in these periods. There was no precipitation at the start of the period and this period ends 1-2 days after the precipitation.

This was done because on the day of precipitation, the soil-water content in the profile is very dynamic and it is impossible to calculate the storage on an hourly or daily basis as water needs time to move down to the root zone and be stored in this zone. After this, change in soil-water storage (ΔSWS) was calculated by subtracting SWS at the beginning of the period from SWS value at the end of the 7 to 10 days' period. These ΔSWS calculations were then used to calculate the ET_a using the soil-water balance approach for each treatment for each field, including the bare soil plots. The seasonal SWS was calculated by averaging all the SWS values over the cover crop growing season for each year. ET_a was then determined using soil-water balance approach as discussed in Sharma et al. (2016; companion Part I paper, this issue) and in Irmak (2015a and b) for all periods between two selected soil water measurement dates. The ET_a rate was calculated for each measurement period as the summation of measured change in soil water storage plus depth of precipitation in that period, divided by number of days in the period, following the procedures by Hunsaker (1999). The precipitation data were obtained from the BREBS station. Run-off was calculated using United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS, formerly called as Soil Conservation Service) curve number method (USDA-NRCS, 1985) as outlined in Sharma et al. (2016; companion Part I; this issue) and Irmak (2015a and b). Deep percolation was assumed to be negligible.

Single (normal) and basal crop coefficients

The ET_a values calculated from soil-water balance approach over the three cover crop growing seasons in all the three fields were used to calculate grass-reference and alfalfa-reference single or normal (K_{co} and K_{cr}) and basal crop coefficients (K_{cbo} and K_{cbr}). Since there was no live vegetation in bare soil and SC treatments, K_{cb} was not estimated for these treatments because of absence of transpiration component. Also, the K_c values of bare soil treatment represent "surface coefficients" (rather than crop coefficients) since there is no vegetation in that treatment. The K_{cbo} and K_{cbr} estimated from ET_a values were determined only from soil water depletion periods i.e., the period between the two soil-water measurement dates when there was no irrigation or precipitation occurred. For all treatments, mean ETa rate for each depletion period was calculated. The corresponding mean ETref rate for each soil water depletion period was also calculated for each treatment.

The crop coefficients as described in FAO-56 (FAO, 1998) have two forms: single K_c form (Doorenbos and Pruitt, 1977) and the dual K_{cb} and K_e form as:

$$K_c = \frac{ET_a}{ET_{ref}} \tag{2}$$

$$K_c = (K_{cb}K_s) + K_e \tag{3}$$

where, ET_a and ET_{ref} are in mm d^{-1}, K_c is the single crop coefficient, K_{cb} is the basal crop coefficient, K_s is the water stress reduction coefficient, and K_e is the soil water evaporation coefficient. The basal crop coefficient K_{cb} represents the ratio of ET_a to ET_{ref} under the conditions when, first, the soil surface layer is dry (i.e., when $K_e = 0$) and, second, when the soil-water within the root zone is sufficient to sustain the full plant transpiration (i.e., when $K_s =1$). The value of K_s coefficient is less than 1.0 when the available soil-water in the root-zone becomes low enough to limit ET_a. Due to wetting of the soil surface by precipitation (there was no irrigation application in any of the fields in any of the cover crop growing season), additional evaporation occurs, which is represented by soil evaporation coefficient, K_e.

In this research, first the K_c values were calculated for all treatments (CC, bare soil, SCCC, and SC) as cumulative ET_a values determined from soil-water balance method for each soil water measurement period divided by the cumulative ET_{ref} (ET_o and ET_r) over that period (equation 2). The K_{cb} values were calculated for CC and SCCC treatments for the periods when no irrigation or precipitation occurred as ET_a rates estimated from soil-water balance divided by ET_{ref} (Figure 2). K_s value was taken as 1 because the available soil-water during all soil-water measurement periods in each soil layer (0-0.75 m) was adequate to sustain full ET_a as soil water in all treatments and all years was above 50% of the available water (Figure 3-6). Figure 3-5 shows the volumetric water content of each layer (0.15m, 0.30m, 0.45 m, 0.60 m and 0.75 m) over the three growing seasons in all the treatments and fields. For almost all the fields and treatments, the volumetric water content of each layer is above 50% total available water line except at few points when it is slightly below it. Figure 6 shows the available soil water in total 0.75 m profile for CC and SCCC treatments. For all the fields, total soil water in CC and SCCC treatment was above 50% of the available water. A K_{cb} value was determined for the soil-water depletion period. In equation 3, Kc is known, but ($K_{cb}K_s$) and K_e are not. Since K_s was taken as 1 for all treatments (Figure 3-6), K_{cb} was then equal to K_c when K_e was zero. However, because evaporation from a wet soil surface can occur several days following precipitation and irrigation event, a portion of soil water depletion following these events may have been due to soil evaporation. Thus, the estimated K_{cb} values were calculated for each soil-water depletion period as ET_a divided by ET_{ref} for the period (Figure 2). Since, K_{cb} was calculated for the soil-water depletion period of two or more days, they represent an average K_{cb} value, which was assumed constant for the measurement period and therefore, shown as horizontal lines in Figure 2. Daily K_{cb} values for the period when there was precipitation and 3-4 days immediately following these events (i.e., when there was significant evaporation) were estimated by linear interpolation based on the values immediately before and after the period as shown in Figure 2, following Hunsaker (1999). Since for the calculation of K_e, daily data of plant height and defined or observed stages of growth for the crop are required, K_e values for cover crops were not estimated in this research as plant height measurements were not conducted due to the difficulties in conducting such measurements in the field conditions during extreme winter conditions in Nebraska. The grass- and alfalfa-reference single crop coefficients (K_{co} and K_{cr}) were plotted against CGDD and time from first soil-water measurement date until the last measurement date for CC, bare soil, SCCC, and SC treatments in all fields for three growing seasons. The grass- and alfalfa-reference basal crop coefficient (K_{cbo}, K_{cbr}) data developed for CC and SCCC treatments of F1, F2 and F3 fields were used to derive thermal unit (growing degree days)-based crop coefficient (K_{cb}) curves. These data were plotted against CGDD after planting and date and fifth order polynomial equations were fitted to the data. Since the K_{cb} values derived in this study were for the period longer than one day, each K_{cb} value was referenced to the middle of the respective time period (Steele et al. 1996; Hunsaker 1999), which means one K_{cb} value was assigned to the number of CGDD since planting that appeared on the middle day of that period for CGDD base. The daily growing degree days (GDD) equation used in this study is:

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base} \tag{4}$$

where, T_{max}, T_{min} and T_{base} are in ^{o}C. T_{base} is that temperature below which the physiological growth of plants stops (McMaster and Wilhelm, 1997). In practice, T_{base} varies with plant species (Jones 1992; Yang et al. 1995; Irmak et al., 2013). In this research, we used a base temperature of 0^{o}C for the cover crop mixtures that were used in all three fields and no upper temperature limit was imposed in equation (4).

RESULTS AND DISCUSSION

Seasonal distribution of ET_o, ET_r and ET_a

The seasonal distribution of ET_o and ET_r for 2012-2013, 2013-2014 and 2014-2015 cover crop growing season is presented in Figures 7a, 7b and 7c, respectively. The ET_o and ET_r values were generally higher during the early and towards the end of the season and lower during the mid-season, i.e., in winters. Although, the maximum and minimum values of ET_r and ET_o were different during the three growing seasons, the seasonal average values were similar. In 2012-2013 growing season (August 1 to April 30), ET_r ranged from 0.11 mm/day to 12.8 mm/day, with a seasonal average of 3.5 mm/day. The maximum and minimum ET_r values of 12.8 mm/day and 0.11 mm/day occurred on September 11 and December 20, respectively. ET_o ranged from 0.1 mm/day to 8.3 mm/day with seasonal average of 2.5 mm/day. The maximum and minimum values of ET_o occurred on the same days as ET_r. In 2013-2014 cover crop growing season (August 1 to April 30), ET_r ranged from 0.16 mm/day (April 3) to 11 mm/day (April 9) and ET_o ranged from 0.2 mm/day (December 8) to 7.2 mm/day (April 9). The seasonal average ET_r and ET_o values were 3.7 mm/day and 2.6 mm/day, respectively. In 2014-2015 growing season, ET_r ranged from 0.06 mm/day (December 21) to 13.5 mm/day (March 16) and ET_o ranged from 0.12 mm/day (December 21) to 8.5 mm/day (March) with seasonal average ET_r and ET_o values of 3.03 mm/day and 2.24 mm/day, respectively.

ET_r and ET_o outpaced measured ET_a for all treatments in 2012-2013, 2013-2014 and 2014-2015 seasons. In 2012-2013, cumulative ET_r was 498, 602 and 621 mm for F1, F2 and F3 fields, respectively, whereas cumulative ET_o was 334, 406 and 420 for the same fields, respectively. In 2013-2014, cumulative ET_r was 663, 970 and 995 mm and cumulative ET_o was 442, 669, and 689 mm for the F1, F2 and F3 fields, respectively. Cumulative ET_r and ET_o for 2014-2015 cover growing season was 633 mm and 453 mm, respectively, for all three fields. The variability in the magnitudes of ET_r and ET_o between the research fields in the same season (2012-2013 and 2013-2014) was because of different planting and termination dates (Sharma et al., 2016; companion Part I paper, this issue). The lower ET_{ref} values were observed in the F1 field than in the F2 and F3 fields in 2012-2013 and 2013-2014 growing season; however, F2 and F3 fields had approximately same cumulative values. This is because of shorter growing season length in the F1 field than in F2 and F3 fields due to late planting of the cover crops in the F1 field in both growing seasons. The F2 and F3 fields on the other hand were planted approximately on the same dates, thus have nearly equal cumulative values. Also, in 2014-2015 season, all three fields were planted on the same date, thus have the same ET_r and ET_o values. As discussed in Sharma et al. (2016; companion Part I paper, this issue), seasonal total ET_a of cover crops (SCCC) was significantly lower ($P<0.05$) than bare soil treatment in 2012-2013, but they were significantly greater ($P<0.05$) in 2014-2015 growing season.

The seasonal total ET_a values for all treatments in the F1, F2 and F3 fields for all three growing seasons are presented in Sharma et al. (2016; companion Part I paper, this issue). ET_a of CC and SCCC treatment was approximately 24% of ET_r and 36% of ET_o in all fields in 2012-2013. In 2013-2014 it was 29% and 40% of ET_r and ET_o, respectively. However, in 2014-2015 season, the CC ET_a was increased to 66% of ET_r and 92% of $ET_{o.}$ ET_a of SCCC treatment was approximately 60% of ET_r and 84% of ET_o in all the three fields. On the other hand, ET_a of bare soil and SC treatment was approximately 25% of ET_r and 38% of ET_o in 2012-2013 and 30% and 40% of ET_r and $ET_{o,}$ respectively, in 2013-2014 growing season. These results were in close agreement with the results presented by Hay and Irmak (2009) for maize fields during non-growing (dormant) seasons in a location (Clay Center, NE) that is about 70 km west of the current research sites. In 2014-2015, the bare soil ET_a increased to 63% of ET_r and 87% of ET_o, whereas SC ET_a was 58% of ET_r and 81% of ET_o Cumulative precipitation was always lower than the actual ET_a of all treatments in all three seasons.

Single (normal) crop coefficients

The K_{co} and K_{cr} curves for the cover crop mixtures for CC, bare soil, SCCC and SC treatments for the F1, F2 and F3 fields in 2012-2013, 2013-2014 and 2014-2015 growing seasons are presented in Figures 8-16. These curves are some of the first K_{co} and K_{cr} values reported in literature for cover crops. Tables 1-3 show monthly average K_{co} and K_{cr} values for all treatments for the F1, F2 and F3 fields for three research years, respectively. The K_c curves exhibited considerable variations with time in three seasons. Also, K_{co} and K_{cr} values exhibited inter-annual variability for the same months and treatments between the years. Figures 8-10 represents the K_{co} and K_{cr} curves for F1, F2 and F3, respectively, in 2012-2013. In 2012-2013 growing season, the K_{co} values ranged from 0.0 to 1.8, 0.0 to 2.3, 0.0 to 1.9, and 0.0 to 1.8 in the CC, bare soil, SCCC and SC treatment, respectively. The K_{cr} values were smaller than K_{co} (due to

$ET_r>ET_o$) and ranged from 0.0 to 1.2, 0.0 to 1.6, 0.0 to 1.1 and 0.0 to 1.4 in the CC, bare soil, SCCC and SC treatments, respectively. In this season, from emergence until mid-December, average K_{co} value in CC and SCCC treatment was 0.37 and 0.41, respectively. The K_{cr} values for the same period were 0.25 and 0.27, respectively. During the winter months, from mid-December to the end of February, average K_{co} for CC and SCCC treatment was 0.5 and 0.4, respectively, and average K_{cr} values were 0.34 and 0.31. These values are comparable to the values reported by Hay and Irmak (2009) for surface coefficients in winter season. The 2013-2014 and 2014-2015 growing seasons also showed very similar trends as 2012-2013. Figures 11-13 and 14-16 shows the K_{co} and K_{cr} curves for 2013-2014 and 2014-2015 seasons, respectively. In 2013-2014, the K_{co} values ranged from 0.0 to 2.3, 0.0 to 2.2, 0.0 to 2.3 and 0.0 to 2.2 in CC, bare soil, SCCC and SC treatments, respectively. For the same treatments the K_{cr} values ranged from 0.0 to 1.7, 0.0 to 1.6, 0.0 to 2.0 and 0.0 to 1.4, respectively. Similar ranges in Kc values were observed in 2014-2015 season.

The K_{cr} and K_{co} curves (Figures 8-16) as well as the monthly average values shown in table 1-3 indicate that from the emergence until mid-December K_{cr} and K_{co} shows a bell-shaped trend, which peaks in September and October that is the peak growing period for the winter cover crops in Midwest and starts decreasing thereafter. While the crop coefficients are characterized by this trend, such a trend is not identifiable after the surface is covered with snow and/or ice and substantial variation is evident during December, January and February. In 2013-2014 and 2014-2015 seasons the average K_{co} value for CC treatments from emergence to mid-December were 0.7 and 0.8, respectively, and 0.6 and 0.7 for SCCC treatments. Corresponding K_{cr} values were 0.5 and 0.6 for CC and 0.4 and 0.5 for SCCC treatment. In all the years during this period, peak K_c value was observed in October except F1 field in 2013-2014 in which due to late plating of the cover crops [crops did not emerge and develop to its full potential in fall, but re-emerged next spring (Figure 11)]. In 2012-2013, the peak K_{co} and K_{cr} values in this period (emergence to mid-December) for CC treatment was 1.3 and 0.9, respectively, and 1.2 and 0.8 for SCCC. However, these values were higher in 2013-2014 and 2014-2015 seasons, which can be attributed to increased soil moisture due to higher rainfall. The similarities in the magnitudes of K_c values in these two seasons can be explained by the presence of turnip and radishes in the cover crop mixture in both seasons. Comparing average K_c values of CC and SCCC treatment with bare soil during the period from emergence until mid-December, CC and SCCC K_c is always higher than bare soil K_c due to higher transpiration water loss in cover crop plots.

In addition, measured K_c values are characterized by rapid increase when wetting events occurred, followed by a decrease as soil dried up. This pattern is most evident in 2014-2015 season, resulting from heavy rainfall events. In all three seasons, the maximum K_c values were observed generally in January when temperatures are very low and evaporative demand is very small as compared to the evaporation from the surface, thus making the ratio of ET_a and ET_{ref} very high. During the winter period (mid-December to early March) the average K_c values from CC and SCCC plots were lower than bare soil K_c values due to lower evaporation rates from the CC and SCCC plots as compared to bare soil.

Basal crop coefficients

Figures 17-19 show grass- and alfalfa-reference basal crop coefficient (K_{cbo} and K_{cbr}) curves as a function of CGDD for CC and SCCC treatments in the F1, F2 and F3 fields for 2012-2013, 2013-2014 and 2014-2015 growing seasons, respectively. The monthly average K_{cbo} and K_{cbr} values are summarized in Table 4. The CGDD values at the start and at the end of the season were different for the three cover crop fields and for two growing seasons as they had different planting and termination dates. The soil-water measurements started approximately two weeks after planting. In 2012-2013 season, the CGDD at the end of the season was 1,444^{o}C, 1,440^{o}C and 1,490^{o}C in the F1, F2 and F3 fields, respectively, whereas the CGDD was 1,082^{o}C, 2,336^{o}C and 2,402^{o}C in the F1, F2 and F3 fields, respectively, at the end of the 2013-2014 season. In 2014-2015 season, the CGDD values at the end of the season were 2,209^{o}C, 2,143^{o}C and 2,165^{o}C in the F1, F2 and F3 fields, respectively. The K_{cb} curves developed are presented in Figures 17, 18 and 19. The adjustment made for the contribution of soil evaporation is reflected by the developed K_{cb} values (indicated by circles in graphs). However, no soil evaporation was estimated during the soil-water depletion periods. A fifth order polynomial equation was fitted to the data is also shown on the graphs. The resultant regression equations for CC and SCCC K_{cb} polynomial curves are presented in tables 5 and 6, respectively. Note that K_s value was taken to be 1 for both treatments as mentioned previously and no soil evaporation was calculated for any period.

Similar to K_c, K_{cb} curves also exhibited inter-annual variability for the same months and treatments between the years. In 2012-2013 season, K_{cb} values increased from September until December when there was no snow or ice cover on the surface (visual observation). From January until early February, the coefficients decreased gradually due to snow cover and/or frozen surface conditions and then gradually increased until the end of the season. The same trend was observed in 2013-2014 and 2014-2015 seasons with an exception F1 field in 2013-2014. Similar to K_c, K_{cb} also showed a bell-shaped trend in the period from emergence until mid-December and peaked in October. In 2012-2013, the maximum K_{cbo} and K_{cbr} values in the CC treatment was 1.2 and 0.97, respectively, at CGDD of 1,046^{o}C; 1.12 and 0.77 at CGDD of 1,246^{o}C; and 1.0 and 0.69 at CGDD of 1,345^{o}C in the F1, F2 and F3 fields, respectively (Figure 17 a-c). The maximum K_{cbo} and K_{cbr} values in the SCCC treatment were 0.91 and 0.63 at CGDD of 615^{o}C; 0.95 and 0.63 at CGDD of 982^{o}C; and 1.2 and 0.9 at CGDD of 1,345^{o}C in the F1, F2 and F3 fields, respectively (Figure 17 d-f). The minimum values of K_{cbo} and K_{cbr} in all fields were observed as 0.03 and 0.02 at CGDD of 226^{o}C and 0.07 and 0.04 at CGDD of 201^{o}C in the CC and SCCC treatments, respectively.

In 2013-2014 growing season, expect F1 field, other two fields showed maximum K_{cb} values at CGDD of about 1,220 ^{o}C (October) which gradually decreased during winter. The average maximum K_{cbo} and K_{cbr} values for CC treatment were 1.2 and 0.8, respectively, and were 1.3 and 0.7 for SCCC treatment. Similar trend was obtained in 2014-2015 season. Figure 19 shows the K_{cb} trend in 2014-2015 season for all the three fields. Some of the high K_{cb} values (especially in the F1 field for SCCC treatment) in this season are primarily due to extremely low ET_{ref} values that resulted in several high ET_a/ET_{ref} ratios. The fitted polynomial curves showed maximum value of K_{cb} at CGDD of approximately 1,300^{o}C (end of October) which then gradually decreased in the winter months. The average K_{cbo} and K_{cbr} values in CC treatment ranged from 0.0 to 1.5 and from 0.0 to 1.1, respectively, whereas for the SCCC treatment it varied from 0.0 to 2.1 and from 0.0 to 1.4, respectively. Higher magnitudes of K_{cb} in 2013-2014 and 2014-2015 as compared to 2012-2013 can be attributed to the above average rainfall occurred during these seasons, which contributed to enhanced cover crop growth and development (visual observation) and increased ET_a.

SUMMARY AND CONCLUSIONS

Grass- and alfalfa-reference single (K_{co} and K_{cr}) and basal crop coefficients (K_{cbo} and K_{cbr}) for cover crop mixtures were developed in three cover crop growing seasons (2012-2013, 2013-2014 and 2014-2015) in Beaver Crossing (Seward County), Nebraska, U.S.A., using soil-water balance-determined actual evapotranspiration (ET_a) and Penman-Monteith-estimated grass- and alfalfa-reference ET (ET_o and ET_r). Four treatments in each field and each growing season were imposed: (i) cover crop only (CC), (ii) seed-maize-cover crop rotation (SCCC), (iii) bare soil treatment without any surface residue, and (iv) seed maize only without cover crop (SC).

The crop coefficients were developed as a function of cumulative growing degree days (CGDD) and exhibited inter-annual variation. Pooled data from three large scale production fields showed that the cover crop K_{co} and K_{cr} varied from 0.0 to 1.8 and from 0.0 to 1.2, respectively, in 2012-2013 season; from 0.0 to 2.3 and from 0.0 to 1.7, respectively, in 2013-2014 season; and from 0.0 to 2.3 and from 0.0 to 1.7 in 2014-2015 cover crop growing season. The bare soil treatment K_c values were higher than the values for cover crops in the winter months (mid-December to March). However, from October until mid-December cover crop treatments had higher K_c values. The K_c and K_{cb} curves exhibited a bell-shaped trend from emergence until mid-December, which peaked in September and October, which is also the peak growing season for the winter cover crops. While the crop coefficients in this period are characterized by this trend, such a trend is not identifiable after the surface is covered with snow and substantial variability is evident even in the short time period. The results from this research show that because of extreme winter and snow covered surface conditions, K_c and K_{cb} measurements can deviate from the common smooth K_c and K_{cb} curves that one usually expects for other crops grown in summer months in warm weather conditions. In addition, K_c values are characterized by rapid increase when wetting events occurred, followed by a decrease as soil dried up. This pattern is most evident in 2014-2015 season, resulting from heavy rainfall events. In all three seasons the maximum K_c values were observed generally in January when temperatures are very low and evaporative demand is very small as compared to the evaporation from the surface, thus making the ratio of ET_a and ET_{ref} very high. The K_{cbo} and K_{cbr} curves that were developed as a function of CGDD can be advantageous to reduce the impact(s) of large variations in planting dates and climatic conditions on the K_c and K_{cb} values. These are some of the first single (normal) and basal crop coefficients in the literature that were developed for cover crop mixtures, and first datasets in the Midwestern U.S.A. The K_c and K_{cb} curves presented in this study can be used to obtain reasonable estimates of cover crop ET_a for particular cover crop mixtures that were used in this research and grown in the environment similar to this research area. Estimating the crop coefficient values for winter cover crops during the winter period is especially important to estimate the water use by these crops to understand the impact of cover crops on the water availability of next cash crop. The K_c and K_{cb} curves developed in this study can be used to estimate cover crop ET_a for particular cover crop mixtures that are similar to those used in this research and grown under climatic conditions similar to the research area.

ACKNOWLEDGEMENT

This project was funded and supported by the United States Department of Agriculture-Natural Resources Conservation Service, National Conservation Innovation Grants Program under the project number: 69-3A75-12-207. As the project PI, Dr. Suat Irmak expresses his appreciation to the USDA-NRCS for collaboration and for providing financial support for this project. Dr. Irmak also expresses his appreciation to David Cast and Doug Cast in Beaver Crossing, NE, for allowing us to conduct these extensive projects in their production fields and for their excellent collaboration. We also thank Kari E. Skaggs for her contributions in field data collection.

REFERENCES

ASCE-EWRI. 2005. The ASCE standardized reference evapotranspiration equation. Standardization of Reference Evapotranspiration Task Committee Final Report. Reston, Va.: ASCE, Environmental and Water Res. Inst.

Bodner, G., W. Loiskandl and H. Kaul. 2007. Cover crop evapotranspiration under semi-arid conditions using FAO dual crop coefficient method with water stress compensation. *Agric. Water Mgmt.* 93(3): 85-98.

Dabney, S., J. Delgado and D. Reeves. 2001. Using winter cover crops to improve soil and water quality. *Communications in Soil Sci. and Plant Analysis* 32(7-8): 1221-1250.

Doorenbos, J., and W. O. Pruitt. 1977. Crop water requirements. Irrig. And Drain. Paper No. 24. Rome, Italy: Food and Agric. Organization of the United Nations.

FAO-56. 1998. Guidelines for computing crop water requirements. Food and Agricultural Organization of the United Nations, Rome: FAO *Irrig. and Drain*. Paper No. 56.

Frye, W.W., J.J. Varco, R.L. Blevins, M.S. Smith, and S.J. Corak. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. pp. 129-154. In: W.L. Hargrove (ed.) Cropping Strategies for Efficient Use of Water and Nitrogen. Spec. Pub. No. 51. ASA. Madison, WI.

Hay, C. H. and S. Irmak. 2009. Actual and reference evaporative losses and surface coefficients of a maize field during non-growing (dormant) periods. *J. Irrig. and Drain. Engg.* 135(3): 313-322.

Hunsaker, D. 1999. Basal crop coefficients and water use for early maturity cotton. *Trans. ASAE*. 42(4): 927-936.

Irmak, S., R.G. Allen, and E.B. Whitty. 2003. Daily grass and alfalfa-reference evapotranspiration estimates and alfalfa-to-grass evapotranspiration ratios in Florida. *J. Irrig. and Drain. Eng., ASCE* 129(5):360-370.

Irmak, S. 2010. Nebraska water and energy flux measurement, modeling, and research network (NEBFLUX). *Trans. ASABE*. 53(4): 1097-1115.

Irmak, S., I. Kabenge, K. Skaggs, and D. Mutiibwa. 2012. Trend and magnitude of changes in climate variables and reference evapotranspiration over 116-year period in the Platte River Basin, central Nebraska-USA. *J. Hydrology* 420-421: 228-244.

Irmak, S., I. Kabenge, I., D. Rudnick, S. Knezevic, D. Woodward, and M. Moravek. 2013. Evapotranspiration crop coefficients for mixed riparian plant community and transpiration crop coefficients for phragmites, cottonwood and peach-leaf willow in the Platte River Basin, Nebraska-USA. *J. Hydrology* 481:177-190.

Irmak, S. 2015a. Inter-annual variation in long-term center pivot-irrigated maize evapotranspiration (ET) and various water productivity response indices: Part I. Grain yield, actual and basal ET, irrigation-yield production functions, ET-yield production functions, and yield response factors. *J. Irrig. and Drain. Eng., ASCE* 141(5): 04014068-1-17. DOI: 10.1061/(ASCE)IR.1943-4774.0000825.

Irmak, S. 2015b. Inter-annual variation in long-term center pivot-irrigated maize evapotranspiration (ET) and various water productivity response indices: Part II. Irrigation water use efficiency (IWUE), crop WUE, evapotranspiration WUE, irrigation-evapotranspiration use efficiency, and precipitation use efficiency. *J. Irrig. and Drain. Eng., ASCE* 141(5): 04014069-1-11. DOI: 10.1061/(ASCE)IR.1943-4774.0000826.

Islam, N., W. W. Wallender, J. Mitchell, S. Wicks and R. E. Howitt. 2006. A comprehensive experimental study with mathematical modeling to investigate the affects of cropping practices on water balance variables. *Agric. Water Mgmt.* 82(1): 129-147.

Jones, H. G. 1992. Plants and microclimate: a quantitative approach to environmental plant physiology. Cambridge University Press, Cambridge, England.

McMaster, G. S. and W. Wilhelm. 1997. Growing degree-days: one equation, two interpretations. *Agric. and Forest Meteorol.* 87(4): 291-300.

Payero, J. O. and S. Irmak. 2013. Daily energy fluxes, evapotranspiration and crop coefficient of soybean. *Agric. Water Mgmt.* 12931-43.

Qi, Z., M. J. Helmers and A. L. Kaleita. 2011. Soil water dynamics under various agricultural land covers on a subsurface drained field in north-central Iowa, USA. *Agric. Water Mgmt.* 98(4): 665-674.

Sharma, V., S. Irmak, V. Sharma, L. Odhiambo and K. Djaman. 2016. Soil-water dynamics and evapotranspiration of cover crop mixtures in seed maize-cover crop rotation fields: Part I. Soil-water dynamics and evapotranspiration. *Trans. ASABE* (this issue, submitted).

Smith, M. S., W. W. Frye and J. J. Varco. 1987. Legume winter cover crops. *In* Advances in Soil Science, 95-139. ed. Anonymous , Springer.

Steele, D., A. Sajid and L. Prunty. 1996. New corn evapotranspiration crop curves for southeastern North Dakota. *Trans. ASAE* 39(3): 931-936.

Unger, P. W. and M. F. Vigil. 1998. Cover crop effects on soil water relationships. *J. Soil and Water Cons.* 53(3): 200-207.

USDA-NASS. 2012. Census of agriculture: Farm and ranch irrigation survey. Washington, D.C.: USDA National Agricultural Statistics Service.

USDA-NRCS. 1985. National Engineering Handbook (NEH) Section 4, Hydrology. Soil Conservation Service, USDA, Washington, D.C.

Wagger, M.G. and D.B. Mengel. 1988. The role of nonleguminous cover crops in the efficient use of water and nitrogen. pp. 115-127. In: W.L. Hargrove (ed.) Cropping Strategies for Efficient Use of Water and Nitrogen. Spec. Pub. No. 51. ASA. Madison, WI.

Wright, J. L. 1982. New evapotranspiration crop coefficients. Proceedings of the *American Society of Civil Engineers. J. Irrig. and Drain. Division* 108(IR2): 57-74.

Yang, S., J. Logan and D. L. Coffey. 1995. Mathematical formulae for calculating the base temperature for growing degree days. *Agric. and Forest Meteorol*. 74(1): 61-74.

Table 9. Monthly average grass-reference and alfalfa-reference single (normal) crop coefficient (K_{co} and K_{cr}) values for F1 field in 2012-2013, 2013-2014 and 2014-2015 growing seasons.

	Treatment	CC			Bare soil			SCCC			SC		
Month	Season	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015
Sep	K_{co}	_	_	0.96	_	_	0.85	_	_	0.85	_	_	0.59
	K_{cr}	_	_	0.78	_	_	0.70	_	_	0.69	_	_	0.49
Oct	K_{co}	0.41	0.33	1.14	0.42	0.29	0.74	0.56	0.20	0.54	0.37	0.33	0.64
	K_{cr}	0.28	0.22	0.79	0.28	0.19	0.52	0.38	0.13	0.38	0.25	0.22	0.45
Nov	K_{co}	0.45	_	0.50	0.49	_	0.73	0.42	_	0.60	0.34	_	0.49
	K_{cr}	0.28	_	0.35	0.30	_	0.50	0.26	_	0.42	0.21	_	0.35
Dec	K_{co}	0.34	0.46	0.49	0.21	0.50	0.91	0.33	0.35	0.44	0.23	0.46	0.56
	K_{cr}	0.22	0.29	0.38	0.14	0.32	0.65	0.22	0.23	0.34	0.15	0.29	0.42
Jan	K_{co}	0.69	_	0.27	0.83	_	0.85	0.35	_	0.67	0.47	_	0.40
	K_{cr}	0.48	_	0.18	0.58	_	0.56	0.24	_	0.43	0.33	_	0.26
Feb	K_{co}	0.16	_	0.88	0.29	_	0.71	0.24	_	1.03	0.25	_	0.77
	K_{cr}	0.12	_	0.62	0.20	_	0.50	0.18	_	0.76	0.17	_	0.57
March	K_{co}	0.44	0.17	0.07	0.35	0.17	0.12	0.41	0.06	0.14	0.18	0.17	0.14
	K_{cr}	0.32	0.12	0.05	0.25	0.11	0.09	0.30	0.04	0.10	0.13	0.12	0.10
April	K_{co}	_	0.34	0.25	_	0.38	0.17	_	0.42	0.25	_	0.34	0.16
	K_{cr}	_	0.24	0.17	_	0.27	0.12	_	0.30	0.17	_	0.24	0.11

Table 10. Monthly average grass-reference and alfalfa-reference single (normal) crop coefficient (K_{co} and K_{cr}) values for F2 field in 2012-2013, 2013-2014 and 2014-2015 growing seasons.

	Treatment	CC			Bare soil			SCCC			SC		
Month	Season	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015
Sep	K_{co}	0.25	0.56	0.98	0.38	0.28	0.89	0.34	0.32	0.78	0.27	0.39	0.80
	K_{cr}	0.17	0.42	0.80	0.26	0.21	0.72	0.24	0.24	0.63	0.19	0.29	0.65
Oct	K_{co}	0.43	1.28	0.81	0.57	1.04	0.75	0.47	1.19	0.60	0.66	0.91	0.56
	K_{cr}	0.29	0.91	0.56	0.38	0.69	0.52	0.32	0.84	0.42	0.44	0.61	0.38
Nov	K_{co}	0.45	0.80	0.53	0.34	0.88	0.75	0.35	0.75	0.73	0.43	0.75	0.67
	K_{cr}	0.29	0.51	0.37	0.22	0.56	0.52	0.22	0.48	0.51	0.27	0.48	0.46
Dec	K_{co}	0.27	0.38	0.79	0.23	0.72	0.71	0.23	0.34	1.13	0.26	0.90	0.62
	K_{cr}	0.17	0.24	0.59	0.15	0.47	0.52	0.15	0.21	0.81	0.17	0.64	0.47
Jan	K_{co}	0.52	_	0.43	0.42	_	0.54	0.46	_	0.39	0.64	_	0.54
	K_{cr}	0.36	_	0.28	0.29	_	0.35	0.32	_	0.25	0.44	_	0.35
Feb	K_{co}	0.63	_	0.30	0.53	_	1.18	0.34	_	0.95	0.48	_	0.94
	K_{cr}	0.45	_	0.21	0.38	_	0.83	0.24	_	0.68	0.34	_	0.67
March	K_{co}	0.08	0.00	0.00	0.13	0.05	0.08	0.12	0.01	0.03	0.17	0.12	0.09
	K_{cr}	0.05	0.00	0.00	0.09	0.03	0.06	0.09	0.01	0.02	0.12	0.08	0.06
April	K_{co}	_	0.20	0.13	_	0.32	0.20	_	0.32	0.25	_	0.29	0.32
	K_{cr}	_	0.14	0.09	_	0.22	0.14	_	0.22	0.18	_	0.20	0.23

Table 11. Monthly average grass-reference and alfalfa reference single (normal) crop coefficient (K_{co} and K_{cr}) values for F3 field in 2012-2013, 2013-2014 and 2014-2015 growing seasons.

	Treatment	CC			Bare			SCCC			SC		
Month	Season	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015
Sep	K_{co}	0.18	0.66	1.04	0.28	0.28	0.79	0.23	0.42	1.00	0.33	0.28	0.94
	K_{cr}	0.12	0.50	0.85	0.19	0.21	0.64	0.16	0.32	0.87	0.23	0.21	0.86
Oct	K_{co}	0.57	1.15	0.72	0.22	1.06	0.51	0.58	1.21	0.67	0.55	0.91	0.51
	K_{cr}	0.39	0.80	0.50	0.14	0.75	0.36	0.39	0.93	0.46	0.37	0.61	0.36
Nov	K_{co}	0.40	0.46	0.51	0.48	0.86	0.70	0.52	0.89	0.52	0.41	0.90	0.78
	K_{cr}	0.26	0.29	0.36	0.31	0.55	0.52	0.33	0.57	0.36	0.26	0.57	0.57
Dec	K_{co}	0.27	0.80	0.52	0.31	0.57	0.75	0.35	0.86	0.43	0.26	1.09	1.01
	K_{cr}	0.18	0.53	0.40	0.20	0.37	0.55	0.23	0.57	0.33	0.17	0.70	0.70
Jan	K_{co}	0.70	_	0.83	0.81	_	0.83	0.67	_	0.73	0.46	_	0.83
	K_{cr}	0.47	_	0.58	0.55	_	0.66	0.38	_	0.47	0.32	_	0.67
Feb	K_{co}	0.38	_	0.33	0.66	_	0.95	0.75	_	0.56	0.64	_	0.70
	K_{cr}	0.26	_	0.24	0.48	_	0.67	0.54	_	0.40	0.47	_	0.50
March	K_{co}	0.23	0.08	0.09	0.28	0.04	0.00	0.18	0.01	0.12	0.16	0.02	0.11
	K_{cr}	0.17	0.05	0.06	0.20	0.03	0.00	0.13	0.01	0.09	0.12	0.01	0.08
April	K_{co}	_	0.29	0.20	_	0.36	0.37	_	0.23	0.12	_	0.33	0.20
	K_{cr}	_	0.20	0.14	_	0.25	0.27	_	0.16	0.09	_	0.23	0.14

Table 12. Monthly average grass-reference and alfalfa-reference basal crop coefficient (K_{cbo} and K_{cbr}) values for the F1, F2 and F3 fields in 2012-2013, 2013-2014 and 2014-2015 cover crop growing seasons. CC: cover crop only; SCCC: seed-corn-cover crop rotation treatment.

	F1 Field	F2 Field	F3 Field

	Treatment	CC			SCCC			CC			SCCC			CC			SCCC		
Month	Growing Season	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015	2012-2013	2013-2014	2014-2015
Sep	K_{cbo}	0.08	_	0.52	0.27	_	0.38	0.26	0.65	0.63	0.33	0.46	0.33	0.21	0.67	0.49	0.26	0.48	0.48
	K_{cbr}	0.06	_	0.42	0.19	_	0.31	0.18	0.47	0.51	0.23	0.34	0.27	0.15	0.49	0.40	0.18	0.35	0.39
Oct	K_{cbo}	0.44	0.42	1.32	0.56	0.38	0.57	0.52	1.10	0.95	0.52	0.93	0.71	0.63	0.86	0.79	0.64	1.01	0.71
	K_{cbr}	0.30	0.28	0.96	0.38	0.26	0.41	0.35	0.74	0.68	0.36	0.63	0.51	0.43	0.58	0.57	0.44	0.68	0.51
Nov	K_{cbo}	0.45	0.38	0.61	0.47	0.44	0.36	0.49	0.33	0.94	0.41	0.35	1.26	0.42	0.37	0.44	0.54	0.24	0.46
	K_{cbr}	0.29	0.25	0.42	0.31	0.29	0.25	0.32	0.22	0.67	0.27	0.26	1.06	0.27	0.25	0.30	0.35	0.16	0.34
Dec	K_{cbo}	0.75	0.37	0.43	0.49	0.44	0.54	0.55	0.25	0.76	0.43	0.30	0.97	0.32	0.35	0.67	0.56	0.19	0.59
	K_{cbr}	0.54	0.25	0.30	0.34	0.29	0.36	0.39	0.17	0.53	0.31	0.22	0.79	0.23	0.23	0.45	0.40	0.12	0.41
Jan	K_{cbo}	0.55	0.37	0.27	0.38	0.44	0.69	0.65	0.25	0.43	0.53	0.30	0.37	0.68	0.35	0.97	0.60	0.19	0.73
	K_{cbr}	0.41	0.25	0.18	0.27	0.29	0.45	0.46	0.17	0.28	0.38	0.22	0.25	0.48	0.23	0.63	0.43	0.12	0.48
Feb	K_{cbo}	0.23	0.37	1.27	0.20	0.44	1.45	0.60	0.25	0.37	0.34	0.30	0.72	0.53	0.35	0.10	0.68	0.19	0.20
	K_{cbr}	0.17	0.25	1.13	0.15	0.29	1.25	0.42	0.17	0.37	0.24	0.22	0.62	0.36	0.23	0.07	0.48	0.12	0.14
March	K_{cbo}	0.37	0.37	0.09	0.43	0.44	0.12	0.26	0.25	0.05	0.23	0.30	0.17	0.21	0.35	0.06	0.35	0.19	0.11
	K_{cbr}	0.27	0.25	0.06	0.32	0.29	0.09	0.19	0.17	0.04	0.17	0.22	0.12	0.16	0.23	0.05	0.25	0.12	0.08
April	K_{cbo}	_	0.26	0.33	_	0.27	0.52	_	0.28	0.17	_	0.27	0.33	_	0.16	0.29	_	0.09	0.27
	K_{cbr}	_	0.17	0.28	_	0.18	0.70	_	0.20	0.23	_	0.19	0.44	_	0.11	0.39	_	0.06	0.39

Table 13. Regression equations for K_{cb} as a function of cumulative growing degree days (CGDD) for cover crop only (CC) treatment.

Year	Field	K_{cb} as a function of cumulative growing degree days (CGDD) for CC treatment
2012-2013	**F1**	$Kcbo= 9E-15x^5 - 3E-11x^4 + 5E-08x^3 - 4E-05x^2 + 0.0139x - 1.9779$ ($R^2 = 0.20$) $Kcbr = 9E-15x^5 - 3E-11x^4 + 5E-08x^3 - 4E-05x^2 + 0.0143x - 1.9535$ ($R^2 = 0.17$)
	F2	$Kcbo = -1E-15x^5 + 8E-12x^4 - 2E-08x^3 + 2E-05x^2 - 0.0061x + 0.8628$ ($R^2 = 0.19$) $Kcbr = -2E-15x^5 + 8E-12x^4 - 2E-08x^3 + 1E-05x^2 - 0.0047x + 0.6404$ ($R^2 = 0.17$)
	F3	$Kcbo = -7E-15x^5 + 4E-11x^4 - 7E-08x^3 + 6E-05x^2 - 0.0207x + 2.4327$ ($R^2 = 0.26$) $Kcbr = -5E-15x^5 + 2E-11x^4 - 5E-08x^3 + 4E-05x^2 - 0.014x + 1.6396$ ($R^2 = 0.24$)
2013-2014	**F1**	$Kcbo= -7E-14x^5 + 1E-10x^4 - 1E-07x^3 + 4E-05x^2 - 0.0058x + 0.704$ ($R^2 = 0.99$) $Kcbr = -5E-14x^5 + 9E-11x^4 - 7E-08x^3 + 2E-05x^2 - 0.004x + 0.4842$ ($R^2 = 0.99$)
	F2	$Kcbo= -5E-15x^5 + 3E-11x^4 - 9E-08x^3 + 1E-04x^2 - 0.0502x + 9.2479$ ($R^2 = 0.85$) $Kcbr = -3E-15x^5 + 2E-11x^4 - 6E-08x^3 + 6E-05x^2 - 0.0328x + 6.0605$ ($R^2 = 0.86$)
	F3	$Kcbo = -3E-15x^5 + 2E-11x^4 - 5E-08x^3 + 6E-05x^2 - 0.033x + 6.8296$ ($R^2 = 0.78$) $Kcbr = -2E-15x^5 + 1E-11x^4 - 3E-08x^3 + 4E-05x^2 - 0.0207x + 4.347$ ($R^2 = 0.81$)
2014-2015	**F1**	$Kcbo = -6E-15x^5 + 4E-11x^4 - 1E-07x^3 + 0.0002x^2 - 0.0899x + 19.254$ ($R^2 = 0.57$) $Kcbr = -5E-15x^5 + 4E-11x^4 - 1E-07x^3 + 0.0001x^2 - 0.0738x + 15.819$ ($R^2 = 0.46$)
	F2	$Kcbo = 2E-15x^5 - 1E-11x^4 + 2E-08x^3 - 6E-06x^2 - 0.0037x + 2.5815$ ($R^2 = 0.82$) $Kcbr = 1E-15x^5 - 6E-12x^4 + 6E-09x^3 + 2E-06x^2 - 0.0062x + 2.6877$ ($R^2 = 0.76$)
	F3	$Kcbo = 3E-15x^5 - 1E-11x^4 + 3E-08x^3 - 2E-05x^2 + 0.0035x + 1.1576$ ($R^2 = 0.34$) $Kcbr = 2E-15x^5 - 9E-12x^4 + 2E-08x^3 - 9E-06x^2 - 0.0004x + 1.6065$ ($R^2 = 0.37$)

Table 14. Regression equations for K_{cb} as a function of cumulative growing degree days (CGDD) for seed corn-cover crop (SCCC) treatment.

Year	Field	K_{cb} as a function of cumulative growing degree days (CGDD) for SCCC treatment
2012-2013	**F1**	$Kcbo = -2E\text{-}14x^5 + 7E\text{-}11x^4 - 1E\text{-}07x^3 + 8E\text{-}05x^2 - 0.026x + 3.1391$ $(R^2 = 0.24)$ $Kcbr = 1E\text{-}14x^5 + 4E\text{-}11x^4 - 7E\text{-}08x^3 + 5E\text{-}05x^2 - 0.0162x + 1.9545$ $(R^2 = 0.18)$
	F2	$Kcbo = 7E\text{-}15x^5 - 3E\text{-}11x^4 + 4E\text{-}08x^3 - 2E\text{-}05x^2 + 0.0076x - 0.6914$ $(R^2 = 0.26)$ $Kcbr = 4E\text{-}15x^5 - 2E\text{-}11x^4 + 2E\text{-}08x^3 - 1E\text{-}05x^2 + 0.0049x - 0.4443$ $(R^2 = 0.21)$
	F3	$Kcbo = -8E\text{-}15x^5 + 4E\text{-}11x^4 - 7E\text{-}08x^3 + 5E\text{-}05x^2 - 0.0176x + 1.9795$ $(R^2 = 0.26)$ $Kcbr = 6E\text{-}15x^5 + 3E\text{-}11x^4 - 5E\text{-}08x^3 + 4E\text{-}05x^2 - 0.0128x + 1.4333$ $(R^2 = 0.23)$
2013-2014	**F1**	$Kcbo = -7E\text{-}14x^5 + 1E\text{-}10x^4 - 9E\text{-}08x^3 + 3E\text{-}05x^2 - 0.003x + 0.496$ $(R^2 = 0.99)$ $Kcbr = -5E\text{-}14x^5 + 9E\text{-}11x^4 - 6E\text{-}08x^3 + 2E\text{-}05x^2 - 0.0021x + 0.3466$ $(R^2 = 0.99)$
	F2	$Kcbo = -3E\text{-}15x^5 + 2E\text{-}11x^4 - 6E\text{-}08x^3 + 7E\text{-}05x^2 - 0.0367x + 6.988$ $(R^2 = 0.76)$ $Kcbr = -2E\text{-}15x^5 + 1E\text{-}11x^4 - 4E\text{-}08x^3 + 4E\text{-}05x^2 - 0.023x + 4.4091$ $(R^2 = 0.76)$
	F3	$Kcbo = -4E\text{-}15x^5 + 3E\text{-}11x^4 - 9E\text{-}08x^3 + 0.0001x^2 - 0.0616x + 12.658$ $(R^2 = 0.74)$ $Kcbr = -3E\text{-}15x^5 + 2E\text{-}11x^4 - 6E\text{-}08x^3 + 7E\text{-}05x^2 - 0.0408x + 8.4088$ $(R^2 = 0.75)$
2014-2015	**F1**	$Kcbo = -1E\text{-}15x^5 + 6E\text{-}12x^4 - 2E\text{-}08x^3 + 2E\text{-}05x^2 - 0.0136x + 3.8179$ $(R^2 = 0.07)$ $Kcbr = -2E\text{-}16x^5 + 1E\text{-}12x^4 - 5E\text{-}09x^3 + 8E\text{-}06x^2 - 0.0064x + 2.2919$ $(R^2 = 0.04)$
	F2	$Kcbo = 4E\text{-}15x^5 - 2E\text{-}11x^4 + 3E\text{-}08x^3 - 2E\text{-}05x^2 + 0.0017x + 1.6379$ $(R^2 = 0.48)$ $Kcbr = 4E\text{-}15x^5 - 2E\text{-}11x^4 + 4E\text{-}08x^3 - 3E\text{-}05x^2 + 0.0068x + 0.4791$ $(R^2 = 0.38)$
	F3	$Kcbo = 2E\text{-}15x^5 - 7E\text{-}12x^4 + 1E\text{-}08x^3 - 4E\text{-}06x^2 - 0.0033x + 2.2557$ $(R^2 = 0.51)$ $Kcbr = 1E\text{-}15x^5 - 6E\text{-}12x^4 + 9E\text{-}09x^3 - 2E\text{-}06x^2 - 0.0033x + 2.0335$ $(R^2 = 0.54)$

SECTION 3: EFFECT OF COVER CROPS ON SOIL QUALITY: SOIL CHEMICAL PROPERTIES – ORGANIC C, TOTAL N, PH, EC, ORGANIC MATTER CONTENT, NO_3-N, AND P

INTRODUCTION

Concerns regarding environmental quality and long term productivity of agro ecosystems call for the adoption of management strategies that safeguard soil, air, and water resources (Villamil et al., 2006). Recent emphasis on environmental quality and the long-term productivity of agro ecosystems has prompted development and implementation of conservation agriculture management strategies that protect soil and water resources (Hu et al., 1997). The concept of conservation agriculture has been promoted in recent years as an integrated management tool to meet the challenges of the future (Verhulst et al., 2010). The conservation agriculture concept includes conservation tillage, diverse crop rotations, residue management, and cover crops as key elements. Many studies have assessed the impact of the different conservation agriculture elements on soil quality individually, however very limited studies have quantified the effect of conservation tillage combined with cover crops (Abdollahi and Munkholm, 2014).

Many researches have shown that crop rotations which include fallow, produce more rapid loss of soil nitrogen and carbon (Rasmussen et al., 1980). Campbell et al. (1976), indicate that soil N loss increased as frequency of fallow increased. Organic residue addition to the soil is one of the most important factors influencing soil nitrogen, carbon and organic matter. In a 12-year study with continuous corn at Iowa, Larson et al. (1972) obtained a linear relationship between the rate of residue applied and change in soil carbon, independent of the kind of residue. Winter cover cropping is an alternative agricultural practice that has received much attention as a means of ameliorating soil chemical and physical properties. Winter cover crops generally have a period of fall growth followed by a winter period when growth stops or slows down. In spring, they again grow rapidly. Cover crops has been shown to protect the soil from erosion, weed suppression, carbon sequestration and from loss of plant nutrients through leaching and runoff (Reeves, 1994). They can protect water quality by reducing losses of nutrients, pesticides, or sediment from agricultural fields (Dabney et al., 2001). The use of winter cover crops also has been shown to be effective in improving soil organic matter, stabilizing soil aggregation, improving water holding capacity, and influencing crop yields compared with no cover crop (McVay et al., 1989; McCracken et al., 1994; Kuo et al., 1997). It is one of the easiest and economical ways for improving soil's physical and chemical properties and to revitalize, protect or build the soil. Implementation of conservation tillage systems combined with cover cropping may lead to significant changes in soil physical, chemical and biological properties. These changes can have a significant impact on the environment hence the sustainability of crop production system.

Soil organic matter (SOM) plays a very important role in nutrient supply and availability for plant uptake by stabilizing the soil pH (Campbell et al., 1996). SOM positively influence cation exchange capacity, water holding capacity, soil structure and microbial activity. In addition, it reduces soil compaction and crusting and binds soil particle together which reduces soil erosion. Levels of SOM depends largely on the type of tillage and residue management (cover crops) which the soil is subjected to. Many studies have shown a decline in SOM with conventional tillage systems (Unger, 1991; Alvarez at al., 1995). No tillage systems in combination with cover cropping agree in keeping the soil surface permanently covered by an organic layer that protects the soil physically from sun, rain and erosion, while suppressing weed growth and feeding soil organisms (De Rouw et al., 2010). Also, concentration of organic carbon (C) and total nitrogen (N) is another good indicator of soil quality and health as they effect soil physical, chemical and biological properties (Bauer and Black, 1994). They play an important role in plant productivity and nutrient cycling. Cover cropping can increase their concentration by increasing the residue addition to the soil. Sequestration of C in the soil through plant fixation is one of the effective ways of mitigating global warming. While non-legume cover crops can fix atmospheric C, and legume cover crops fix both C and N in the plants by increasing the biomass production. No-till practice can reduce the rate of plant decomposition by reducing the degree of plant incorporation in the soil. Since, much of the cover crops research prior to the 1980s was conducted with conventional tillage systems in which cover crops were incorporated into the soil, most recent cover crops research has combined cover crops into no tillage or reduced tillage systems (Dabney, 1998).

Little information is available on effect of cover crops in no-till practice on soil physical and chemical properties. Our objectives were to investigate the short term effects of growing cover crops in seed maize or soybean rotation under no tillage practice on soil pH, EC, soil organic matter (SOM), Nitrate-N (NO_3-N), soil phosphorous (P), organic carbon (C) and total nitrogen (N) to a depth of 120 cm.

MATERIAL AND METHODS

Description of Study area

The research was conducted in three large scale farmer production fields (BREBS field, East and West fields), all located in the same area in Seward County near Beaver Crossing, Nebraska, USA from 2012-2015. The research fields are located in the transition zone between the wetter Nebraska Vegetative Zone IV and slightly drier zone III (http://efotg.sc.egov.usda.gov/references/public/NE/NebraskaVegetativeZones.pdf) (Figure 1). All three research fields are center-pivot irrigated with seed maize-cover crop rotation and no-till practice. For the year 2015, soybean was planted in all three field instead of seed maize. All fields have very similar topography and soil properties. Predominant soil at the BREBS field is Hasting silt loam, which is a well-drained loamy upland soil with high available water holding capacity (average field capacity: 32% vol. and permanent wilting point: 20% vol.). The other two fields (East and West) have similar silt loam soils, including Butler and Muir silt loam. Almost same amount of organic matter content (OMC) was observed in all three fields with an average value of 1.22% in the BREBS field and 2.15% in the West and East fields. The particle size distribution of BREBS field is 31.2% clay, 8.6% silt and 60.2% sand, with an average saturated hydraulic conductivity of 4.6 µm/s. Very similar particle size distribution was observed in West and East fields with 25.9% clay, 9.1% silt, 65% sand. Detailed description of the study sites has been described in Sharma et al., 2016.

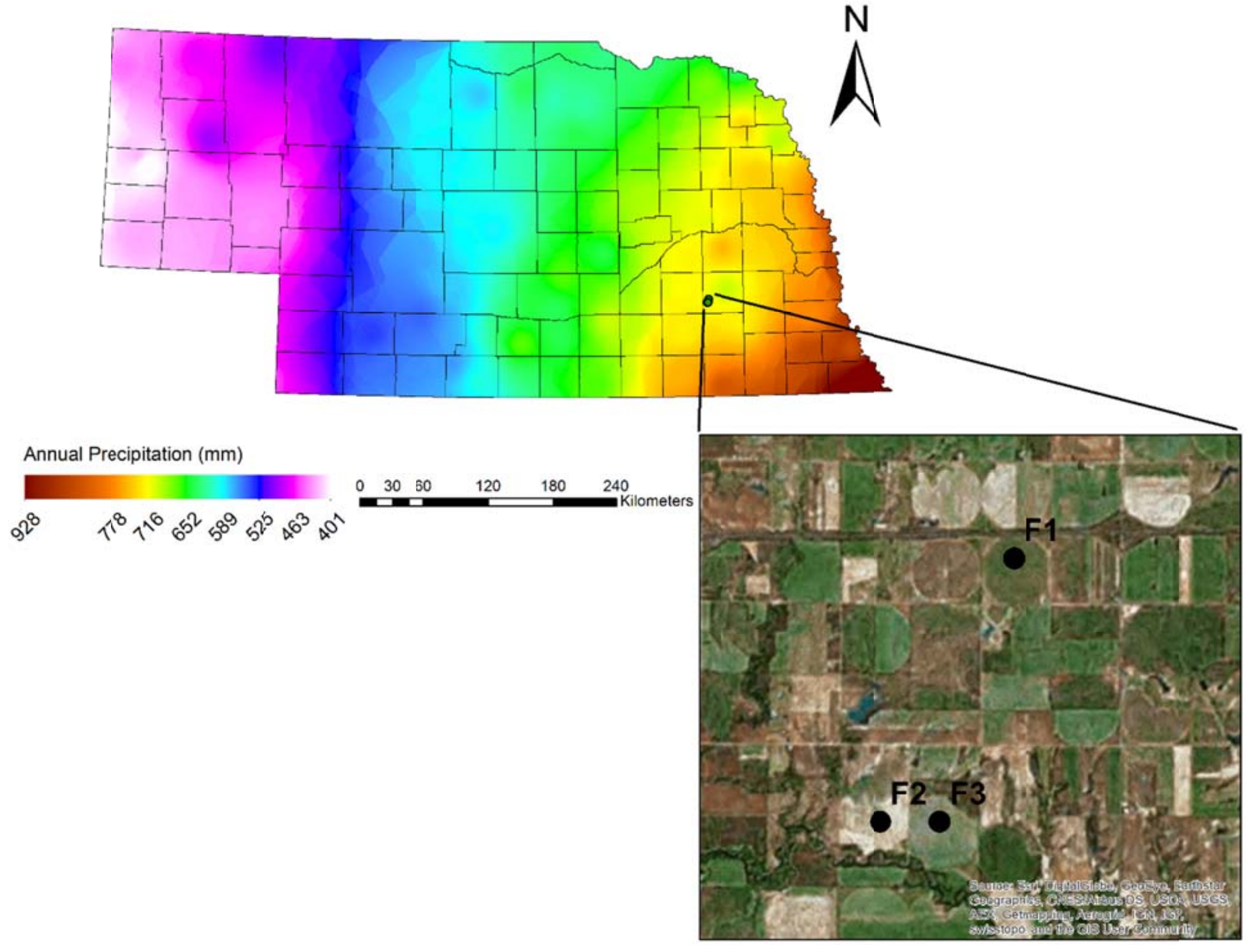
Experimental design and cover crop management practices

Four land cover treatments were created and evaluated in each individual year in all three fields: (i) cover crop only without seed maize or soybean residue (CC), (ii) cover crop mixtures planted in seed maize or soybean residue (SCCC), (iii) seed maize or soybean residue (SC) only without cover crops and (iv) bare soil (Bare soil) without any considerable seed maize or soybean residue. In addition to this, long term bare soil data was also collected from field F1 from 2012-2015. This was the area in field F1 where no planting has been done for than last 10 years. The cover crop treatment (CC) in this research represented the conditions when there is only cover crop without any seed maize or soybean residue from the previous crop. The SCCC treatment represented the conditions where cover crops are planted in the seed-maize or soybean residue after harvest or broadcasted within the maize or soybean plants around physiological maturity before harvest. The SCCC treatment represents the actual production system that growers typically practice in the Midwest. The SC treatment corresponds to condition where there is no cover crop after seed maize or soybean harvest and only seed maize or soybean residue existed in the plot. Bare soil treatment refers to the bare soil plot in the field with no seed maize, soybean, cover crop or any other crop cultivated for several years. All the plots in three fields were maintained throughout the research period. It was made sure that during the seed maize or soybean planting, CC and bare soil plots do not get any seed. In addition, bare soil and SC plots were covered with tarp whenever cover crop seeds were broadcasted so that these plots do not get any cover crop seeds. Weeds and other unwanted plants like volunteer corn were manually uprooted on regular basis from all the plots. Though, the plots in all three fields were created and maintained since 2012, soil sampling in F2 and F3 fields was started from spring 2014. In F2 and F3 field, the effect of these land cover treatments was evaluated over the four (2014 spring, 2014 fall, 2015 spring and 2015 fall) seasons. In 2015 fall, cover crop was planted only in the west field, however, all four plots were maintained in all three field in order to see the effect of long term cover cropping and no-till practice on soil properties. The seasons and corresponding treatments evaluated in each field are well explained in Table 1. Overall, the effect of four land cover treatments was on the soil properties were studied over four (2014 spring, 2014 fall, 2015 spring and 2015 fall) seasons. Because only 2014 spring, 2015 fall, 2015 spring and 2015 fall seasons have data for all the treatments (bare soil, CC, SC and SCCC) (Table 1), the statistical analysis was performed only on these three seasons.

Table 15. Seasons and corresponding treatments evaluated in each filed.

Season	Fields	CC	SCCC	Bare	SC	Bare Road
2012 spring	F1		☐			☐
	F2					
	F3					
2012 Fall	F1		☐			☐
	F2					
	F3					
2013 Spring	F1		☐			☐
	F2					
	F3					

2013 Fall	F1		☐			☐
	F2					
	F3					
2014 Spring	F1	☐	☐	☐	☐	☐
	F2	☐	☐	☐	☐	
	F3	☐	☐	☐	☐	
2014 Fall	F1	☐	☐	☐	☐	☐
	F2	☐	☐	☐	☐	
	F3	☐	☐	☐	☐	
2015 Spring	F1	☐	☐	☐	☐	☐
	F2	☐	☐	☐	☐	
	F3	☐	☐	☐	☐	
2015 Fall	F1	☐	☐	☐	☐	☐
	F2	☐	☐	☐	☐	
	F3	☐	☐	☐	☐	



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 10. Location of three research fields with annual precipitation variation in the state of Nebraska, USA.

Cover crop mixes (more than one cover crop) were used in all the three fields in all seasons except filed F2 in 2012-2013 and 2015-2016 and F1 2013-2014 when single cover crop was grown (Table 2). Cover crop mixtures were used to ensure good soil cover across variety of conditions as different cover crops may respond differently to varying soil, management, and weather conditions. Also, cover crops were planted either into the existing seed maize/soybean or after harvest of seed-maize before the next crop was planted the following spring. Table 2 represents the information about the cover crop mixtures, cover crop planting dates, seed maize harvesting dates, cover crop termination dates, and some of the other agronomic management practices and dates for F1, F2 and F3 fields.

Table 16. Management information for three research fields for (2012-2013, 2013-2014, 2014-2015 and 2015-2016) cover crop growing seasons

2012-2013

Management	F1	F2	F3
Seed maize planting	22-Apr-12	29-Apr-12	30-Apr-12
Seed maize harvesting	21-Aug-12	28-Aug-12	28-Aug-12
CC planting	8-Sep-12	30-Aug-12	28-Aug-12
Method of CC planting	Drill	Drill	Broadcast
CC type	Winter pea, Common vetch, Hairy vetch, Cereal rye, Oats, Nitro- radish, and rapeseed	Forage sorghum	Turnip, Radish, and Ethiopian cabbage
CC termination date	30-Apr-13	Winter kill	Winter kill

2013-2014

Management	F1	F2	F3
Seed maize planting	11-May-13	1-Jun-13	24-May-13
Seed maize harvesting	2-Oct-13	10-Oct-13	9-Oct-13
CC planting	13-Oct-13	14-Aug-13	11-Aug-13
Method of CC planting	Drill	Broadcast	Broadcast
CC type	Cereal rye	Turnip, Radish	Turnip, Radish, millet, and Winter pea
CC termination date	6-May-14	Winter kill	Winter kill

2014-2015

Management	F1	F2	F3
Seed maize planting	17-May-14	8-May-14	7-May-14
Seed maize harvesting	26-Sep-14	25-Sep-14	25-Sep-14
CC planting	7-Aug-14	10-Aug-14	9-Aug-14
Method of CC planting	Broadcast	Broadcast	Broadcast
CC type	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage
CC termination date	Winter kill	Winter kill	Winter kill

2015-2016

Management	F1	F2	F3
Soybean planting	13-May-15	3-May-15	2-May-15
Soybean harvesting	7-Oct-15	3-Oct-15	10-Oct-15
CC planting	no cover crop	5-Oct-15	no cover crop
Method of CC planting		Drilled	
CC type		Cereal rye	
CC termination date			

F1: BREBS station field, F2: West Field, F3: East Field, CC: Cover Crop

Soil Sampling

In each cover crop growing season, two soil samplings were done, one in the spring, before the planting of cash crop and other in the fall season after the harvest of cash crop which is also the peak growing season for the cover crops. From 2014 spring to 2015 fall, four soil samplings were done; May 15, 2014; Nov 10, 2014; April 7, 2015 and Nov 5, 2015. Soil samples were collected from two locations in each land cover treatment plot from 0-1.2 m soil depth using Giddings soil sampling equipment for soil pH, electrical conductivity (EC), soil organic matter (SOM), soil phosphorous (P), Nitrate-Nitrogen (NO_3-N), total Nitrogen (N) and organic carbon (C) analysis. Two cores were mixed per depth and per treatment and sent to the soil processing laboratory to determine the above mentioned soil properties.

Data analysis

The experiment followed a randomized complete block design with three fields described in the study (F1, F2 and F3) as three replications or blocks. Each block has four treatments/plots (CC, SCCC, SC and bare soil; 4.5 m X 4.5 m each) throughout the study period. Treatments were repeated on the same plots in 2014 and 2015 seasons. Data for average C, N, pH, EC, SOM, NO_3-N and P over four seasons (2014 spring, 2014 fall, 2015 spring and 2015 fall) from each treatment was analyzed using Proc Glimmix Procedure in SAS program. Statistical significance was evaluated at $P<0.05$. In addition to that, extensive soil sampling data was collected from field F1 from 2012 to 2015 (table1) from two treatments (SCCC and long term bare soil) to see the long term impact of cover crops on soil properties. Also, percentage change between different seasons was evaluated.

RESULTS AND DISCUSSION

Cover Crop effect on Organic Carbon and Total Nitrogen

Cover crops had small but significant effects on the soil organic C and total N. Continuous cover cropping since 2012 resulted in small increase of organic C in SCCC treatment for 0-40 cm layer and total N in all soil layers. Concentration of C and N in all the four land cover treatments in four seasons are shown in Figure 2. Table 3 shows the average C and N concentration in all four seasons at all depths with standard errors shown in brackets. C concentration varied from 0.1% in SCCC treatment at 20-40 cm in 2015 fall to 2.29% in SCCC at 0-5 cm in 2015 spring and N concentration varied from 0.07% in SCCC at 60-120 cm in 2014 spring to 0.24% in SCCC at 0-5 cm in 2015 fall.

For top 0-5 cm soil depth, no significant difference existed in C and N concentration between the treatments in 2014 spring. However, in 2014 fall, there was significant difference between SCCC and bare soil treatment's C and N concentration. From 2014 spring to 2014 fall, cover crops and seed maize residue in SCCC treatment had increased C concentration by 2%, however, decreased N concentration by 9.5%. This decrease in N concentration in SCCC treatment might be due to the reason that 2014 fall soil sampling was done when seed maize was just harvested and cover crops were at their peak growth period, and most of the nitrogen in the top soil has been used up either by seed maize or cover crops. From 2014 fall to 2015 spring i.e., during the winter period, C and N concentration in SCCC plots had increased by 5% and 21%, respectively and CC plots by 10 % and 8%, respectively. There was no increase in N concentration for bare soil and SC plots from 2014 fall to 2015 spring. Comparing SCCC treatment (cover crops in seed maize/soybean) with SC treatment (no cover crops), we found that at the beginning of the experiment (figure 2a and 2e) N and C concentration at 0-40 cm soil in both treatments was approximately same or SC being higher than SCCC, however, at the end of the experiment in fall 2015 (figure 2d and 2h), N and C concentration in SCCC treatment at this depth was on average 12.5% and 32% higher than SC treatment, respectively. From 2014 spring to 2015 fall, in 0-20 cm soil depth, C concentration had decreased in all treatments except SCCC treatment. For 20-40 cm soil depth, plots with cover crops (CC and SCCC) had increased the C concentration by 9.1% and 22%, respectively. No definite trend was observed in the depths lower than 40 cm. Compared to the beginning of the experiment in spring 2014, there was an increase in N concentration in all treatments (table 4), with maximum increase in SCCC treatment at all depths expect 0-5 cm, ranging from 38% to 95% increase in 2015 fall. The results of change in C and N concentration with incorporation of cover crops in seed maize/soybean cover crop rotation from 2012 fall to 2015 fall at 5 soil depths in F1 field are shown in figure 5. From these results we found that there is no to very little increase in C and N concentration from 2012 to 2015, however, difference between bare soil and SCCC treatment had widened in 2015, with SCCC being higher than bare soil for 0-5 cm soil depth. From the above mentioned results we found that cover crops helped in maintaining the C and N concentrations in soil during fallow periods in the cropping systems by taking up nutrients, especially N, that would be lost if plants are not present and then giving them back to the soil by decomposition during winter.

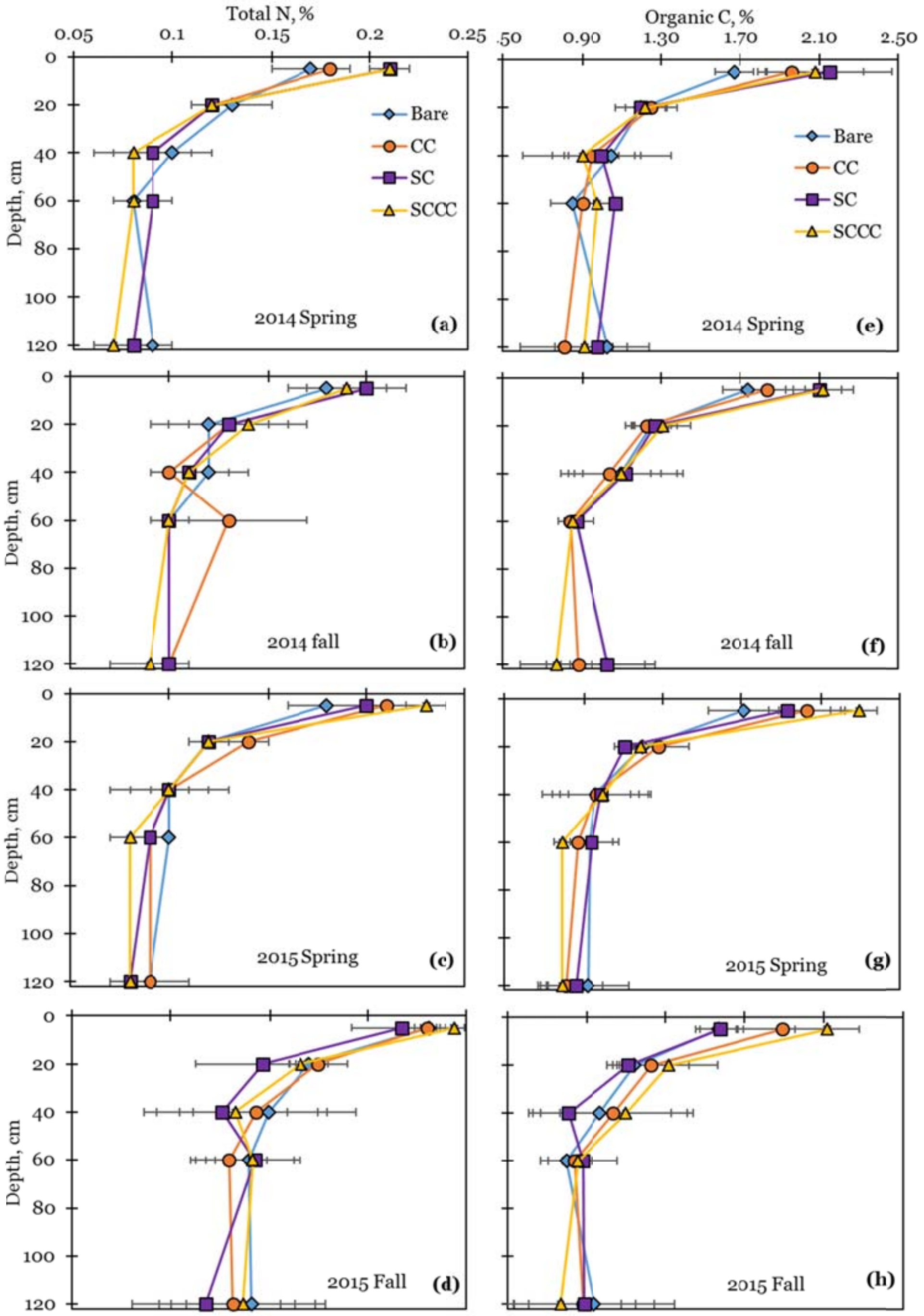


Figure 11. Depth distribution of organic C (a-d) and total N (e-h) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring, and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 17. Average Organic Carbon (C) and Total Nitrogen (N) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

		Soil depths (cm)									
Season	Treatment	0-5		5-20		20-40		40-60		60-120	
		Organic C (%)	Total N (%)	Organic C (%)	Total N (%)	Organic C (%)	Total N (%)	Organic C (%)	Total N (%)	Organic C (%)	Total N (%)
2014 Spring	SC	2.15(0.32)a	0.21(0.01)a	1.2(0.13)a	0.12(0.01)a	1(0.17)a	0.09(0.02)a	1.08(0.02)a	0.09(0.01)a	0.98(0.15)ab	0.08(0.01)a
	SCCC	2.08(0.24)a	0.21(0.01)a	1.22(0.1)a	0.12(0.01)a	0.9(30)a	0.08(0.02)a	0.98(0.07)a	0.08(0)a	0.9(0.15)ab	0.07(0.01)a
	CC	1.96(0.17)a	0.18(0.01)a	1.25(0.13)a	0.12(0.01)a	0.95(0.14)a	0.09(0.01)a	0.9(0)a	0.09(0.01)a	0.83(0.22)b	0.08(0.01)a
	BARE	1.66(0.1)a	0.17(0.02)a	1.2(0.13)a	0.13(0.02)a	1.05(0.3)a	0.1(0.02)a	0.85(0.11)a	0.08(0.01)a	1.03(0.21)a	0.09(0.01)b
2014 Fall	SC	2.1(0.17)b	0.2(0.02)a	1.27(0.11)a	0.13(0.02)a	1.12(0.26)a	0.11(0.02)a	0.87(0.09)a	0.1(0.01)a	1.03(0.19)a	0.1(0)a
	SCCC	2.12(0.09)b	0.19(0.02)a	1.31(0.14)a	0.14(0.03)a	1.1(0.2)a	0.11(0.01)a	0.85(0.04)a	0.1(0.01)a	0.77(0.18)a	0.09(0.02)a
	CC	1.89(0.13)a	0.2(0.02)a	1.23(0.11)a	0.13(0.03)a	1.04(0.21)a	0.1(0.01)a	0.84(0.02)a	0.13(0.04)a	0.88(0.16)a	0.1(0.01)a
	BARE	1.74(0.13)a	0.18(0.02)b	1.25(0.1)a	0.12(0.03)a	1.11(0.31)a	0.12(0.02)a	0.87(0.09)a	0.1(0.01)a	1.03(0.24)a	0.1(0.01)a
2015 Spring	SC	1.93(0.22)a	0.2(0.02)ab	1.11(0.05)a	0.12(0)a	0.99(0.25)a	0.1(0.02)a	0.94(0.14)a	0.09(0.01)a	0.86(0.14)a	0.08(0.01)a
	SCCC	2.29(0.09)b	0.23(0.01)a	1.19(0.02)a	0.12(0.01)a	1(0.18)a	0.1(0.01)a	0.79(0.04)a	0.08(0.01)a	0.79(0.12)a	0.08(0.01)a
	CC	2.03(0.19)ab	0.21(0)ab	1.28(0.15)a	0.14(0.01)a	0.96(0.18)a	0.1(0.02)a	0.87(0.08)a	0.09(0)a	0.81(0.13)a	0.09(0)a
	BARE	1.71(0.18)a	0.18(0.02)b	1.2(0.05)a	0.12(0.01)a	1.03(0.27)a	0.1(0.03)a	0.93(0.12)a	0.1(0)a	0.92(0.21)a	0.09(0.02)a
2015 Fall	SC	1.57(0.12)a	2.22(0.02)a	1.11(0.11)a	0.15(0.03)a	0.81(0.18)a	0.13(0.03)a	0.88(0.18)a	0.142(0.01)a	0.89(0.36)a	0.12(0.03)a
	SCCC	2.12(0.16)b	0.24(0.005)a	1.31(0.24)a	0.17(0.006)a	1.1(0.33)a	0.13(0.04)a	0.85(0.07)a	0.14(0.02)a	0.77(0.31)a	0.14(0.04)b
	CC	1.89(0.23)b	0.23(0.006)a	1.23(0.19)a	0.17(0.014)a	1.04(0.37)a	0.14(0.03)a	0.84(0.04)a	0.13(0.01)a	0.88(0.27)a	0.13(0.03)ab
	BARE	1.56(0.09)a	0.23(0.004)a	1.14(0.08)a	0.17(0.007)a	0.97(0.36)a	0.15(0.04)a	0.79(0.13)a	0.14(0.02)a	0.94(0.40)a	0.14(0.03)b

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 18. Percentage change in Organic Carbon (C) and Total Nitrogen (N) from one season to another in four land cover treatments.

Depth, cm	Treatment	1		2		3		4	
		Organic C	Total N	Organic C	Total N	Organic C	Total N	Organic C	Total N
0-5	Bare	4.2	5.9	-1.7	0.0	-8.6	28.0	-6.4	35.5
	CC	-6.1	11.1	10.3	5.0	-6.9	9.4	-3.6	27.6
	SC	-2.3	-4.8	-8.1	0.0	-18.5	8.5	-26.8	3.3
	SCCC	1.9	-9.5	8.0	21.1	-7.6	6.1	1.8	16.2
5-20	Bare	4.2	-7.7	-4.0	0.0	-4.7	41.7	-4.7	30.8
	CC	-1.6	8.3	4.1	7.7	-4.2	24.8	-1.9	45.6
	SC	5.8	8.3	-12.6	-7.7	0.0	21.9	-7.5	21.9
	SCCC	7.4	16.7	-9.2	-14.3	10.4	38.1	7.7	38.1
20-40	Bare	4.8	20.0	-12.7	-16.7	0.7	49.3	-7.9	49.3
	CC	9.5	11.1	-7.7	0.0	8.0	43.0	9.1	58.9
	SC	12.0	22.2	-11.6	-9.1	-18.5	26.0	-19.3	40.0
	SCCC	22.2	37.5	-9.1	-9.1	10.0	32.7	22.2	65.8
40-60	Bare	2.4	25.0	6.9	0.0	-14.3	39.3	-6.3	74.2
	CC	-6.7	44.4	3.6	-30.8	-3.8	43.7	-7.0	43.7
	SC	-18.7	11.1	8.0	-10.0	-6.4	58.1	-17.8	58.1
	SCCC	-13.3	25.0	-7.1	-20.0	8.0	76.7	-12.9	76.7
60-120	Bare	0.0	11.1	-10.7	-10.0	2.2	56.3	-8.7	56.3
	CC	8.6	25.0	-8.0	-10.0	8.6	45.9	8.6	64.2
	SC	5.1	25.0	-16.5	-20.0	3.1	47.1	-9.5	47.1
	SCCC	-15.4	28.6	2.6	-11.1	-3.0	70.4	-15.8	94.8

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

Cover Crop effect on pH and EC

Comparison of depth distribution of soil pH and EC from four land cover treatments is shown in figure 3 and table 5. Within each soil depth, on three field average basis, there was no significant change in soil pH due to treatments (Table 5). Though not significant, pH in SCCC and CC treatment at the end of the experiment in 2015 fall was always higher than that of SC treatments by 0.1 to 0.3 units for top 0-5 cm soil. This shows that the treatments with cover crops and residue from the previous crop (CC and SCCC) helped in increasing the alkalinity in top soils as compared to bare soil. There was no specific increasing or decreasing trends at lower depths. This might be due to the high buffering capacity of the soil below 5 cm soil depth or possibly the short duration of the study. Average pH value varied from 6.9-7.2, 7.2-7.3, 6.9-7.3 and 7.1-7.4 during 2014 spring, 2014 fall, 2015 spring and 2015 fall, respectively, within 0-5 cm soil depth for all the four land cover treatments. Overall the pH value in four seasons at all depths and treatments varied from 6-7.4.

After cover crop termination in spring 2015, EC in the 5-20, 20-40, 40-60 and 60-120 cm soil depths in SCCC treatment was 33 %, 34 %, 40 %, and 31 %, respectively, lower ($P < 0.05$) than that in bare soil plots (Table 6). Similarly, in CC treatment, EC in 20-40, 40-60 and 60-120 cm soil depths was 44 %, 43 % and 49 % lower ($P<0.05$) than bare soil treatments in spring 2015 (Table 5). It was also observed that SC treatment (surface covered with seed maize residue) in 5-20 and 20-40 cm also lowered the soil EC ($P<0.05$) by 41% than that of bare soil treatment. Compared to the beginning of the experiment in spring 2014, CC and SCCC treatments has decreased the soil EC at all depths ranging from 7.3% decrease to 74% in fall 2015 (Table 6). This decrease in EC of soil might be due to the decrease in soil moisture in these treatments. Water content and soil management plays a major role in soil's electrical conductivity. Since, cover crops reduce the soil water due to high rate of transpiration, it might be possible that this decrease in soil moisture decreased the EC of the soil. The other reason might be the reduction in soil compaction by cover crops. Hamedeh and Reeder (2000) reported a decrease in thermal conductivity of soil with decreasing soil density. It has been found that for all treatments and for all depths, the lowest EC was observed in fall season. This might be due to the fact that the fall soil sampling was done right after the seed maize harvest and at the peak growing season of cover crops. At this time, due to higher transpiration rates of cover crops and water used by previous cash crop decreased the soil moisture thus decreased the EC of all treatments. Maximum average EC was observed in bare treatment during 2015 spring at all depths. Figure 5 shows the change in pH and EC in SCCC and long term bare treatment from 2012 to 2015 in Field F1. From the figure it is clear that cover crops and seed maize residue maintains a higher soil pH as compared to long term bare soil, where no cultivation has been done for more than 15 years. The difference between pH of bare soil and SCCC treatment has increased after 4 years cover cropping at all depths. EC at depths lower than 5 cm did not vary much from bare soil, however, top soil (0-5 cm) difference has increased from 2012 to 2015. EC for all depths was higher in bare soil than SCCC treatment.

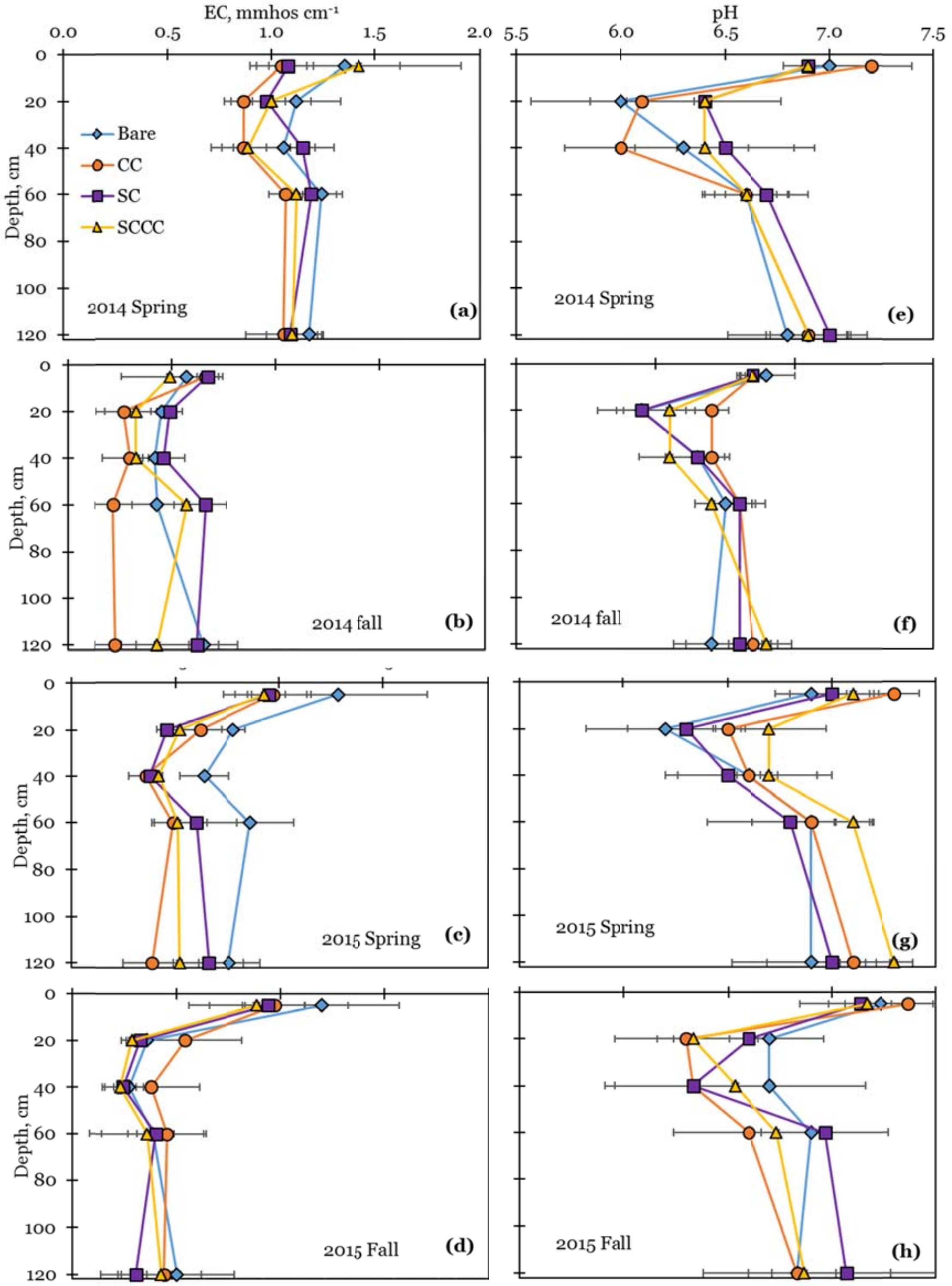


Figure 12. Depth distribution of EC (a-d) and pH (e-h) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring, and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 19. Average pH and Electrical Conductivity (EC) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

		Soil depths (cm)									
Season	**Treatment**	**0-5**		**5-20**		**20-40**		**40-60**		**60-120**	
		pH	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**
2014 Spring	SC	6.9(0.2) a	1.09(0.09)a	6.4(0.23)a	0.99(0.09)ab	6.5(0.24)a	1.15(0.06)a	6.7(0.35)a	1.19(0.15)a	7(0.48)a	1.09(0.11)a
	SCCC	6.9(0.03) a	1.43(0.49)a	6.4(0.37)a	1.02(0.19)ab	6.4(0.43)a	0.9(0.18)a	6.6(0.2)a	1.12(0.05)a	6.9(0.18)a	1.11(0.12)a
	CC	7.2(0.2) a	1.05(0.15)a	6.1(0.25)a	0.87(0.1)b	6(0.27)a	0.87(0.11)a	6.6(0.15)a	1.07(0.08)a	6.9(0.2)a	1.06(0.18)a
	BARE	7.0(0.2) a	1.35(0.27)a	6(0.43)a	1.13(0.21)a	6.3(0.31)a	1.06(0.24)a	6.6(0.21)a	1.25(0.07)a	6.8(0.29)a	1.19(0.07)a
2014 Fall	SC	7.2(0.06) a	0.67(0.05)a	6.4(0.19)a	0.49(0.06)a	6.8(0.23)a	0.46(0.1)a	7.1(0.19)a	0.66(0.1)b	7.1(0.38)a	0.61(0.2)a
	SCCC	7.2(0.1) a	0.49(0.23)a	6.6(0.33)a	0.33(0.15)a	6.6(0.22)a	0.33(0.16)a	6.9(0.12)a	0.57(0.06)b	7.3(0.03)a	0.43(0.17)a
	CC	7.2(0.1) a	0.66(0.08)a	6.9(0.12)a	0.27(0.13)a	6.9(0.09)a	0.3(0.13)a	7.1(0.1)a	0.22(0.09)a	7.2(0.18)a	0.23(0.1)a
	BARE	7.3(0.2) a	0.57(0.09)a	6.4(0.32)a	0.45(0.01)a	6.8(0.23)a	0.42(0.03)a	7(0.22)a	0.43(0.12)ab	6.9(0.27)a	0.65(0.07)a
2015 Spring	SC	7.0(0.2) a	0.95(0.08)a	6.3(0.28)a	0.46(0.03)b	6.5(0.24)a	0.38(0.04)b	6.8(0.4)a	0.6(0.2)ab	7(0.31)a	0.66(0.17)a
	SCCC	7.1(0.1) a	0.93(0.2)a	6.7(0.27)a	0.52(0.11)b	6.7(0.23)a	0.42(0.01)b	7.1(0.09)a	0.51(0.12)b	7.3(0.09)a	0.52(0.11)b
	CC	7.3(0.1) a	0.97(0.18)a	6.3(0.06)a	0.63(0.15)ab	6.5(0.06)a	0.36(0.08)b	6.9(0.12)a	0.49(0.02)b	7.1(0.06)a	0.39(0.14)b
	BARE	6.9(0.2) a	1.28(0.43)a	6.2(0.38)a	0.79(0.06)a	6.6(0.4)a	0.64(0.12)a	6.9(0.28)a	0.87(0.21)a	6.9(0.38)a	0.77(0.15)a
2015 Fall	SC	7.1(0.15)a	0.94(0.38)a	6.6(0.36)a	0.33(0.04)a	6.3(0.38)a	0.25(0.05)a	7(0.31)a	0.4(0.09)a	7.1(0.47)a	0.30(0.17)a
	SCCC	7.2(0.06)a	0.89(0.23)a	6.3(0.64)a	0.29(0.05)a	6.5(0.83)a	0.23(0.08)a	6.7(0.23)ab	0.36(0.28)a	6.9(0.38)a	0.43(0.19)ab
	CC	7.4(0.31)a	0.97(0.14)a	6.3(0.35)a	0.54(0.28)a	6.3(0.38)a	0.38(0.23)a	6.6(0.36)b	0.45(0.19)a	6.8(0.45)a	0.44(0.08)ab
	BARE	7.2(0.32)a	1.19(0.38)a	6.7(0.17)a	0.36(0.02)a	6.7(0.62)a	0.27(0.07)a	6.9(0.0)ab	0.39(0.24)a	6.8(0.15)a	0.5(0.28)b

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 20. Percentage change in pH and Electrical Conductivity (EC) from one season to another in four land cover treatments.

Depth, cm	Treatment	1		2		3		4	
		pH	EC	pH	EC	pH	EC	pH	EC
0-5	Bare	4.3	-57.8	-5.5	124.6	4.8	-6.6	3.3	-11.5
	CC	0.0	-37.1	1.4	47.0	0.9	0.3	2.3	-7.3
	SC	4.3	-38.0	-2.8	41.8	1.9	-1.1	3.4	-13.0
	SCCC	4.3	-65.5	-1.4	89.8	0.9	-4.7	3.9	-37.6
5-20	Bare	6.7	-59.8	-3.1	73.3	8.1	-53.8	11.7	-67.9
	CC	13.1	-69.0	-5.8	129.6	-3.1	-12.9	3.3	-37.9
	SC	0.0	-50.0	-1.6	-6.1	4.8	-29.0	3.1	-66.7
	SCCC	3.1	-67.0	1.5	57.6	-5.5	-44.9	-1.0	-71.3
20-40	Bare	7.9	-60.4	-2.9	52.4	1.5	-57.3	6.3	-74.2
	CC	15.0	-65.5	-4.3	20.0	-4.0	5.6	5.6	-56.3
	SC	4.6	-60.0	-4.4	-17.4	-2.6	-35.1	-2.6	-78.6
	SCCC	3.1	-62.9	1.5	27.3	-2.5	-44.4	2.1	-73.8
40-60	Bare	6.1	-65.3	-1.4	100.0	0.0	-55.0	4.5	-68.8
	CC	7.6	-79.4	-2.8	122.7	-4.3	-7.5	0.0	-57.6
	SC	6.0	-44.5	-4.2	-9.1	2.5	-33.3	4.0	-66.4
	SCCC	4.5	-49.1	2.9	-10.5	-5.2	-29.4	2.0	-67.9
60-120	Bare	1.5	-44.9	0.0	16.9	-1.0	-34.2	0.5	-57.6
	CC	4.3	-78.3	-1.4	69.6	-3.8	12.8	-1.0	-58.5
	SC	1.4	-43.1	-1.4	6.5	1.0	-53.5	1.0	-71.9
	SCCC	5.8	-60.9	0.0	20.9	-5.9	-17.9	-0.5	-61.2

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

Cover Crop effect on Soil Organic matter, Nitrate Nitrogen and Phosphorous

Profile distribution of SOM, NO_3-N and extractable P are shown in figure 4 and table 7 and 8. No significant difference in SOM was observed between the treatments at 0-60 cm soil depth for Spring 2014, however, in fall 2014, SOM in all treatments were significantly higher than bare soil, where CC and SCCC being the highest with 3% SOM (Table 7) for 0-5 cm. Similar trends were observed for lower depths, though not significant. Lowest average SOM content was observed in bare soil treatment within 0-5 cm soil depth in all the three seasons. The reason behind the lower SOM in bare soil was that the fall 2014 sampling was done on Nov 10, 2014, right after the corn harvest and at peak cover crop growing period. Since all the plots, except bare soil plot had some residue from the harvested corn crop or the active cover crop, SOM values were higher in these plots. Average SOM content varied from 2.5-3.3%, 1.7-2.2%, 1.5-1.9%, 1.3-2% and 1.4-1.9% at 0-5, 5-20, 20-40, 40-60 and 60-120 cm depth, respectively, for all the treatments over four seasons (Table 7). Among the four land cover treatments, highest average SOM content during 2014 spring, 2014 fall, 2015 spring and 2015 fall in top 5 cm soil was found to be in SC, CC, SCCC and SCCC treatment, respectively. Within 5-20 cm soil depth, highest average SOM content was in CC during 2014 spring, 2015 spring and 2015 fall and in SCCC during 2014 fall. This shows that in top 20 cm of soil, cover crops (CC) and cover crops with seed maize residue (SCCC) increased the SOM as compared to other treatments. This is because the residue contribution by the cover crops is the greatest source of SOM. Also, the residue from previous crop is equally important in SOM improvement. From 2014 fall to 2015 fall SOM in SCCC treatment at 0-5 cm soil had increased from 3% to 3.3%. Table 9 shows the percentage change in SOM from spring 2014 to fall 2014; from fall 2014 to spring 2015; from spring 2015 to fall 2015 and from spring 2014 to fall 2015. For 5-120 cm soil depth, plots with cover crops (CC and SCCC) had increased the SOM ranging from 10% increase to 29 % increase from 2014 spring to 2015 fall. This increase ranged from 6 to 17% in bare soil. Comparing SCCC (cover crops in seed maize/soybean) with SC treatment (no cover crops), from 2014 spring to 2015 fall, SCCC treatment showed an increase in SOM for 0-60 cm soil profile ranging from 5.4% to18%, much higher than SC treatment which showed 1 % and 1.8% decrease in SOM at 0-5 cm and 20-40 cm soil depth. Although, residue from cover crops (mainly radish, turnips and Ethiopian cabbage) is highly decomposable, big changes in SOM were not detectable in this study. The reason behind this might be the shorter duration of the study. Also, more sensitive measures like microbial biomass C and particulate organic matter may be required to able to detect changes in SOM resulting from cover cropping (Gruver et al.,2016). From 2012-2015, changes in SOM in SCCC and long term bare soil in F1 filed are shown in figure 5. As mentioned above, only for the top 5 cm soil depth, cover crops in previous crops residue (SCCC) maintained a higher SOM than bare soil. For all other lower depths, SOM in SCCC plots was equal or lower than the bare soil.

Depth distribution of NO_3-N concentration clearly indicates an impact due to cover crops (figure 4 (e-h)). Results from the fall soil sampling in 2014, indicates that cover crops (actively growing at the time), scavenged the residual N following the summer seed corn crop (Tables 7 and 9) and reduces its concentration in soil. Comparing to spring 2014, CC and SCCC plots had decreased the NO_3-N concentration ranging from by 68% in CC at 20-40 cm soil profile to 91% in SCCC at 0-5 cm in fall 2014 (Table 9). The reduction in NO_3-N concentration in this period in bare and SC plots was lower than CC and SCCC plots, ranging from 0% in bare soil in 40-60 cm to 83% in SC in 60-120 cm. These results showed that cover crops helped in scavenging residual N from the soil after the cash crop has been harvested. The soil sampling results of 2015 spring indicates an increase in NO_3-N as compared to fall 2014 at all depths (Table 9). This percentage increase was highest in CC and SCCC treatments ranging from 40% in SCCC at 60-120 cm to 860% in CC treatment at 5-20 cm (Table 9). This increase can be explained by the fact that during winters, when cover crops are no longer transpiring or dead, they decompose slowly and immobilize N. Significant differences were observed in NO_3-N concentration between bare soil and other treatments which either have cover crops or residue cover for fall 2014 and spring 2015 in soil depths 20-120 cm (Table 7). Overall, from 2014 spring to 2015 fall, CC plots showed an increase in NO_3-N at all depths ranging from 25% to 319%, however, SCCC treatment showed a decrease ranging from 8.3 %to 71% at 5-120 cm. This might be due to the reason that last soil sampling that was done in fall 2015 was right after the soybean harvesting. At that time, SCCC plots had less NO_3-N than CC plots as it was used up by soybeans in the growing season nut there was no soybean in the CC plots. Also, in figure 5, from 2012 to 2015, there was a decrease in NO_3-N concentration in SCCC treatments for 0-40 cm soil depth. Lower depths remained unchanged.

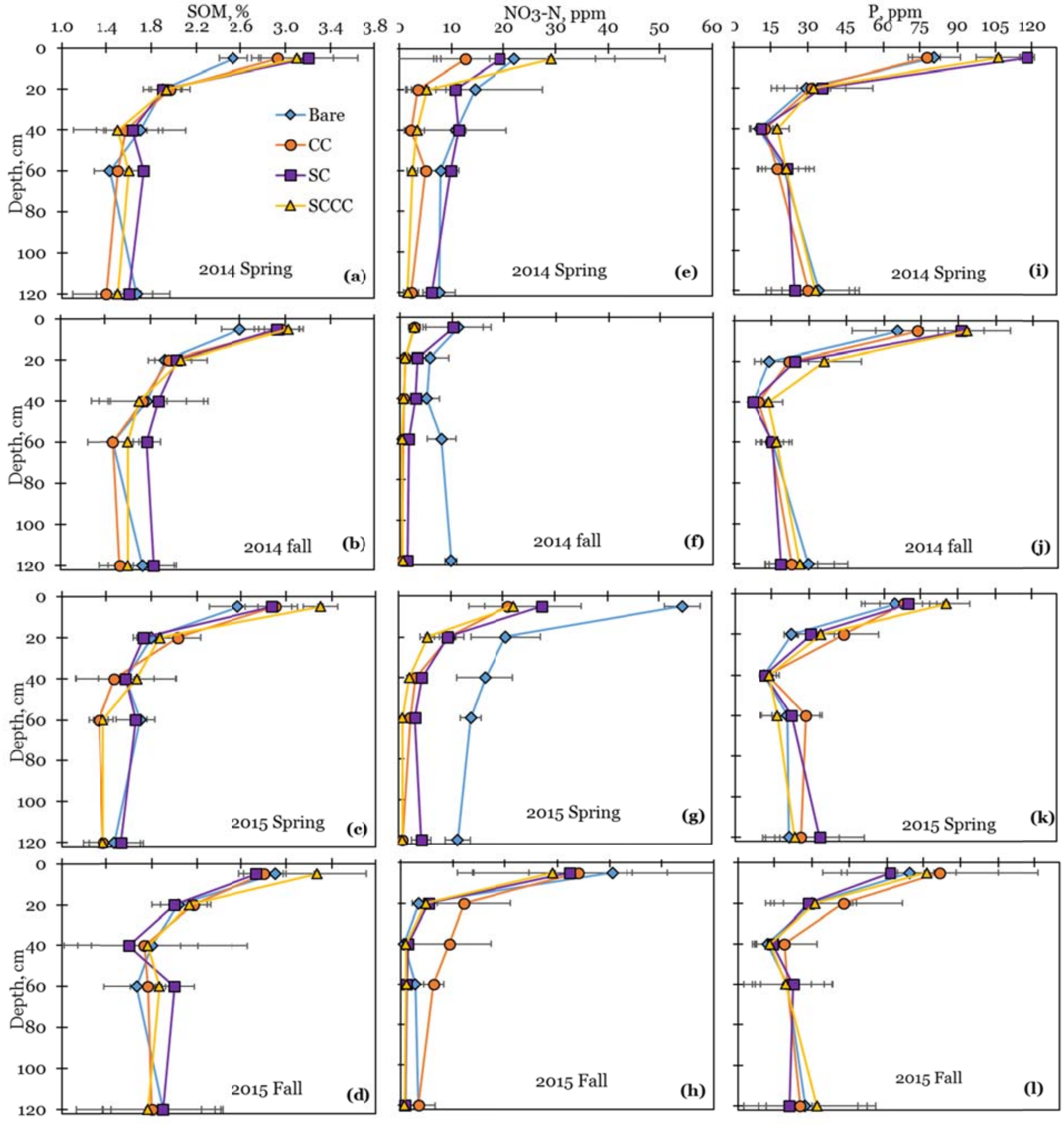


Figure 13. Depth distribution of SOM (a-d), NO_3-N (e-h) and P (i-l) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Figure 4 (i-l) shows the profile distribution of P in four land cover treatments in three seasons. Some changes in the soil P can be seen in the upper depths of soil (0-20 cm), however, P in the lower depths seems to be unchanged from one season to another. At the beginning of the experiment in spring 2014, SC and SCCC treatments had the highest concentration of P at 0-5 cm soil depth, which was significantly higher than bare soil and CC plots (Table 9). In fall 2014, P level in all the treatments at all depths has dropped except SCCC treatment at 5-20 cm soil depth where P concentration has increased by 11.5% as compared to spring 2014. The maximum percentage decrease (52%) was observed in bare soil treatment at 5-20 cm depth. Results from the soil sampling done in spring 2015 revealed that cover crops residue over the winter period had increased the P concentration in soil (Table 9) except 0-5 cm soil depth. P concentration in CC plots had increased from 2014 fall to 2015 spring, ranging from 16.1% increase at 60-120 cm soil depth to 99% increase at 5-20 cm depth. However, for top 20 cm of soil, SCCC treatment had reduced the P levels in soil. Overall, from 2014 spring to 2015 fall, SCCC treatment had decreased the P concentration in soil whereas there was an increase in P concentration in CC plots at 0-60 cm soil depth. The opposite trend of two cover crop treatments can be attributed to summer cash crop usage of P. In all summers during the study period, SCCC plots had cash crop which used the soil P thus reducing its concentration as compared to CC plots where there was no cash crop in summer. The increase of P concentration in CC plots in top 0-60 cm can be attributed to root dry matter of cover crops (mostly radish and turnips) which contains more than 0.5% of P (Gruver et al., 2016) when it decomposes in winter. Cover crops in previous seasons residue (SCCC) maintained a higher P concentration than bare soil for all soil depths (figure 5).

Table 21. Average Soil Organic Matter (SOM) and Nitrate-Nitrogen (NO_3-N) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

		Soil depths (cm)									
Season	Treatment	0-5		5-20		20-40		40-60		60-120	
		SOM (%)	NO_3-N (ppm)	SOM (%)	NO_3-N (ppm)	SOM (%)	NO_3-N (ppm)	SOM (%)	NO_3-N (ppm)	SOM (%)	NO_3-N (ppm)
2014 Spring	SC	3.2(0.44)a	19.2(9.55)a	1.9(0.17)a	10.6(2.58)a	1.6(0.23)a	11.3(2.1)a	1.7(0.03)a	9.8(5.85)a	1.6(0.21)ab	6.2(5.56)a
	SCCC	3.1(0.32)a	29.1(22)a	1.9(0.13)a	5.2(3.69)a	1.5(0.4)a	3.4(1.34)a	1.6(0.1)a	2.5(1.03)a	1.5(0.2)ab	1.6(0.79)a
	CC	2.9(0.23)a	12.5(4.63)a	2(0.18)a	3.5(1.15)a	1.6(0.19)a	2.2(0.95)a	1.5(0)a	5(0.85)a	1.4(0.31)b	2.3(1.46)a
	BARE	2.5(0.13)a	22.1(15.5)a	1.9(0.17)a	14.4(13.11)a	1.7(0.4)a	10.8(9.76)a	1.4(0.15)a	7.9(3.4)a	1.7(0.29)a	7.6(3.07)a
2014 Fall	SC	2.9(0.2)a	10.1(5.72)a	2(0.13)a	3.3(1.63)a	1.9(0.44)a	3(1.33)ab	1.8(0.12)a	1.7(0.77)a	1.8(0.18)a	1.4(0.19)a
	SCCC	3(0.13)a	2.7(0.44)a	2.1(0.23)a	1(0.17)a	1.7(0.25)a	0.7(0.15)a	1.6(0.15)a	0.4(0.07)a	1.6(0.17)a	0.5(0.12)a
	CC	3(0.15)a	2.7(1.07)a	2(0.12)a	1(0.09)a	1.7(0.39)a	0.7(0.12)a	1.5(0.03)a	0.6(0.06)a	1.5(0.19)a	0.4(0.03)a
	BARE	2.6(0.17)b	11.1(6.2)a	1.9(0.15)a	5.7(3.56)a	1.8(0.5)a	5.1(2.4)b	1.5(0.23)a	7.9(2.68)b	1.7(0.3)a	9.7(1.08)b
2015 Spring	SC	2.9(0.23)ab	27.5(7.45)a	1.7(0.09)a	9.3(1.53)ab	1.6(0.44)a	4.4(1.01)a	1.7(0.17)a	3.1(0.72)a	1.5(0.2)a	4.3(1.89)a
	SCCC	3.3(0.15)c	22(5.63)a	1.9(0.09)a	5.5(1.35)a	1.7(0.22)a	2(0.18)a	1.4(0.09)a	0.7(0.15)a	1.4(0.17)b	0.7(0.12)a
	CC	2.9(0.15)b	20.9(7.54)a	2(0.2)a	9.6(2.83)ab	1.5(0.35)a	3.2(0.33)a	1.3(0.09)a	2.2(0.64)a	1.4(0.18)b	0.7(0.03)a
	BARE	2.6(0.26)a	54.4(34.12)a	1.8(0.06)a	20.5(6.7)b	1.6(0.44)a	16.5(5.48)b	1.7(0.06)a	13.7(1.93)b	1.5(0.23)ab	11.2(2.35)b
2015 Fall	SC	2.7(0.2)a	32.3(18.8)a	2(0.2)a	5.3(1.58)a	1.6(0.5)a	1.4(0.72)a	2(0.2)a	1.1(0.61)a	1.9(0.5)a	0.9(0.73)a
	SCCC	3.3(0.45)b	27.2(15.2)a	2.1(0.15)a	4.8(1.40)a	1.8(0.75)a	1(0.81)ab	1.9(0.12)a	1.1(0.36)a	1.8(0.64)a	0.7(0.43)a
	CC	2.8(0.17)ab	34(9.3)a	2.2(0.15)a	12(9.12)a	1.7(0.47)a	9.2(7.9)b	1.8(0.15)a	6.3(1.84)b	1.8(0.44)a	3.4(0.70)a
	BARE	2.9(0.1)ab	40.5(29.7)a	2(0.15)a	3.5(1.26)a	1.8(0.85)a	0.7(0.1)a	1.7(0.28)a	2.8(3.32)ab	1.9(0.52)a	3.4(3.2)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 22. Average Soil Phosphorous (P) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

Season	**Treatment**	**Soil depths (cm)** **0-5** **P (ppm)**	**5-20** **P (ppm)**	**20-40** **P (ppm)**	**40-60** **P (ppm)**	**60-120** **P (ppm)**
2014 Spring	SC	118(3.06)a	35.7(20.2)a	11(4.84)a	21.7(8.74)a	24.7(5.17)a
	SCCC	106.3(8.88)a	32.3(6.64)a	17.7(4.67)a	21.3(11.3)a	33(17.52)a
	CC	77.7(5.49)b	31.3(13.6)a	12.7(5.78)a	17.7(8.41)a	30(16.5)a
	BARE	80.7(10.35)b	29.3(8.76)a	10.3(1.45)a	20.3(8.65)a	34.3(14.52)a
2014 Fall	SC	91(9.17)ab	24.3(13.4)ab	7.3(0.88)a	15.3(4.48)a	18.7(6.17)a
	SCCC	93.3(17.37)a	36(14.73)a	13.7(5.78)a	17(6.24)a	26.3(13.6)a
	CC	73.7(17)bc	22(7.64)ab	9.7(2.19)a	14.7(3.48)a	23(10.54)a
	BARE	65.7(18.66)c	14(6.03)b	7.3(1.33)a	15.3(6.89)a	29.7(15.71)a
2015 Spring	SC	70(11.5)a	30.7(9.33)ab	12.3(2.4)a	23(12.1)ab	34.3(17.89)a
	SCCC	85.3(9.39)a	34.7(9.39)ab	14(4)a	17.3(6.89)a	24.3(11.57)a
	CC	68.3(15.94)a	43.7(14.08)a	13.3(3.53)a	28.7(5.78)b	26.7(15.24)a
	BARE	64.7(13.86)a	23(2.89)b	12(0.58)a	21.3(6.01)ab	22(3.79)a
2015 Fall	SC	61.7(17.5)a	28.7(17.0)a	14.3(7.02)a	22.7(15.8)a	21(9.16)a
	SCCC	76.3(11.7)a	31.3(16.4)a	13.3(6.65)a	19.7(10.2)a	32(23.51)a
	CC	81.7(39.7)a	42.7(24.0)a	19(13.22)a	20.3(14.5)a	25.3(23.09)a
	BARE	69.7(35.4)a	30(16.3)a	12.3(4.7)a	20.3(17.9)a	27.3(24.90)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 23. Percentage change in Nitrate Nitrogen (NO_3-N), Soil Phosphorous (P) and Soil Organic Matter (SOM) from one season to another in four land cover treatments.

Depth, cm	Treatment	1			2			3			4		
		NO3-N	P	SOM	NO3-N	P	SOM	NO3-N	P	SOM	NO3-N	P	SOM
0-5	Bare	-49.8	-18.6	2.8	390.1	-1.5	-1.2	-25.6	7.7	12.8	83.1	-13.7	14.6
	CC	-78.4	-5.1	1.4	674.1	-7.3	-2.4	62.7	19.6	-3.4	172.0	5.1	-4.4
	SC	-47.4	-22.9	-8.4	172.3	-23.1	-2.0	17.6	-11.9	-4.8	68.4	-47.7	-14.6
	SCCC	-90.7	-12.2	-2.3	714.8	-8.6	8.9	32.6	-10.5	-1.0	0.2	-28.2	5.4
5-20	Bare	-60.4	-52.2	1.6	259.6	64.3	-6.7	-83.1	30.4	13.0	-75.9	2.4	7.0
	CC	-71.4	-29.7	0.0	860.0	98.6	3.6	25.0	-2.4	6.7	242.9	36.3	10.5
	SC	-68.9	-31.9	6.8	181.8	26.3	-14.8	-43.0	-6.6	15.6	-50.0	-19.7	5.3
	SCCC	-80.8	11.5	7.3	450.0	-3.6	-9.7	-13.3	-9.7	14.1	-8.3	-3.0	10.5
20-40	Bare	-52.8	-29.1	4.1	223.5	64.4	-11.3	-96.0	2.8	14.6	-93.8	19.7	5.9
	CC	-68.2	-23.6	10.2	357.1	37.1	-15.0	188.5	42.9	17.9	319.7	49.6	10.4
	SC	-73.5	-33.6	14.7	46.7	68.5	-16.0	-67.4	16.5	1.9	-87.3	30.3	-1.8
	SCCC	-79.4	-22.6	13.3	185.7	2.2	-1.8	-50.0	-4.8	5.8	-70.6	-24.7	17.8
40-60	Bare	0.0	-24.6	2.8	73.4	39.2	15.6	-79.8	-4.5	-2.0	-65.0	0.2	16.6
	CC	-88.0	-16.9	-2.0	266.7	95.2	-9.5	184.8	-29.2	32.8	25.3	14.9	17.8
	SC	-82.7	-29.5	2.3	82.4	50.3	-6.2	-63.4	-1.4	20.5	-88.4	4.5	15.6
	SCCC	-84.0	-20.2	0.0	75.0	1.8	-14.4	57.1	13.7	36.3	-56.0	-7.7	16.7
60-120	Bare	27.6	-13.4	3.6	15.5	-25.9	-15.0	-69.6	24.2	29.3	-55.3	-20.3	13.8
	CC	-82.6	-23.3	9.3	75.0	16.1	-10.5	381.0	-5.1	31.4	46.4	-15.6	28.6
	SC	-77.4	-24.3	14.4	207.1	83.4	-16.4	-79.8	-38.8	24.2	-86.0	-15.0	18.8
	SCCC	-68.8	-20.3	6.7	40.0	-7.6	-14.4	0.0	31.7	29.0	-56.3	-3.0	17.8

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

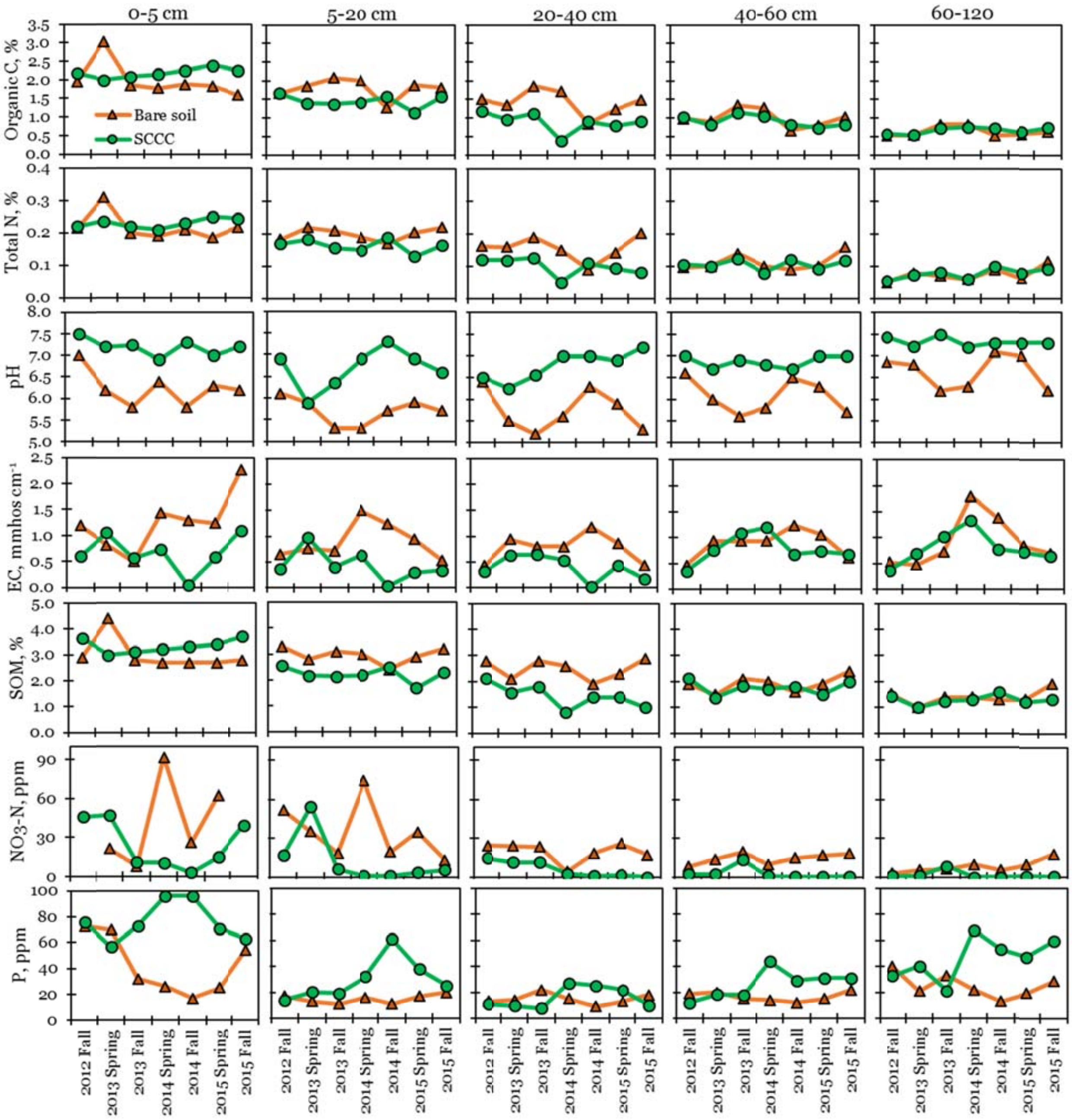


Figure 14. Soil organic C, total N, pH, EC, SOM, NO_3-N and P in SCCC plots as affected by no till and cover cropping, and bare soil in filed F1 from 2012-2015.

CONCLUSIONS

Results from this study show that cover crops have the potential to alter the soil chemical properties in south east region of Nebraska even in a very short time span. We found that cover crops significantly reduced the P and NO_3-N quantities in the soil when they are alive and actively growing. This can be attributed to their ability to scavenge residual N and P from the soil through their deep root system and rapid root extension, however, they also helped in providing N and P to the next cash crop by residue decomposition in the winter. We found that cover crops rapidly increase the top soil SOM by residue decomposition. Although, cover crops are highly decomposable, increase in SOM levels following cover crops was limited to the top soil (5-20 cm) only. This might be due to the shorter duration of the study or can be explained by the fact that more sensitive measures like microbial biomass C and particulate organic matter may be required to able to detect changes in SOM resulting from cover cropping. Cover crops had small but significant effects on the soil organic C and total N. Continuous cover cropping since 2012 resulted in small increase of organic C in SCCC treatment for 0-40 cm layer and total N in all soil layers. Comparing SCCC treatment (cover crops in seed maize/soybean) with SC treatment (no cover crops), we found that at the beginning of the experiment in spring 2014, N and C concentration at 0-40 cm soil in both treatments was approximately same or SC being higher than SCCC, however, at the end of the experiment in fall 2015, N and C concentration in SCCC treatment at this depth was on average 12.5% and 32% higher than SC treatment, respectively. No significant differences in C and N for different treatments were observed for the lower depths. Since, cover crops can conserve and/or maintain C and N concentrations in soil, they thereby help in improving soil quality and productivity. There was no significant change in soil pH due to treatment which might be due to the high buffering capacity of the soil below 5 cm soil depth or possibly the short duration of the study. Though not significant, on three field average basis, pH in SCCC and CC treatment at the end of the experiment in 2015 fall was always higher than that of SC treatments by 0.1 to 0.3 units for top 0-5 cm soil. On the other hand, compared to the beginning of the experiment in spring 2014, CC and SCCC treatments has decreased the soil EC at all depths of soil ranging from 7.3% decrease to 74% decrease in EC in fall 2015. Due to the short duration of the study, it is not known that how long these effects on soil properties will persist. Further research should investigate the long term impacts of cover crops on these selected soil properties. The results of this study are beneficial to the producers in Mid-west for better management of soil and water resources in cover crop production.

REFERENCES

Abdollahi, L., & Munkholm, L. J. (2014). Tillage system and cover crop effects on soil quality: I. chemical, mechanical, and biological properties. *Soil Sci. Soc. of Am. J., 78*(1), 262-270.

Abu-Hamdeh, N. H., & Reeder, R. C. (2000). Soil thermal conductivity effects of density, moisture, salt concentration, and organic matter. *Soil Sci. Soc. of Am. J., 64*(4), 1285-1290.

Alvarez, R., Diaz, R. A., Barbero, N., Santanatoglia, O. J., & Blotta, L. (1995). Soil organic carbon, microbial biomass and CO 2-C production from three tillage systems. *Soil and Tillage Res., 33*(1), 17-28.

Bauer, A., & Black, A. (1994). Quantification of the effect of soil organic matter content on soil productivity. *Soil Sci. Soc. of Am. J., 58*(1), 185-193.

Campbell, C., McConkey, B., Zentner, R., Selles, F., & Curtin, D. (1996). Tillage and crop rotation effects on soil organic C and N in a coarse-textured typic haploboroll in southwestern saskatchewan. *Soil and Tillage Res., 37*(1), 3-14.

Campbell, C. A., E. A. Paul and W. McGill. 1976. Effect of cultivation and cropping on the amounts and forms of soil N. p. 7-101. Proc. symp. on western can. on nitrogen, Calgary, Alberta, Canada.

Dabney, S. M. (1998). Cover crop impacts on watershed hydrology. *J. Soil and Water Conserv., 53*(3), 207-213.

Dabney, S., Delgado, J., & Reeves, D. (2001). Using winter cover crops to improve soil and water quality. *Commun. in Soil Sci. and Plant Analysis, 32*(7-8), 1221-1250.

De Rouw, A., Huon, S., Soulileuth, B., Jouquet, P., Pierret, A., Ribolzi, O., . . . Chantharath, B. (2010). Possibilities of carbon and nitrogen sequestration under conventional tillage and no-till cover crop farming (mekong valley, laos). *Agric., Ecosystems & Environ., 136*(1), 148-161.

Gruver, J., Weil, R. R., White, C., & Lawley, Y. (2016). Radishes- A new cover crop for organic farming systems. Organic Agriculture., 20160226. Retrieved from http://articles.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farming-systems

Hu, S., Grunwald, N., Van Bruggen, A., Gamble, G., Drinkwater, L., Shennan, C., & Demment, M. (1997). Short-term effects of cover crop incorporation on soil carbon pools and nitrogen availability. *Soil Sci. Soc. of Am. J., 61*(3), 901-911.

Irmak, S. (2010). Nebraska water and energy flux measurement, modeling, and research network (NEBFLUX). *Trans. ASABE, 53*(4), 1097-1115.

Kuo, S., Sainju, U., & Jellum, E. (1997). Winter cover crop effects on soil organic carbon and carbohydrate in soil. *Soil Sci. Soc. of Am. J., 61*(1), 145-152.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. (1972). Effects of increasing amounts of organic residues on continuous corn. II. Organic carbon, nitrogen, phosphorous, and sulphur. *Agron. J.* 64:204-208.

McCracken, D. V., Smith, M. S., Grove, J. H., Blevins, R. L., & MacKown, C. T. (1994). Nitrate leaching as influenced by cover cropping and nitrogen source *Soil Sci. Soc. of Am. J., 58*(5), 1476-1483.

McVay, K., Radcliffe, D., & Hargrove, W. (1989). Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Sci. Soc. of Am. J., 53*(6), 1856-1862.

Rasmussen, P. E., R. Allmaras, C. Rohde and N. Roager. (1980). Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. *Soil Sci. Soc. of Am. J.,* 44(3): 596-600.

Reeves, D. (1994). Cover crops and rotations. *Adv. in Soil Sci.: Crops Residue Manag.,* 125-172.

Sharma, V., S. Irmak, V. Sharma, L. Odhiambo and K. Djaman. 2016. Soil-water dynamics and evapotranspiration of cover crop mixtures in seed maize-cover crop rotation fields: Part I. Soil-water dynamics and evapotranspiration. *J. Irrig. and Drain. Eng.* (submitted)

Unger, P. W. (1991). Organic matter, nutrient, and pH distribution in no-and conventional-tillage semiarid soils. *Agron. J., 83*(1), 186-189.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P., . . . Sayre, K. D. (2010). Conservation agriculture, improving soil quality for sustainable production systems. *Adv. in Soil Sci.: Food Security and Soil Qual., 1799267585*, 137-208.

Villamil, M., Bollero, G., Darmody, R., Simmons, F., & Bullock, D. (2006). No-till corn/soybean systems including winter cover crops. *Soil Sci. Soc. of Am. J., 70*(6), 1936-1944.

White, C. M., & Weil, R. R. (2011). Forage radish cover crops increase soil test phosphorus surrounding radish taproot holes. *Soil Sci. Soc. of Am. J., 75*(1), 121-130.

SECTION IV: EFFECT OF COVER CROPS ON SOIL QUALITY: SOIL EXCHANGEABLE BASES (K, Mg, Na, Ca) AND SOIL MICRONUTRIENTS (Zn, Mn, Fe, Cu and B)

INTRODUCTION

Sustainability of the farming system can be improved by combining winter cover cropping with conservation tillage. Returning crop residue to the soil improves soil quality and productivity through promising effects on soil properties (Lal and Stewart, 1995). Cover crops may be recommended to offer supplementary mulch for no-till crop production when previous residue cover is insufficient for optimum production. Cover crops have been suggested as a means of improving soil organic matter, aggregation, and water holding capacity, and influencing crop yields (McVay et al., 1989; McCracken et al., 1994; Kuo et al., 1997a). Cover crop rotation and conservation tillage systems as compared with monoculture and conventional tillage systems supposedly maintain more favorable soil properties (Mahboubi and Fauset, 1994). On the other hand, many researchers have reported that depending on soil, climate and management conditions, cover crops in no-till systems may increase, decrease, or have no effect on the yield of the cash crop planted in cover crops (Wagger, 1989; Eckert, 1988; Moschler et al., 1967).

Cover crops improve soil in number of ways. The most obvious soil benefit from the cover crops is the protection against soil loss from erosion, however, long term benefit includes providing organic matter to the soil which is equally important goal. Cover crops contribute indirectly to overall soil health by catching excess nutrients before they can leach out of the soil profile or by adding nitrogen to soil in case of legume cover crops (Clark, 2007). Brassica cover crops play an important role in management of nematodes, weeds and disease by releasing chemical compounds from decomposing residue. They produce large taproots that can penetrate up to six feet to alleviate soil compaction. These deep roots allow these crop to scavenge excess nutrients from the soil profile. On decomposition, they provide channels which improves soil penetration by the roots of subsequent crop as well as may change the chemical composition of soil.

Aside from the various benefits or impacts of cover crops on soil discussed above, very little is known about the effect of cover crops on soil micronutrients and exchangeable bases.

The amount of exchangeable bases (K, Mg, Ca and Na) and cation exchange capacity (ECE) are very vital properties of soils and sediments. They relate information on a soils ability to sustain plant growth, retain nutrients, buffer acid deposition or sequester toxic heavy metals. The cation exchange capacity of a soil determines the number of positively-charged ions that the soil can hold. It has a significant effect on the fertility management of the soil.

In addition to exchangeable bases, soil micronutrients also play a very important role in plant growth and crop yields. Shortage of micronutrients can limit the plant growth and could even cause plant death. The importance of micronutrients to a plant's health has gotten more attention recently with increasing trends of per acre crop yields. This trend removes very high amount of micronutrients from the fields, and soil is unable to compensate this loss naturally. However, cropping systems influence soil micronutrients largely and helps in their replenishment. Liu et al., (2002) studied the effect of rice based cropping on Mn and found that rice crop rotation promoted the reduction of Mn in surface layer and accelerated the accumulation of Mn in the subsoil. On the other hand, Eckert (1991) studied the effect of rye cover cropping on exchangeable bases and soil micronutrients and found that rye crop had little effect on the distribution of chemical attributes, other than increasing concentrations of exchangeable K near the soil surface. It has also been observed that mulching (thick layer of crop residue) at the rates as low as 2.25 Mg/ha reduced the losses of available P, K, Ca and Mg in Canada (Rees et al., 1999).

Likewise, reduced tillage may lead to soil compaction, and concentration of nutrients in soil horizon. It promotes the development of stratified distribution of several chemicals associated with soil fertility (Dick, 1983). Cruse et al. (1983), Fink and Wesley (1974), and Ketcheson (1980) observed accumulation of K at the surface due to deposition of crop residue and lack of incorporation. During the times of the year not associated with crop production in Nebraska, including cover crops in no till cropping system can promote additional biomass accumulation and rooting activity in the soil profile. Very little is known about the effect of such additional plant activity on soil properties such as soil micronutrients. This study was conducted to determine the effect of cover crops on the availability and distribution soil exchangeable bases (K, Mg, Na and Ca), CEC and micronutrients (Zn, Cu, Mn, Fe and B) in the soil profile.

MATERIAL AND METHODS

Site description and crop and soil management practices

Field research campaigns were conducted from 2012-2015 in three large production fields (F1-BREBS field, F2-West Field and F3- East field) that were located within very close proximity (3 km) in Seward County near Beaver Crossing, Nebraska, USA (Figure 1). The research fields are located in the transition zone between the wetter Nebraska Vegetative Zone IV and slightly drier zone III (http://efotg.sc.egov.usda.gov/references/public/NE/NebraskaVegetativeZones.pdf). All three research fields are center-pivot irrigated with seed maize-cover crop rotation and no-till practice. These fields have been planted with cover crops since 2002. The predominant soil at the F1 field is Hasting silt loam, which is a well-drained loamy upland soil with available water capacity of 126 mm m-1 in the top 0.90 m (average field capacity: 32% vol and permanent wilting point: 20% vol). The other two fields have similar silt loam soils, including Butler and Muir silt loam with a very similar available water holding capacity of 142 mm m^{-1}. The long term (1996 – 2015) cover crop growing season (August-April) average precipitation in the area is 340 mm with significant variability during the cover crop growing season. Average organic matter content (OMC) in the BREBS field was 1.22% and 2.15% in the West and East fields. The particle size distribution of BREBS field is 31.2% clay, 8.6% silt and 60.2% sand, with an average saturated hydraulic conductivity of 4.6 µm/s. Very similar particle size distribution was observed in West and East fields with 25.9% clay, 9.1% silt, 65% sand.

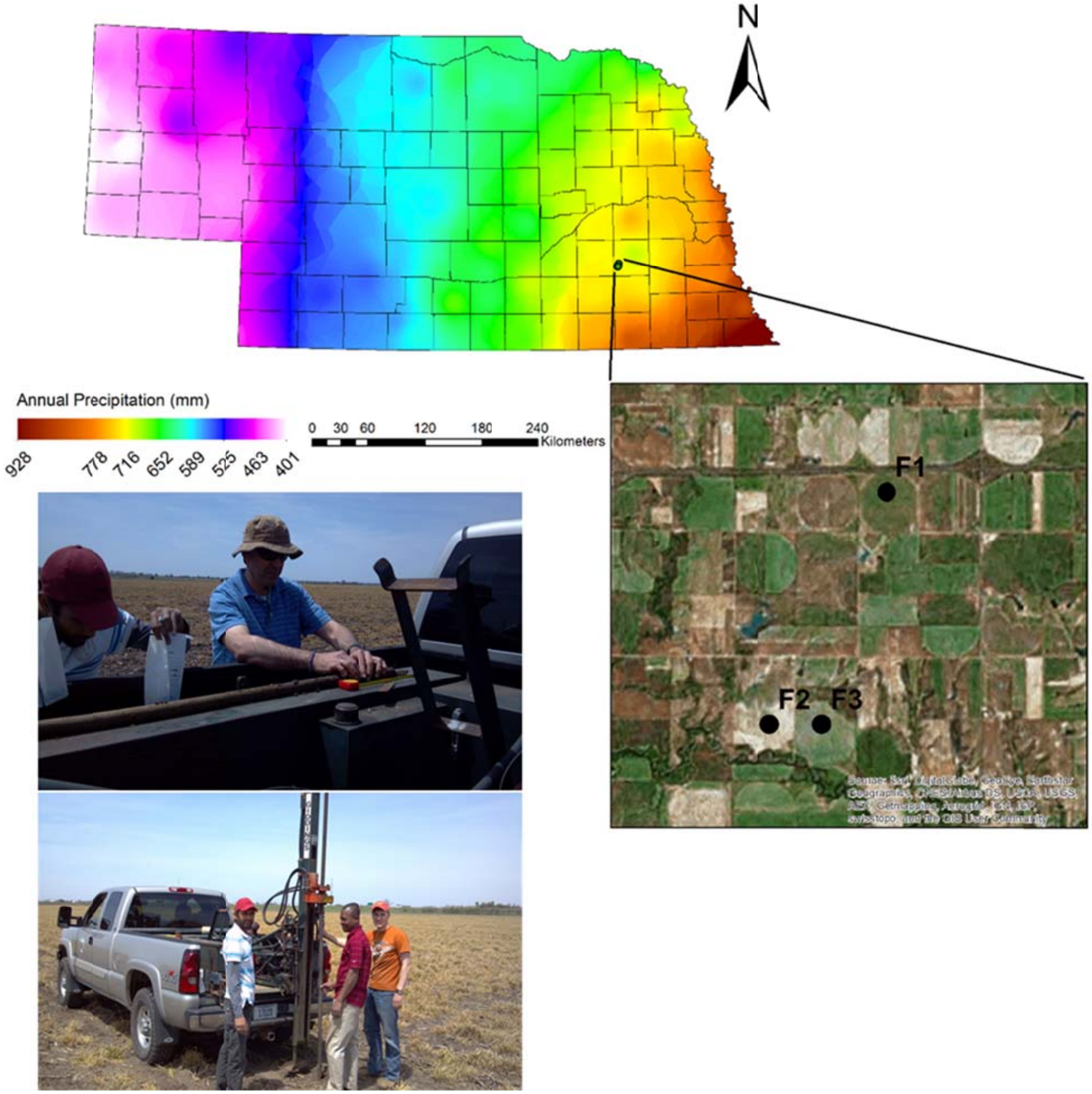
To determine the impact of cover crops on soil chemical properties, four land cover treatments were imposed in each individual year in all three fields: (i) cover crop only without seed maize or soybean residue (CC), (ii) cover crop mixtures planted in seed maize or soybean residue (SCCC), (iii) seed maize or soybean residue (SC) only without cover crops and (iv) bare soil (Bare soil) without any considerable seed maize or soybean residue. Each plot in all the fields was 4.5 m X 4.5 m. In addition to this, long term bare soil data was also collected from field F1 from 2012-2015. This was the area in field F1 where no planting has been done for more than last 10 years. The cover crop treatment (CC) in this research represented the conditions when there is only cover crop without any seed maize or soybean residue from the previous crop. The SCCC treatment represented the conditions where cover crops are planted in the seed-maize or soybean residue after harvest or broadcasted within the maize or soybean plants around physiological maturity before harvest. The SCCC treatment represents the actual production system that growers typically practice in the Midwest. The SC treatment corresponds to condition where there is no cover crop after seed maize or soybean harvest and only seed maize or soybean residue existed in the plot. Bare soil treatment refers to the bare soil plot in the field with no seed maize, soybean, cover crop or any other crop cultivated for several years. All the plots in three fields were maintained throughout the research period. It was made sure that during the seed maize or soybean planting, CC and bare soil plots do not get any seed. In addition, bare soil and SC plots were covered with tarp whenever cover crop seeds were broadcasted so that these plots do not get any cover crop seeds. Weeds and other unwanted plants like volunteer corn were manually uprooted on regular basis from all the plots. Though, the plots in all three fields were created and maintained since 2012, soil sampling in F2 and F3 fields was started from spring 2014. In F2 and F3 field, the effect of these land cover treatments was evaluated over the four (2014 spring, 2014 fall, 2015 spring and 2015 fall) seasons. In 2015 fall, cover crop was planted only in the west field, however, all four plots were maintained in all three field in order to see the effect of long term cover cropping and no-till practice on soil properties. The seasons and corresponding treatments evaluated in each field are well explained in Table 1 (Sharma et al. 2016; Part I, companion paper, this issue). Overall, the effect of four land cover treatments on the soil properties were studied over four (2014 spring, 2014 fall, 2015 spring and 2015 fall) seasons. Because only 2014 spring, 2015 fall, 2015 spring and 2015 fall seasons have data for all the fields (F1, F2 and F3) and treatments (bare soil, CC, SC and SCCC), the statistical analysis was performed only for these four seasons. Other detailed information about the type of cover crop mixes that are planted, cover crop planting and termination dates and some other agronomic management practices and dates are described in table 2 (Sharma et al. 2016; Part I, companion paper, this issue).

Soil Sampling

Soil samples were collected two times in each year, one in the spring i.e., before planting of cash crop and other in the fall season i.e., right after the harvest of cash crop which is also the peak growing season for the cover crops. From 2014 spring to 2015 fall, four soil samplings were done; May 15, 2014; Nov 10, 2014; April 7, 2015 and Nov 5, 2015. Soil samples were collected from two locations in each treatment plot from 0-1.2 m soil depth using Giddings soil sampling equipment. Two cores from each plot were mixed per depth and sent to soil processing laboratory to determine the concentration of exchangeable bases (K, Mg, Na and Ca), CEC and soil micronutrients (Zn, Fe, Cu, B and Mn). Available Zn, Cu, Mn and Fe were extracted by DTPA procedure (Lindsay and Norvell, 1978). Ammonium acetate method was used by the laboratory to determine exchangeable bases and CEC.

Data analysis

The experiment followed a randomized complete block design with three fields described in the study (F1, F2 and F3) as three replications or blocks. Each block (field) has four treatments/plots (CC, SCCC, SC and bare soil; 6.5 m X 4.5 m each) throughout the study period. Treatments were repeated on the same plots in 2014 and 2015 seasons. Data for average values of K, Mg, Na, Ca, CEC, Zn, Cu, B, Fe and Mn over four seasons (2014 spring, 2014 fall, 2015 spring and 2015 fall) from each treatment was analyzed using Proc Glimmix Procedure in SAS program. Statistical significance was evaluated at $P<0.05$. In addition to that, extensive soil sampling data was collected from field F1 from 2012 to 2015 (table1, Sharma et al., 2016, Part I companion paper, this issue) from two treatments (SCCC and long term bare soil) to see the long term impact of cover crops on soil properties. Also, percentage change between different seasons for each treatment was evaluated.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 15. Location of three research fields with annual precipitation variation in the state of Nebraska, USA.

RESULTS AND DISCUSSION

Effect of cover cropping on soil exchangeable bases (K, Mg, Ca and Na) and Cation exchange capacity of soil (CEC)

Imposition of cover crops in seed maize/soybean cropping system in south eastern Nebraska had differing effects on soil chemical attributes (soil exchangeable bases) (table 1-5). Figures 2 and 3 as well as table 1-5 showed what appeared to be some concentration differences in soil exchangeable bases at different depths. Top 0-5 cm soil profile had maximum accumulation of exchangeable K after soybean harvest in fall 2015 for CC treatment (655 ppm) (figure 2d). There was 47%, 27%, 0.3% and 8.3% increase in K concentration in CC treatment from 2014 spring to 2015 fall at 0-5, 5-20, 20-40 and 40-60 cm soil depth, respectively (Table 2). Also, at the end of the experiment in 2015 fall, K concentration in CC treatment at 0-5 cm was significantly higher than all other treatments (Table 1) which might be the result of cover crop residue deposition on the soil surface. This result is also in agreement with Eckert et al., (1991) where accumulation of exchangeable K at 0-5 cm soil depth was enhanced by inclusion of rye cover crop. Comparing SCCC treatment with SC, we observed that for 0-5 cm soil depth, SCCC treatment had reduced the K concentration by 4%, whereas SC treatment enhanced it by 11%, however, the concentration was not significantly different in both treatments. For 5-60 cm, both treatments had lowered the K concentration as compared to the study inception. This effect was probably due to the uptake of K by seed corn in its growing season more than it was added by cover crops. Cover crops did not affect exchangeable K concentration below the 5 cm depth as there was no significant difference among the treatments below this depth (table 1).

No significant difference in exchangeable Ca occurred among the treatments at any time except 5-20 cm soil depth in 2015 spring when Ca concentration in bare soil was significantly lower (1650 ppm) than all other treatments and in 20-40 cm soil depth in 2015 fall, when bare soil Ca concentration (1770 ppm) was significantly higher than SC and SCCC treatment (table 1). Opposite to the profile distribution of K (figure 2a-d), exchangeable Ca showed an increasing trend as the depth increases (figure 2e-2h). Table 2 shows the percentage change in Ca from one season to another and a very little to no increase or decrease was observed at the end of the study period as compared to study inception. This suggests that exchangeable Ca concentration were unaffected by any land cover treatment imposed in this study.

Profile distribution of exchangeable Mg, Na and CEC from spring 2014 to fall 2015 (Figure 3a-3l) indicates lower concentration in upper layers which then increases as we move down the profile for all treatment. The Mg and Na concentrations at 20-40 cm soil depth in SC treatment (261 ppm and 32.3 ppm, respectively) was significantly higher than in SCCC treatment (215 ppm and 21 ppm) at the end of the study in fall 2015 (table 2). Though not significant, for all other depths too, Na concentration in SC treatment at the end of the study period was higher than in SCCC treatment. In addition, at 20-40 cm soil depth, SCCC treatment had significantly lower Mg concentration (215 ppm) than in CC treatment (277 ppm). This means that cover crops alone did not reduce the concentration of Mg, but, when imposed in conjunction with seed maize during the growing season, seed maize took up most of the available Mg which could not be recovered by cover crops in this short period. Overall, comparing to the beginning of the study, at 20-40 cm soil depth, bare soil and CC treatment showed 9.2% and 5.4% increase in Mg concentration, whereas, there was 25.3% and 9.7% decrease in SC and SCCC treatment, respectively, at the end of the study period (table 5). This finding suggests that incorporating cover crops in no till seed maize/soybean cropping system (SCCC), might help in maintaining the exchangeable Mg concentration better than no cover crop treatment (SC), especially in 20-40 cm soil profile. Similarly, as discussed above, at the end of the study period, no significant differences in Na concentration were observed between the treatments except 20-40 cm soil depth (table 2). At this depth, bare soil did not show any increase or decrease in Na concentration as compared to the study inception, whereas, there was 32%, 31% and 29% decrease in CC, SC and SCCC treatment, respectively (table 5). Cover cropping has significant effects on CEC at 5-40 cm soil depth (table 4). At 5-20 cm soil depth, CEC in SCCC treatment was significantly higher (14.2 me/100g) than SC treatment (11.6 me/100g) whereas was significantly lower than CC (13.7 me/100g) and bare soil (12.6 me/100g) at 20-40 cm soil profile (table 4). Table 5 shows the percentage change in Mg, Na and CEC from one season to another. At 5-20 cm soil depth, SCCC treatment had increased the CEC by 8.4% as compared to study inception whereas, bare soil, CC and SC treatment had reduced it by 10% 4.1% and 21%, respectively. This can be attributed to 10.5% increase in soil organic matter at this depth in SCCC treatment (Sharma et al., 2016 Companion paper, part I). addition of cover crop residue to the soil helped in maintaining the optimum levels of levels soil cations thus CEC. The CEC values that were obtained through soil sampling at the research site (F1) was also compared with NRCS web soil survey data for SCCC treatment. For 0-5, 5-20, 20-40, 40-60 and 60-120 cm soil depth, NRCS CEC values were 20.1, 21.4, 26.1, 28.4 and 23.1 me/100g, respectively, whereas, in 2015, field measured CEC for these depths were 71, 38, 22, 31 and 47 me/100g, respectively. The research field under consideration have been planted with cover crops since 2002, however, the values provided by NRCS are based on data collected before 2002. This mean cover crops increased the CEC value at this research site up to 40 cm of soil profile.

The results of change in soil exchangeable bases concentration and CEC with incorporation of cover crops in seed maize/soybean cover crop rotation from 2012 fall to 2015 fall at 5 soil depths in F1 field are shown in figure 6. From 5-40 cm soil depth, bare soil K was higher in all seasons than in SCCC treatment. For 40-120 cm soil depth, SCCC treatment had increased the K concentration at the end of the study period as compared to study inception and was also higher than bare soil K at all times. Ca also showed very similar trend as that of K. No increase or decrease was observed for top 0-20 cm soil profile. There was reduction in soil Ca from 2012 to 2015 at 20-40 cm soil depth for both treatments. No change was detected in SCCC treatment at 40-60 cm, however, bare soil Ca had reduced by 1000 units at the end of the study period (figure 6). Higher concentrations of Mg were detected in bare soil treatment for all the seasons than in SCCC treatment from 0-40 cm soil depth. From 0-20 cm, there was no difference in Mg concentration in SCCC treatment at the beginning and end of the study. The Mg concentration decreased in 20-40 cm profile from 2012 to 2015 in both treatments. In 40-60 cm, no change occurred in Mg in SCCC treatment whereas it decreased in bare soil from 2012-2015 by 350 units. Cover crops in seed maize (SCCC) maintained higher concentration of Na than bare soil from 5-120 cm soil depth, except in few seasons like fall 2014 where bare soil Na was higher in 5-40 cm and 60-120 cm soil profile. 0-5 cm soil profile did not show any specific trend. CEC trend for all depths in SCCC treatment showed an increasing trend from 2012 until 2014 fall and then decreased after that. This can be attributed to the fact that there was no cover crop planted in 2015 in BREBS field (F1) which reduced the cation exchange capacity in the SCCC plot.

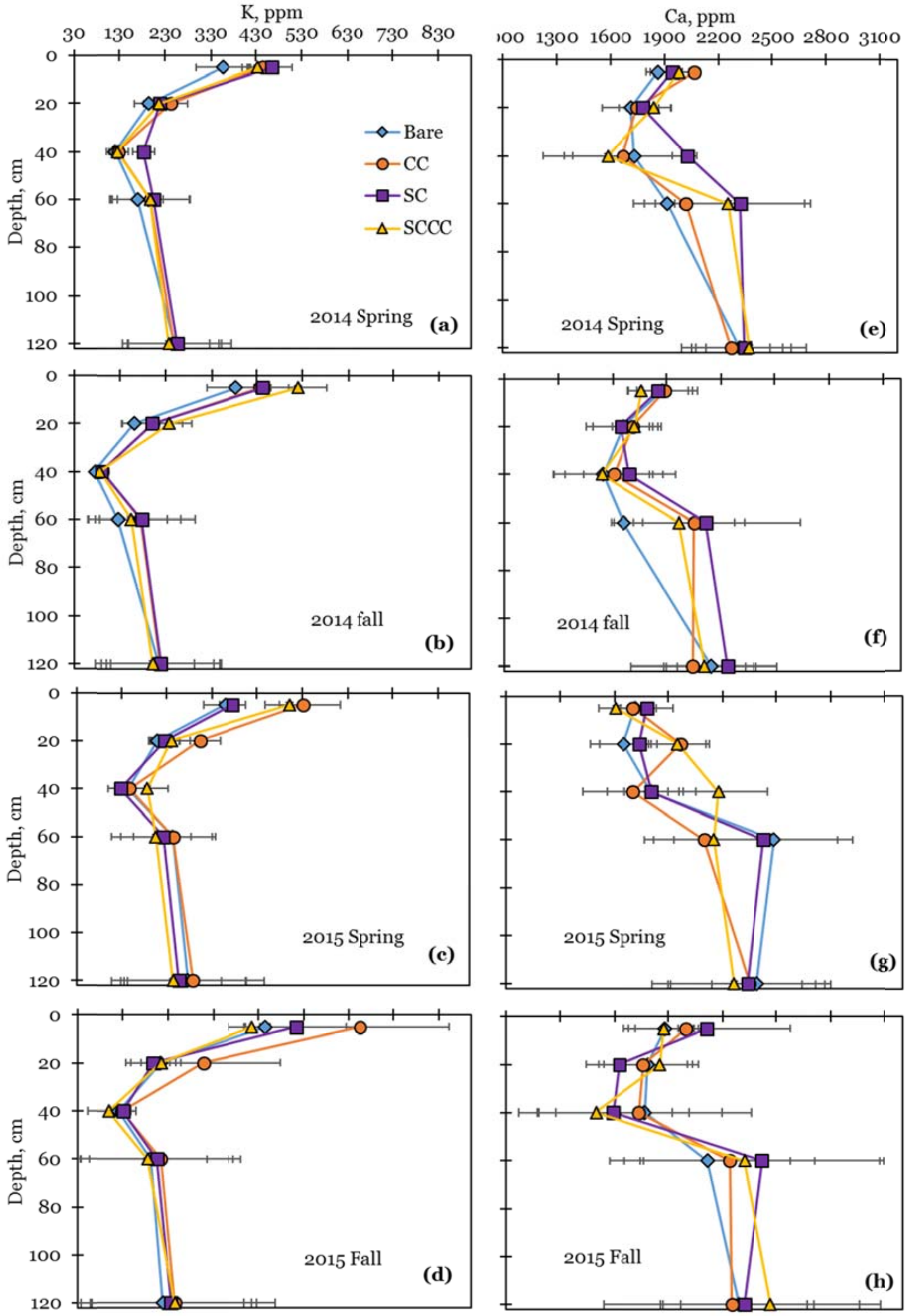


Figure 16. Depth distribution of organic K (a-d) and Ca (e-h) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring, and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 24. Average Potassium (K) and Calcium (Ca) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

Season	Treatment	Soil depths (cm)									
		0-5		5-20		20-40		40-60		60-120	
		K (ppm)	Ca (ppm)	K (ppm)	Ca (ppm)	K (ppm)	Ca (ppm)	K (ppm)	Ca (ppm)	K (ppm)	Ca (ppm)
2014 Spring	SC	464(44.5)a	1943.3(121.7)a	219(36.39)a	1780(87.18)a	183(23.35)a	2030(5.77)a	204.7(79.19)a	2320(361.66)a	256.7(119.69)a	2343.3(349.54)a
	SCCC	433(32.08)a	1980(20.82)a	217(18.33)a	1840(96.44)a	126(24.54)a	1583.3(360.29)a	198(84.07)a	2253.3(462.25)a	238(89.51)a	2370(238.61)a
	CC	444.3(33.07)a	2066.7(31.8)a	242(37.07)a	1746.7(194.28)a	128(3.06)a	1666.7(326.21)a	197.3(87.83)a	2020(289.89)a	247.7(99.73)a	2270(219.32)a
	BARE	355.7(59.18)b	1863.3(64.38)a	194.7(32.19)a	1713.3(68.39)a	121(13.08)a	1733.3(346.04)a	170(55.15)a	1916.7(67.66)a	250.7(101.22)a	2316.7(242.51)a
2014 Fall	SC	443.3(18.68)ab	1853.3(165.06)a	201(64.69)a	1646.7(158.99)a	90.3(17.02)a	1693.3(254.58)a	177.3(116.88)a	2116.7(526.79)a	219(129.1)a	2236.7(276.67)a
	SCCC	520.3(62.78)a	1760(10)a	237.7(49.01)a	1723.3(129.14)a	87(10.58)a	1540(265.02)a	154.3(79.9)a	1966.7(306.88)a	201.3(90.56)a	2110(225.39)a
	CC	437(63.01)ab	1890(152.75)a	201.3(40.34)a	1710(115.04)a	91(4.51)a	1606.7(273.39)a	175(88.09)a	2050(281.6)a	218(117.36)a	2043.3(339.08)a
	BARE	384(63.85)b	1876.7(194.28)a	161(26.06)a	1660(210)a	75(5.29)a	1546.7(278.71)a	126(67.64)a	1660(55.68)a	213.7(137.68)a	2146.7(248.62)a
2015 Spring	SC	375.7(29.23)ab	1780(145.72)a	226.3(32.27)ab	1740(223.68)ab	128.7(27.35)a	1806.7(150.26)a	222(114.21)a	2426.7(496.47)ab	256.7(148.25)a	2340(429.3)a
	SCCC	502.3(23.15)ab	1606.7(32.83)a	239.7(41.39)ab	1950(168.23)a	187.3(45.83)a	2176.7(106.51)a	205.7(76.69)a	2150(285.13)ab	243.7(107.12)a	2263.3(251.82)a
	CC	531.3(82.7)a	1703.3(92.8)a	302.7(44.79)a	1966.7(159.62)a	147.7(7.22)a	1703.3(277.03)a	243.7(86.33)a	2096.7(329.76)a	287.3(159.1)a	2350(452.11)a
	BARE	358.7(47.75)b	1716.7(114.65)a	209(18.88)b	1650(186.1)b	145.3(6.17)a	1803.3(246.6)a	242.7(10.72)a	2486.7(353.1)b	275.7(132.03)a	2390(251.06)a
2015 Fall	SC	514(111)ab	2113(462)a	197(48.9)a	1627(185)a	131(28)a	1593(422)ab	206(169)a	2420(676)a	236(179)a	2320(352)a
	SCCC	416(17.2)b	1873(193)a	214(18.8)a	1853(215)a	100(48.3)a	1497(425)a	185(130)a	2320(749)a	244(182)a	2467(610)a
	CC	655(197)a	1997(41.6)a	308(170)a	1760(245)a	128(11.3)a	1737(460)bc	214(178)a	2240(474)a	244(224)a	2250(708)a
	BARE	446(82)b	1880(161)a	214(43.3)a	1787(245)a	121(5.7)a	1770(589)c	192(172)a	2117(460)a	218(181)a	2290(420)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 25. Percentage change in Potassium (K) and Calcium (Ca) from one season to another in four land cover treatments.

Depth, cm	Treatment	1		2		3		4	
		K	Ca	K	Ca	K	Ca	K	Ca
0-5	Bare	8.0	0.7	-6.6	-8.5	24.2	9.5	25.3	0.9
	CC	-1.6	-8.5	21.6	-9.9	23.2	17.2	47.3	-3.4
	SC	-4.5	-4.6	-15.2	-4.0	36.7	18.7	10.7	8.7
	SCCC	20.2	-11.1	-3.5	-8.7	-17.1	16.6	-3.8	-5.4
5-20	Bare	-17.3	-3.1	29.8	-0.6	2.4	8.3	9.9	4.3
	CC	-16.8	-2.1	50.4	15.0	1.8	-10.5	27.3	0.8
	SC	-8.2	-7.5	12.6	5.7	-12.8	-6.5	-9.9	-8.6
	SCCC	9.5	-6.3	0.8	13.2	-10.6	-5.0	-1.2	0.7
20-40	Bare	-38.0	-10.8	93.7	16.6	-17.0	-1.8	-0.3	2.1
	CC	-28.9	-3.6	62.3	6.0	-13.1	2.0	0.3	4.2
	SC	-50.7	-16.6	42.5	6.7	1.8	-11.8	-28.4	-21.5
	SCCC	-31.0	-2.7	115.3	41.3	-46.8	-31.2	-20.9	-5.5
40-60	Bare	-25.9	-13.4	92.6	49.8	-20.9	-14.9	12.9	10.4
	CC	-11.3	1.5	39.3	2.3	-12.3	6.8	8.3	10.9
	SC	-13.4	-8.8	25.2	14.6	-7.4	-0.3	0.5	4.3
	SCCC	-22.1	-12.7	33.3	9.3	-9.9	7.9	-6.4	3.0
60-120	Bare	-14.8	-7.3	29.0	11.3	-20.8	-4.2	-12.9	-1.2
	CC	-12.0	-10.0	31.8	15.0	-15.1	-4.3	-1.5	-0.9
	SC	-14.7	-4.5	17.2	4.6	-7.9	-0.9	-7.9	-1.0
	SCCC	-15.4	-11.0	21.1	7.3	0.1	9.0	2.5	4.1

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

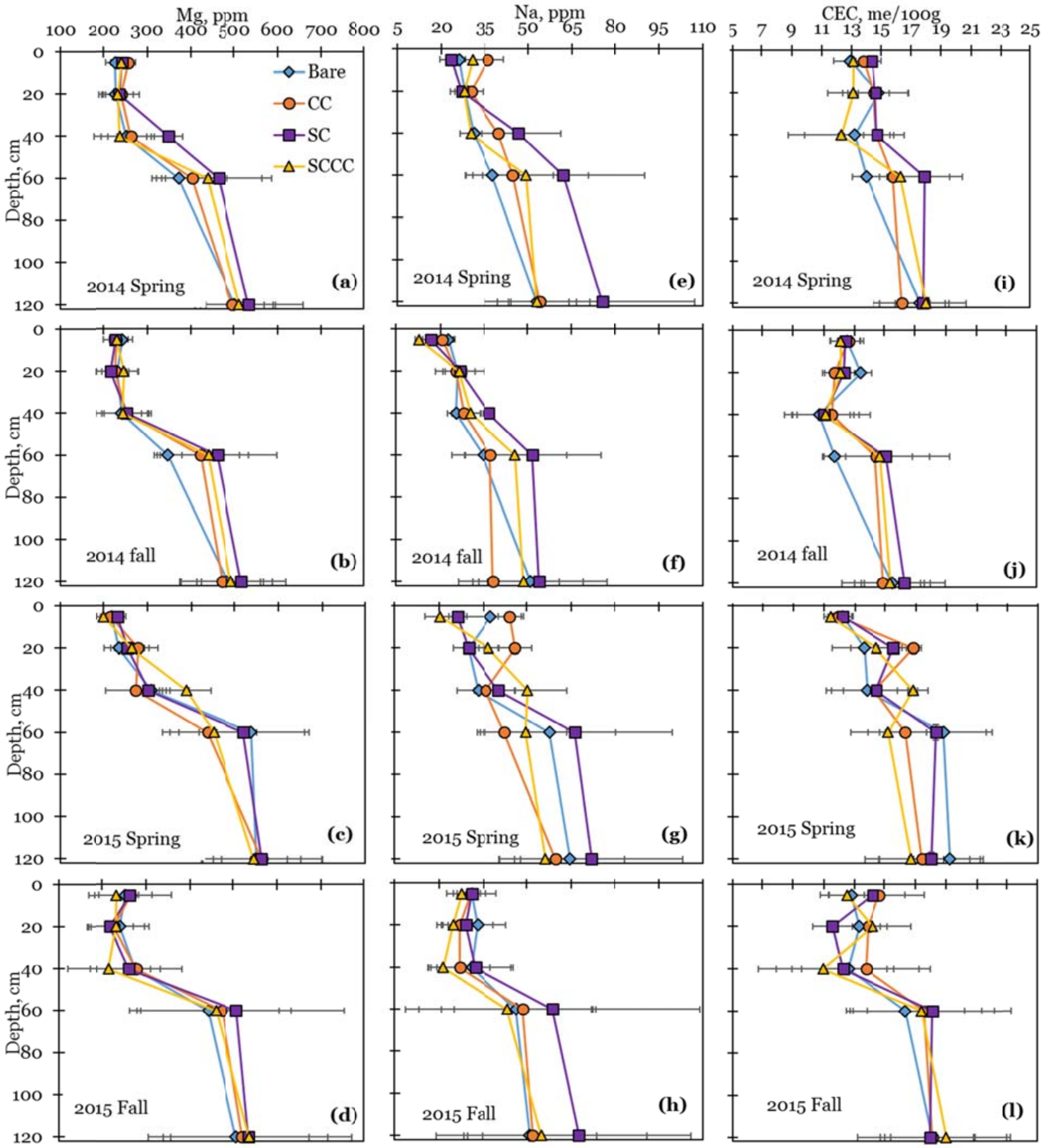


Figure 17. Depth distribution of Mg (a-d), Na (e-h) and CEC (i-l) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 26. Average Organic Magnesium (Mg) and Sodium (Na) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths

Season	Treatment	Soil depths (cm)									
		0-5		5-20		20-40		40-60		60-120	
		Mg (ppm)	Na (ppm)	Mg (ppm)	Na (ppm)	Mg (ppm)	Na (ppm)	Mg (ppm)	Na (ppm)	Mg (ppm)	Na (ppm)
2014 Spring	SC	242.3(25.21)a	23.3(3.84)a	236.3(46.48)a	27(4.04)a	349(32.72)a	46.7(14.45)a	464.3(123.23)a	62(28.02)a	534(124.71)a	75.3(31.94)a
	SCCC	241.7(5.36)a	30.7(4.67)ab	232.7(36.3)a	27.7(3.28)a	237.7(61.87)a	30(3.61)a	438.3(126.87)a	49.3(21.17)a	512.7(78.61)a	53(18.15)a
	CC	256.7(15.96)a	36(5.57)b	240.7(40.67)a	30(4.16)a	263(52.62)a	39.7(7.62)a	403(82.34)a	44.7(13.97)a	496.3(73.69)a	54(9.85)a
	BARE	226.7(21.84)a	26(2)ab	228.3(22.39)a	28(0.58)a	252.7(56.91)a	31(1)a	371.7(37.82)a	37.67(9.28)a	502(93.5)a	53(13.45)a
2014 Fall	SC	228.3(27.67)a	16.7(4.18)a	217(35.37)a	26.7(8.41)a	253.3(50.89)a	36.7(2.19)a	461(137.31)a	51.7(23.21)a	516.7(102.99)a	54(23.01)a
	SCCC	230.7(16.75)a	12.7(1.33)a	246.3(33.67)a	26.3(5.49)a	244(42.52)a	30.3(3.18)ab	440(94.24)a	45.7(17.57)a	493(68.81)a	48.7(12.2)a
	CC	230(14.57)a	20.7(3.71)a	227.3(30.64)a	25.3(3.76)a	253(55.58)a	28(5.69)b	422(91.44)a	37.3(13.5)a	471.3(96.54)a	38.3(12.12)a
	BARE	243(24.01)a	22.7(2.19)a	231.7(47.06)a	25.7(0.67)a	241.7(59.38)a	25.3(1.45)b	347.3(31.32)a	34.7(10.91)a	483.3(105.6)a	51(18.01)a
2015 Spring	SC	231.7(18.84)a	26.3(2.96)a	255(38.44)ab	30(5.13)b	302.7(24.46)a	40.3(5.93)a	520.3(149.35)ab	66.3(33.4)a	561.7(139.34)a	72(31.01)a
	SCCC	200.3(16.01)a	20.3(5.04)a	264.7(39.14)ab	37(3.61)ab	388.7(55.18)a	50.3(13.38)a	451.3(100.33)ab	49.7(13.78)a	544.3(76.81)a	56.3(15.72)a
	CC	216(5.77)a	44.3(3.84)a	279(44.66)a	46(5.69)a	274(68.49)a	36(10.07)a	437(102.32)a	42.3(8.45)a	562.67(136.57)a	59.7(11.67)a
	BARE	219(0.58)a	37.7(11.17)a	235.67(34.17)b	30(1.53)b	309(42.19)a	33.3(1.45)a	538(121.2)b	57.7(22.67)a	549.7(100.93)a	64.7(18.81)a
2015 Fall	SC	262.7(95)a	31(5)a	217.7(53)a	29(9.6)a	260.7(72)a	32.3(13.2)b	507.7(245)a	58.7(50.1)a	535.3(179)a	67.7(38)a
	SCCC	232.7(31)a	27.7(2.9)a	232(60.7)a	24.7(3.5)a	214.7(90.7)b	21.3(5)a	459.7(201)a	43.3(30)a	537.3(217)a	55(36)a
	CC	264.3(51)a	30.7(3)a	226.3(65)a	27(6.24)a	277.3(94.5)a	27(10.6)ab	473.7(172.3)a	48.7(23.7)a	520.7(232)a	52(17.5)a
	BARE	253(60.5)a	31(8.5)a	240(67.5)a	33(10)a	276(105.5)a	31 (2.7)b	442.3(162)a	46.3(25.5)a	506.3(167)a	51(22.6)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 27. Average Cation exchange capacity (CEC) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths

Season	Treatment	Soil depths (cm)				
		0-5	5-20	20-40	40-60	60-120
		CEC (me/100g)	CEC (me/100g)	CEC (me/100g)	CEC (me/100g)	CEC (me/100g)
2014 Spring	SC	14.4(0.62)a	14.6(2.22)a	14.7(0.23)a	17.9(2.5)a	17.8(2.88)a
	SCCC	13.1(0.12)a	13.1(1.71)a	12.3(3.54)a	16.3(3.28)a	18(1.52)a
	CC	13.8(0.19)a	14.5(1.05)a	14.7(0.91)a	15.8(2.05)a	16.4(1.91)a
	BARE	12.9(1.1)a	14.8(2.07)a	13.2(3.35)a	14(0.94)a	17.6(1.66)a
2014 Fall	SC	12.4(1)a	12.3(0.71)a	11(1.71)a	15.1(4.16)a	16.3(2.67)a
	SCCC	12.1(0.15)a	12.1(1.17)a	11.1(2.17)a	14.7(3.25)a	15.4(1.95)a
	CC	12.6(0.73)a	11.7(0.62)a	11.5(2.5)a	14.4(2.41)a	14.9(2.72)a
	BARE	12.5(1.07)a	13.4(0.72)a	10.7(2.26)a	11.7(0.71)a	15.5(2.51)a
2015 Spring	SC	12.2(0.54)a	15.5(1.84)ab	14.4(2.17)a	18.3(3.64)ac	18(3.36)a
	SCCC	11.4(0.44)a	14.4(1.68)ab	16.8(0.98)a	15.2(2.5)b	16.7(2.1)a
	CC	11.9(0.3)a	16.8(0.42)a	14.3(2.83)a	16.3(2.48)ab	17.4(3.78)a
	BARE	12.2(0.64)a	13.6(2.11)b	13.8(2.69)a	18.8(2.77)c	19.2(1.28)a
2015 Fall	SC	14.2(3.4)a	11.6(1.3)a	12.3(3.3)ab	18.1(5.2)a	17.9(2.9)a
	SCCC	12.5(1.1)a	14.2(2.5)b	10.9(4.2)a	17.4(4.7)a	19(4.2)a
	CC	14.6(1.7)a	13.9(0.8)ab	13.7(4.2)c	17.5(3.7)a	18.1(4.9)a
	BARE	12.8(1.5)a	13.3(1.8)ab	12.6(4.7)bc	16.3(3.8)a	18.1(2.7)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 28. Percentage change in Magnesium (Mg), Sodium (Na) and Cation exchange capacity (CEC) from one season to another in four land cover treatments.

Depth, cm	Treat.	1			2			3			4		
		Mg	Na	CEC	Mg	Na	CEC	Mg	Na	CEC	Mg	Na	CEC
0-5	Bare	7.2	-12.7	-3.1	-9.9	66.1	-2.4	15.5	-17.8	4.9	11.6	19.2	-0.8
	CC	-10.4	-42.5	-8.7	-6.1	114.0	-5.6	22.4	-30.8	23.0	3.0	-14.8	6.0
	SC	-5.8	-28.3	-13.9	1.5	57.5	-1.6	13.4	17.9	16.4	8.4	33.0	-1.4
	SCCC	-4.6	-58.6	-7.6	-13.2	59.8	-5.8	16.2	36.3	9.6	-3.7	-9.9	-4.6
5-20	Bare	1.5	-8.2	-9.5	1.7	16.7	1.5	1.8	10.0	-2.2	5.1	17.9	-10.1
	CC	-5.6	-15.7	-19.3	22.7	81.8	43.6	-18.9	-41.3	-17.3	-6.0	-10.0	-4.1
	SC	-8.2	-1.1	-15.8	17.5	12.4	26.0	-14.6	-3.3	-25.4	-7.9	7.4	-20.8
	SCCC	5.8	-5.1	-7.6	7.5	40.7	19.0	-12.4	-33.3	-1.4	-0.3	-11.0	8.4
20-40	Bare	-4.4	-18.4	-18.9	27.8	31.6	29.0	-10.7	-6.9	-8.7	9.2	0.0	-4.5
	CC	-3.8	-29.5	-21.8	8.3	28.6	24.3	1.2	-25.0	-3.7	5.4	-32.0	-6.3
	SC	-27.4	-21.4	-25.2	19.5	9.8	30.9	-13.9	-19.8	-14.8	-25.3	-30.8	-16.6
	SCCC	2.7	1.0	-9.8	59.3	66.0	51.4	-44.8	-57.6	-34.7	-9.7	-28.9	-10.8
40-60	Bare	-6.6	-7.9	-16.4	54.9	66.3	60.7	-17.8	-19.7	-13.1	19.0	23.0	16.7
	CC	4.7	-16.6	-8.9	3.6	13.4	13.2	8.4	15.1	7.8	17.5	8.9	11.2
	SC	-0.7	-16.6	-15.6	12.9	28.2	21.2	-2.4	-11.5	-1.1	9.3	-5.4	1.1
	SCCC	0.4	-7.3	-9.8	2.6	8.8	3.4	1.9	-12.8	14.5	4.9	-12.1	6.7
60-120	Bare	-3.7	-3.8	-11.9	13.7	26.9	23.9	-7.9	-21.2	-5.7	0.9	-3.8	2.8
	CC	-5.0	-29.1	-9.1	19.4	55.9	16.8	-7.5	-12.9	4.0	4.9	-3.7	10.4
	SC	-3.2	-28.3	-8.4	8.7	33.3	10.4	-4.7	-6.0	-0.2	0.2	-10.1	0.9
	SCCC	-3.8	-8.1	-14.4	10.4	15.6	8.4	-1.3	-2.3	13.8	4.8	3.8	5.6

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

Effect of cover cropping on soil micronutrients (Zn, Cu, B, Fe and Mn)

The effect of cover cropping on soil micronutrients i.e., Zn and Cu, B, and Fe and Mn are shown in Table 6, 7 and 9, respectively. Profile distribution of these nutrients are shown in figure 4 and 5. Inclusion of winter cover crops in seed maize cropping system (SCCC) reduced the concentration of Zn in 0-5 cm soil profile by 11% in Fall 2015 than at the study inception, whereas, only seed maize treatment (SC) had lowered the Zn concentration in the same depth by 33% (Table 8). This indicates that winter cover cropping in rotation with seed maize (SCCC) has the ability to maintain Zn concentration in top soil better than the only seed maize and no cover crop in winter (SC). For 5-40 cm soil depth, SCCC treatment has increased the Zn concentration whereas SC treatment lowered it (Table 8). Furthermore, at the end of the experiment in 2015 fall, Zn levels in SCCC and SC treatment at 0-5 cm soil depth were 3.2 ppm and 2.7 ppm, respectively (not significantly different) (Table 6). Low Zn in SC treatment than SCCC can be attributed to the removal of Zn by seed corn due to harvest, however in SCCC treatment cover crops in winters replenish this used up Zn by corn. At 20-40 cm soil depth, Zn concentration in SC and bare soil was significantly different than SCCC and CC treatment in spring 2014 (beginning of the experiment), however, no differences were observed at the end of the experiment between any treatment (Table 6). There was 33% increase in Zn concentration in SCCC and CC treatment at 20-40 cm soil depth at the end of the experiment compared to the beginning, whereas, 25% and decrease in Bare soil and SC treatment (table 8).

Cu was lower in SCCC treatment in 0-5 cm soil as compared to other treatments at the end of the experiment in fall 2015 (Table 6). The amount of Cu in top 0-5 cm soil profile was in order: CC=Bare=SC > SCCC. Difference between SCCC and other treatments can be attributed to the differences in the Cu uptake capacity of each land cover treatment. This trend indicates that cover crops in conjunction with seed maize/soybean, reduced the Cu concentration in top soil layer. For lower soil depths, no significant differences were observed between the treatments. Overall, from spring 2014 to fall 2015, there was 11% decrease in Cu concentration in 0-5 cm soil in SCCC treatment, however, there was no change in SC treatment (table 8). For 5-40 cm soil depth, SCCC treatment increased the amount of Cu in the profile ranging from 6% to 11% increase. Profile distribution of Cu from spring 2014 to fall 2015 is shown in figure 4e-4h.

The B profile (figure 4i-4l) for four land cover treatments exhibited no significant differences for 0-5 cm and 40-60 cm soil depth at any time (table 7). B concentration in CC treatment at the end of the experiment in 2015 fall was significantly higher than SCCC treatment at 5-20 cm soil depth. Also, at 20-40 cm soil depth, bare soil had significantly higher soil B than SCCC treatment. Since, SCCC treatment had seed corn before planting of cover crops, this decrease in B concentration can be attributed to higher uptake of B by seed corn. No significant differences were observed between SC and SCCC treatments at any depth. Overall from Spring

2014 to fall 2015, SC and SCCC treatments decreased the B concentration (31.5% and 21%, respectively) in top 0-5 cm soil in much higher amounts than by CC and Bare soil treatments (6.4% and 0.6% decrease, respectively) (table 8).

Inclusion of cover crops in cropping systems has increased the concentration Fe especially in 20-60 cm soil profile (Figure 5a-5d). However, no significant differences occurred between the four land cover treatments except 60-120 cm soil profile in 2014 spring, where Fe in CC treatment (18 ppm) was significantly lower than bare soil treatment (26 ppm) (table 9). At this depth, no differences were observed at the end of the experiment in fall 2015, with highest Fe concentration in SCCC treatment (23 ppm). There was 22% increase in Zn concentration at 60-120 cm soil depth in SCCC treatment. Overall, Fe concentrations in CC treatment were greater in fall 2015 than at the study inception for 0-5 cm and 40-120 cm soil profile (table 10). But, concentrations of Fe in CC treatment at 5-40 cm soil profile in fall 2015 were lower than at study inception. Comparing SCCC treatment with SC, at 0-5 cm soil depth, SC treatment lowered the concentration of Fe at the end of the experiment by 25% as compared to the beginning in 2014 spring, whereas, for the same depth SCCC treatment decreased the Fe concentration by only 14.5%. This suggests that winter cover crops in rotation with the main crop can maintain the levels of Fe and helped in improving the Fe nutrient status of subsequent cash crop in a better way than in the treatments with no cover crops. From 5-40 cm soil depth, SC treatment increase the Fe concentration by approximately 11% whereas Fe concentration in SCCC treatment at this depth has decreased by 14% (table 10). Opposite trend was observed for 40-120 cm soil depth where Fe in SCCC treatment showed an increasing trend from spring 2014 to fall 2015, whereas decreasing trend was observed for SC treatment.

Overall, Mn concentration in all treatments was lower in fall 2015 than at the beginning of the study in spring 2014 (table 10). As seen in figure 5h, maximum Mn concentration at the end of the experiment (fall 2015) was observed in SCCC treatment for all depth, whereas, lowest was observed for bare soil treatment. Significant difference between SCCC and bare soil has been observed for 40-60 cm soil depth in fall 2015 (table 9). This might have been related to changes in soil microenvironment by leguminous cover crops that resulted in the release of plant available Mn (Wei et al., 2006). This can also be attributed to lower pH and higher organic matter levels in this treatment in fall 2015 as compared to bare soil (Sharma et al., 2016

Companion paper, part I). The lower pH might have triggered the release of previously unavailable Mn from soil minerals. Also, the decomposition of organic matter would have helped in dissolution and reduction of Mn, thus increasing its availability.

The long term effect of cover cropping on soil micronutrients from 2012 to 2015 at 0-120 cm soil profile in field F1 has been depicted in figure 6. Green lines indicate the cover crop-seed maize rotation treatment (SCCC) whereas orange line is the bare soil treatment. As clear from the figure 6, Zn concentration was higher in SCCC treatment than in bare soil for top 0-20 cm profile, however, lower depth does not seem to have any impact of cover cropping. Opposite trend was observed for Cu concentration. For 0-40 cm soil profile, SCCC and bare soil treatment showed more or less same amounts of Cu, whereas for lower depths (40-120 cm) SCCC treatment exhibit higher Cu concentration in soil. The B concentration in both SCCC and bare soil treatment did not differ much from each other. From 2012-2015 both treatments lowered the concentration of B from 5-60 cm. SCCC treatment has increased Fe concentration from 2012-2015 from 0-20 and 40-120 cm soil depth. For Mn, no definite increase or decrease trend was observed for any depth.

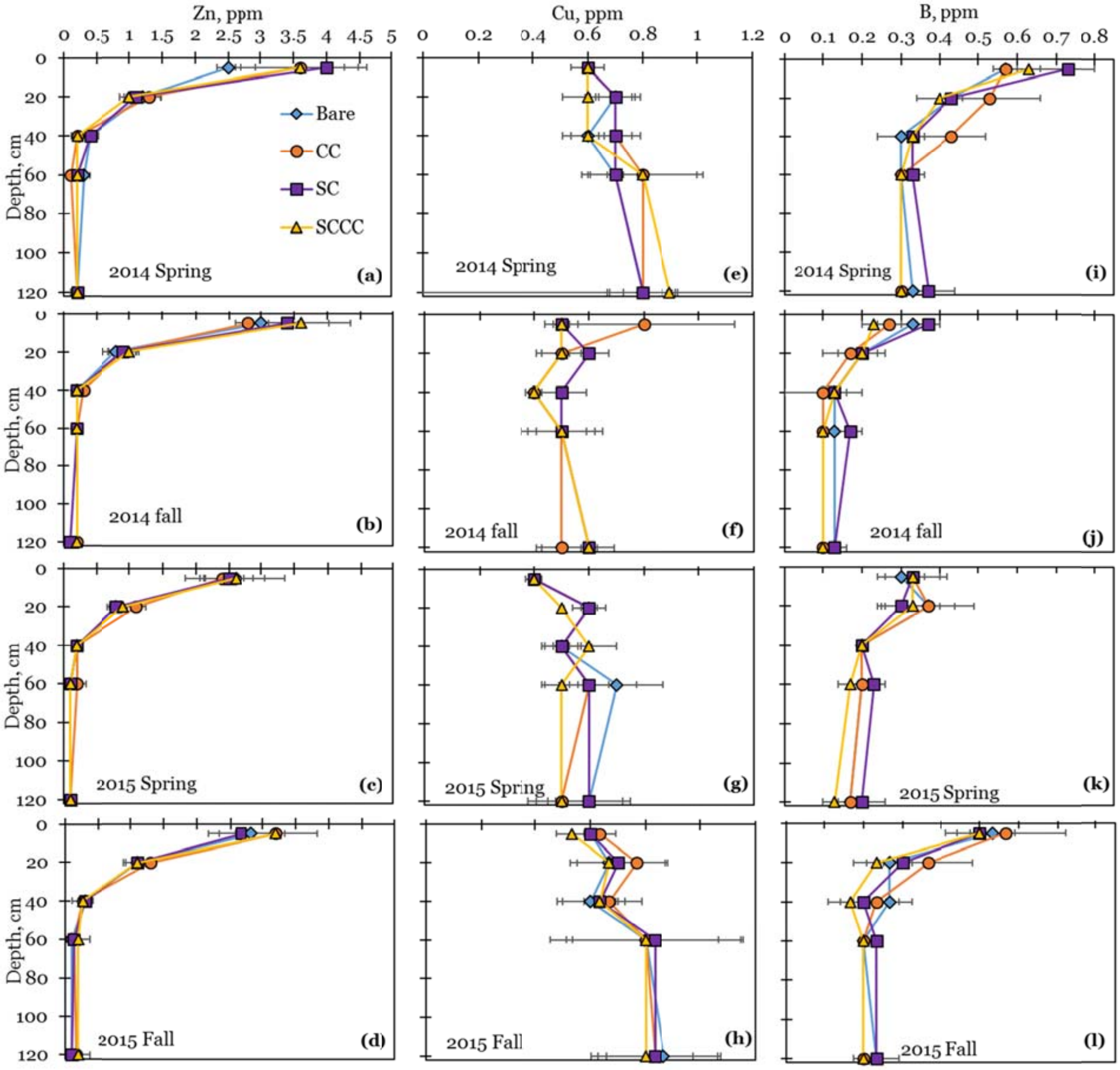


Figure 18. Depth distribution of Zn (a-d), Cu (e-h) and B (i-l) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 29. Average Zinc (Zn) and Copper (Cu) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

Season	Treatment	Soil depths (cm) 0-5		5-20		20-40		40-60		60-120	
		Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)	Zn (ppm)	Cu (ppm)
2014 Spring	SC	4(0.47)a	0.6(0.06)a	1.1(0.13)a	0.7(0.07)a	0.4(0.07)b	0.7(0.06)a	0.2(0.07)ab	0.7(0.09)a	0.2(0.1)a	0.8(0.13)a
	SCCC	3.6(0.67)a	0.6(0)a	1(0.15)a	0.6(0.09)a	0.2(0.09)a	0.6(0.09)a	0.2(0.03)ab	0.8(0.2)a	0.2(0.03)a	0.9(9)a
	CC	3.6(1)a	0.6(0)a	1.3(0.18)a	0.7(0.09)a	0.2(0.09)a	0.7(0.09)a	0.1(0.03)a	0.8(0.22)a	0.2(0.03)a	0.8(0.12)a
	BARE	2.5(0.18)a	0.6(0.06)a	1.2(0.27)a	0.7(0.06)a	0.4(0.12)b	0.6(0.06)a	0.3(0.09)b	0.7(0.03)a	0.2(0.03)a	0.8(0.07)a
2014 Fall	SC	3.4(0.62)a	0.5(0.06)a	0.9(0.21)a	0.6(0.07)a	0.2(0.03)a	0.5(0.09)a	0.2(0.03)a	0.5(0.15)a	0.1(0.03)a	0.6(0.09)a
	SCCC	3.6(0.75)a	0.5(0.06)a	1(0.15)a	0.5(0.09)a	0.2(0.07)ab	0.4(0)a	0.2(0.03)a	0.5(0.12)a	0.2(0)a	0.6(0.03)a
	CC	2.8(0.2)a	0.8(0.33)a	0.9(0.2)a	0.5(0.09)a	0.3(0.06)b	0.4(0.03)a	0.2(0.03)a	0.5(0.09)a	0.2(0)a	0.5(0.07)a
	BARE	3(0.12)a	0.5(0.03)a	0.8(0.2)a	0.5(0.07)a	0.2(0.03)ab	0.4(0.03)a	0.2(0.06)a	0.5(0.09)a	0.2(0.03)a	0.5(0.09)a
2015 Spring	SC	2.5(0.38)a	0.4(0.03)a	0.8(0.13)a	0.6(0)a	0.2(0.03)a	0.5(0.06)a	0.1(0)a	0.6(0.17)a	0.1(0.03)a	0.6(0.15)a
	SCCC	2.6(0.46)a	0.4(0.03)a	0.9(0.07)a	0.5(0)b	0.2(0.06)a	0.6(0.1)a	0.1(0)a	0.5(0.06)a	0.1(0)a	0.5(0.09)a
	CC	2.4(0.34)a	0.4(0.03)a	1.1(0.15)a	0.6(0.03)a	0.2(0.07)a	0.5(0.03)a	0.2(0.13)a	0.6(0.07)a	0.1(0)a	0.5(0.12)a
	BARE	2.6(0.76)a	0.4(0.03)a	0.8(0.09)a	0.6(0.06)a	0.2(0.09)a	0.5(0.07)a	0.1(0)a	0.7(0.17)a	0.1(0)a	0.6(0.12)a
2015 Fall	SC	2.7(0.49)a	0.6(0)a	1.1(0.2)a	0.7(0.17)a	0.3(0)a	0.6(0.06)a	0.1(0.06)a	0.8(0.32)a	0.1(0)a	0.8(0.23)a
	SCCC	3.2(0.62)a	0.5(0.06)b	1.1(0.17)a	0.7(0.11)a	0.3(0.15)a	0.6(0.15)a	0.2(0.17)a	0.8(0.26)a	0.2(0.17)a	0.8(0.17)a
	CC	3.2(0.52)a	0.6(0.06)a	1.3(0.26)a	0.8(0.11)a	0.3(0.11)a	0.7(0.06)a	0.1(0.06)a	0.8(0.34)a	0.2(0.06)a	0.8(0.23)a
	BARE	2.8(0.50)a	0.6(0)a	1.1(0.2)a	0.7(0.11)a	0.3(0.1)a	0.6(0.1)a	0.1(0)a	0.8(0.34)a	0.1(0)a	0.9(0.21)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 30. Average Boron (B) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

		Soil depths (cm)				
Season	**Treatment**	**0-5**	**5-20**	**20-40**	**40-60**	**60-120**
		B (ppm)	**B (ppm)**	**B (ppm)**	**B (ppm)**	**B (ppm)**
2014 Spring	SC	0.73(0.07)a	0.43(0.03)a	0.33(0.03)ab	0.33(0.03)a	0.37(0.07)a
	SCCC	0.63(0.03)a	0.4(0)a	0.33(0.03)ab	0.3(0)a	0.3(0)a
	CC	0.57(0.03)a	0.53(0.13)a	0.43(0.09)a	0.3(0)a	0.3(0)a
	BARE	0.57(0.03)a	0.43(0.09)a	0.3(0.06)b	0.3(0)a	0.33(0.03)a
2014 Fall	SC	0.37(0.03)a	0.2(0)a	0.13(0.03)a	0.17(0.03)a	0.13(0.03)a
	SCCC	0.23(0.03)a	0.2(0)a	0.13(0.03)a	0.1(0)a	0.1(0)a
	CC	0.27(0.03)a	0.17(0.07)a	0.1(0.1)a	0.1(0)a	0.1(0)a
	BARE	0.33(0.03)a	0.2(0.06)a	0.13(0.03)a	0.13(0.03)a	0.13(0.03)a
2015 Spring	SC	0.33(0.03)a	0.3(0.06)a	0.2(0)a	0.23(0.03)a	0.2(0.06)a
	SCCC	0.33(0.07)a	0.33(0.07)a	0.2(0)a	0.17(0.03)b	0.13(0.03)a
	CC	0.33(0.09)a	0.37(0.12)a	0.2(0)a	0.2(0)ab	0.17(0.03)a
	BARE	0.3(0.06)a	0.37(0.07)a	0.2(0)a	0.2(0)ab	0.17(0.03)a
2015 Fall	SC	0.5(0.1)a	0.3(0)ab	0.2(0)ab	0.2(0.06)a	0.2(0.06)a
	SCCC	0.5(0)a	0.2(0.06)a	0.2(0.06)a	0.2(0)a	0.2(0)a
	CC	0.6(01.5)a	0.4(0.11)b	0.2(0.06)ab	0.2(0)a	0.2(0)a
	BARE	0.5(0.06)a	0.3(0.06)ab	0.3(0.06)b	0.2(0)a	0.2(0.06)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 31. Percentage change in Zinc (Zn), Copper (Cu) and Boron (B) from one season to another in four land cover treatments.

Depth, cm	Treatment	1			2			3			4		
		Zn	Cu	B	Zn	Cu	B	Zn	Cu	B	Zn	Cu	B
0-5	Bare	20.0	-16.7	-42.1	-13.3	-20.0	-9.1	9.0	50.0	77.8	13.3	0.0	-6.4
	CC	-22.2	33.3	-52.6	-14.3	-50.0	22.2	33.3	58.3	71.7	-11.1	5.6	-0.6
	SC	-15.0	-16.7	-49.3	-26.5	-20.0	-10.8	6.7	50.0	51.5	-33.3	0.0	-31.5
	SCCC	0.0	-16.7	-63.5	-27.8	-20.0	43.5	23.1	33.3	51.5	-11.1	-11.1	-20.6
5-20	Bare	-33.3	-28.6	-53.5	0.0	20.0	85.0	37.5	11.1	-27.9	-8.3	-4.8	-38.0
	CC	-30.8	-28.6	-67.9	22.2	20.0	117.6	18.2	27.8	-0.9	0.0	9.5	-30.8
	SC	-18.2	-14.3	-53.5	-11.1	0.0	50.0	37.5	16.7	0.0	0.0	0.0	-30.2
	SCCC	0.0	-16.7	-50.0	-10.0	0.0	65.0	22.2	33.3	-29.3	10.0	11.1	-41.7
20-40	Bare	-50.0	-33.3	-56.7	0.0	25.0	53.8	50.0	20.0	33.3	-25.0	0.0	-11.1
	CC	50.0	-42.9	-76.7	-33.3	25.0	100.0	33.3	33.3	16.7	33.3	-4.8	-45.7
	SC	-50.0	-28.6	-60.6	0.0	0.0	53.8	50.0	26.7	0.0	-25.0	-9.5	-39.4
	SCCC	0.0	-33.3	-60.6	0.0	50.0	53.8	33.3	5.6	-16.7	33.3	5.6	-49.5
40-60	Bare	-33.3	-28.6	-56.7	-50.0	40.0	53.8	0.0	14.3	0.0	-66.7	14.3	-33.3
	CC	100.0	-37.5	-66.7	0.0	20.0	100.0	-33.3	33.3	0.0	33.3	0.0	-33.3
	SC	0.0	-28.6	-48.5	-50.0	20.0	35.3	33.3	38.9	1.4	-33.3	19.0	-29.3
	SCCC	0.0	-37.5	-66.7	-50.0	0.0	70.0	100.0	60.0	17.6	0.0	0.0	-33.3
60-120	Bare	0.0	-37.5	-60.6	-50.0	20.0	30.8	0.0	44.4	37.3	-50.0	8.3	-29.3
	CC	0.0	-37.5	-66.7	-50.0	0.0	70.0	66.7	66.7	17.6	-16.7	4.2	-33.3
	SC	-50.0	-25.0	-64.9	0.0	0.0	53.8	0.0	38.9	16.7	-50.0	4.2	-36.9
	SCCC	0.0	-33.3	-66.7	-50.0	-16.7	30.0	100.0	60.0	53.8	0.0	-11.1	-33.3

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

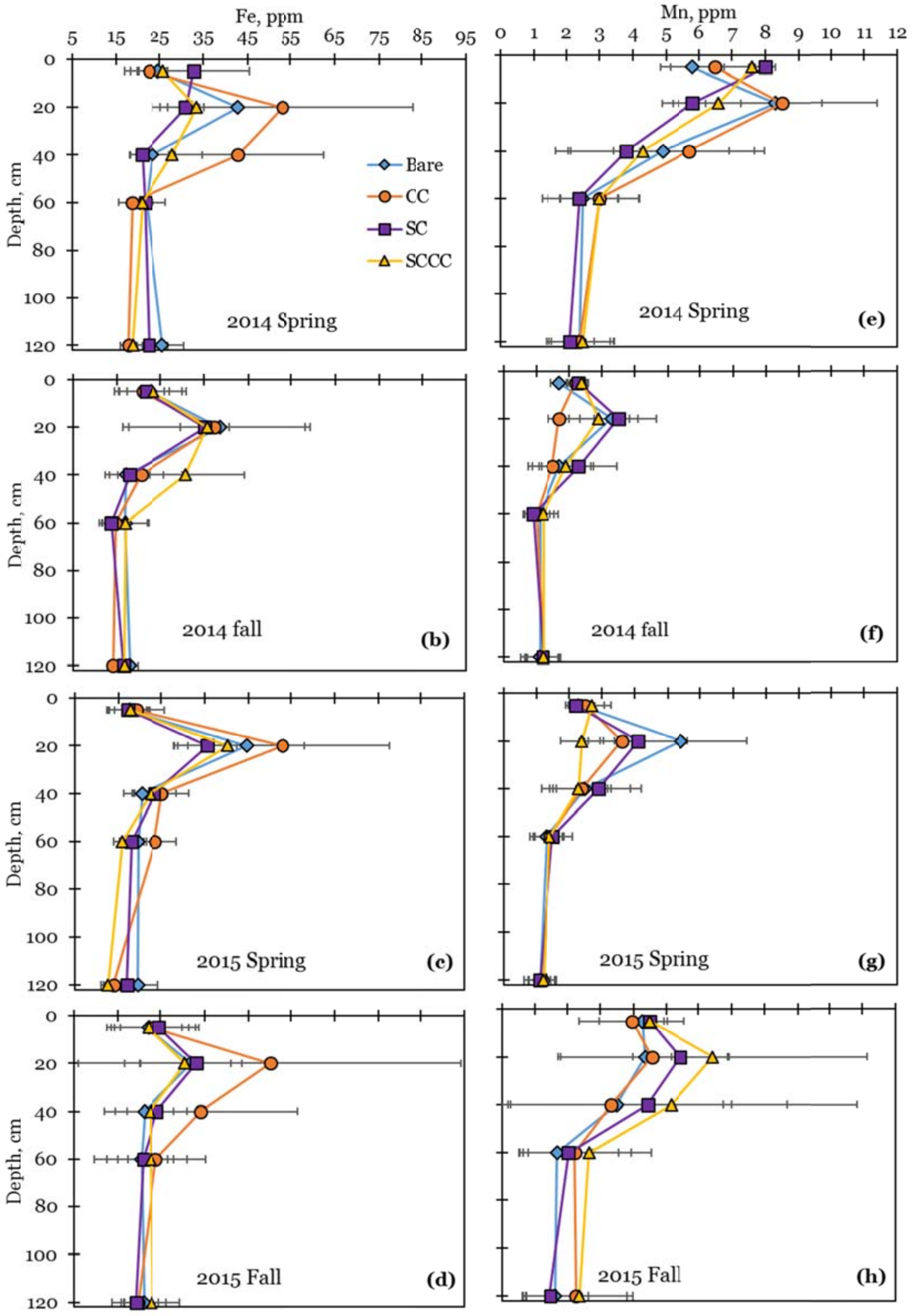


Figure 19. Depth distribution of Fe (a-d) and Mn (e-h) from four land cover treatments (Bare soil, CC, SC and SCCC) in 2014 spring, 2014 fall, 2015 spring and 2015 fall. Bars are the SE at each depth for the means of each treatment.

Table 32. Average iron (Fe) and Manganese (Mn) (standard errors in parenthesis) in four land cover treatments for 2014 spring, 2014 fall, 2015 spring and 2015 fall at five depths.

		Soil depths (cm)									
Season	**Treatment**	**0-5**		**5-20**		**20-40**		**40-60**		**60-120**	
		Fe (ppm)	**Mn (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Mn (ppm)**
2014 Spring	SC	32.8(12.67)a	8(0.3)a	31(4.14)a	5.8(0.42)a	20.9(2.78)a	3.8(1.75)a	21.6(1.91)a	2.4(1.14)a	22.5(4.42)ab	2.1(0.73)a
	SCCC	25.8(6.15)a	7.6(0.09)a	33.5(8.37)a	6.6(1.73)a	27.8(6.97)a	4.3(2.61)a	20.9(5.46)a	3(1.2)a	18.7(0.55)ab	2.5(0.94)a
	CC	22.6(4.38)a	6.5(1.38)a	53(29.72)a	8.5(1.24)a	42.8(19.8)a	5.7(2.28)a	18.6(3)a	3(1.17)a	17.8(1.88)a	2.4(0.91)a
	BARE	24.7(7.8)a	5.8(0.96)a	42.8(10.29)a	8.3(3.09)a	23.3(5.33)a	4.9(2.77)a	21.9(4.45)a	2.5(1.07)a	25.7(4.82)b	2.4(1.03)a
2014 Fall	SC	21.7(4.4)a	2.3(0.25)a	35.2(5.57)a	3.5(1.16)a	17.9(4.54)a	2.3(1.15)a	13.7(2.62)a	0.9(0.3)a	16.5(2.14)a	1.2(0.55)a
	SCCC	23.3(7.65)a	2.4(0.19)a	35.7(1.39)a	2.9(1.19)a	30.7(13.45)a	1.9(0.84)ab	16.9(5.39)a	1.2(0.49)a	16.7(1.98)a	1.2(0.51)a
	CC	20.8(6.33)a	2.2(0.21)a	37.2(20.97)a	1.7(0.32)a	20.5(5.39)a	1.5(0.63)b	14.7(1.17)a	1(0.42)a	14.1(1.08)a	1.2(0.48)a
	BARE	22.7(7.4)a	1.7(0.24)a	38.5(20.82)a	3.3(0.53)a	17(4.59)a	1.7(0.97)ab	16.8(5.06)a	1.1(0.46)a	17.9(1.84)a	1.1(0.59)a
2015 Spring	SC	17.2(4.51)a	2.2(0.13)a	35.6(6.8)a	4.1(1.51)ab	23.3(5.24)a	2.9(1.28)a	18(2.85)a	1.5(0.62)a	16.9(1.11)a	1.1(0.36)a
	SCCC	17.8(3.64)a	2.7(0.55)a	40.2(12.36)a	2.4(0.89)a	22.5(4.07)a	2.3(1.12)a	15.9(2.06)a	1.4(0.55)a	12.6(0.95)a	1.2(0.44)a
	CC	19.1(6.7)a	2.5(0.58)a	52.8(24.69)a	3.6(0.65)ab	25.1(6.33)a	2.4(0.87)a	23.4(5.1)a	1.4(0.46)a	13.8(2.84)a	1.2(0.44)a
	BARE	17.5(4.66)a	2.3(0.31)a	44.6(13.39)a	5.4(2.02)b	20.5(4.28)a	2.5(1.35)a	19.5(1.88)a	1.3(0.5)a	19.4(4.83)a	1.1(0.49)a
2015 Fall	SC	24.6(9.1)a	4.5(0.52)a	33.1(16.6)a	5.4(1.44)a	24(7.1)a	4.4(4.25)a	20.8(5.8)a	2(1.52)ab	19(5.4)a	1.5(0.85)a
	SCCC	22.1(7.8)a	4.5(0.43)a	30.5(10.5)a	6.4(4.7)a	22.5(10.6)a	5.2(5.66)a	22.6(5.4)a	2.7(1.88)a	22.8(6.5)a	2.4(1.62)a
	CC	23.1(9.8)a	4(1.6)a	50(44.1)a	4.6(0.58)a	34.2(22.4)a	3.3(3.66)a	23.8(11.4)a	2.2(1.70)ab	19.5(3.1)a	2.3(1.55)a
	BARE	22(9.5)a	4.3(1.3)a	31.8(11.6)a	4.4(2.55)a	21.1(6.8)a	3.5(3.24)a	20.3(10.6)a	1.7(1.05)b	20.9(5.2)a	1.6(1.0)a

Means for treatments in the same column and season followed by the same letter are not significantly different at the 5% level.

Table 33. Percentage change in iron (Fe) and Manganese (Mn) from one season to another in four land cover treatments.

Depth, cm	Treatment	1		2		3		4	
		Fe	Mn	Fe	Mn	Fe	Mn	Fe	Mn
0-5	Bare	-8.1	-70.7	-22.9	35.3	25.7	85.5	-10.9	-26.4
	CC	-8.0	-66.2	-8.2	13.6	21.1	58.7	2.4	-39.0
	SC	-33.8	-71.3	-20.7	-4.3	43.0	104.5	-25.0	-43.8
	SCCC	-9.7	-68.4	-23.6	12.5	24.0	66.7	-14.5	-40.8
5-20	Bare	-10.0	-60.2	15.8	63.6	-28.6	-19.1	-25.6	-47.4
	CC	-29.8	-80.0	41.9	111.8	-5.2	26.9	-5.6	-46.3
	SC	13.5	-39.7	1.1	17.1	-7.0	32.5	6.8	-6.3
	SCCC	6.6	-56.1	12.6	-17.2	-24.0	168.1	-8.9	-2.5
20-40	Bare	-27.0	-65.3	20.6	47.1	3.1	40.0	-9.3	-28.6
	CC	-52.1	-73.7	22.4	60.0	36.3	38.9	-20.1	-41.5
	SC	-14.4	-39.5	30.2	26.1	3.1	52.9	15.0	16.7
	SCCC	10.4	-55.8	-26.7	21.1	0.0	124.6	-19.1	20.2
40-60	Bare	-23.3	-56.0	16.1	18.2	4.3	30.8	-7.2	-32.0
	CC	-21.0	-66.7	59.2	40.0	1.9	59.5	28.1	-25.6
	SC	-36.6	-62.5	31.4	66.7	15.6	35.6	-3.7	-15.3
	SCCC	-19.1	-60.0	-5.9	16.7	42.1	90.5	8.1	-11.1
60-120	Bare	-30.4	-54.2	8.4	0.0	8.1	48.5	-18.4	-31.9
	CC	-20.8	-50.0	-2.1	0.0	41.5	88.9	9.7	-5.6
	SC	-26.7	-42.9	2.4	-8.3	12.8	33.3	-15.3	-30.2
	SCCC	-10.7	-52.0	-24.6	0.0	81.2	97.2	22.1	-5.3

1- Percentage change in from 2014 Spring to 2014 Fall, 2- Percentage change from 2014 Fall to 2015 spring, 3- Percentage change from 2015 Spring to 2015 Fall, 4 - Percentage change from 2014 Spring to 2015 Fall.

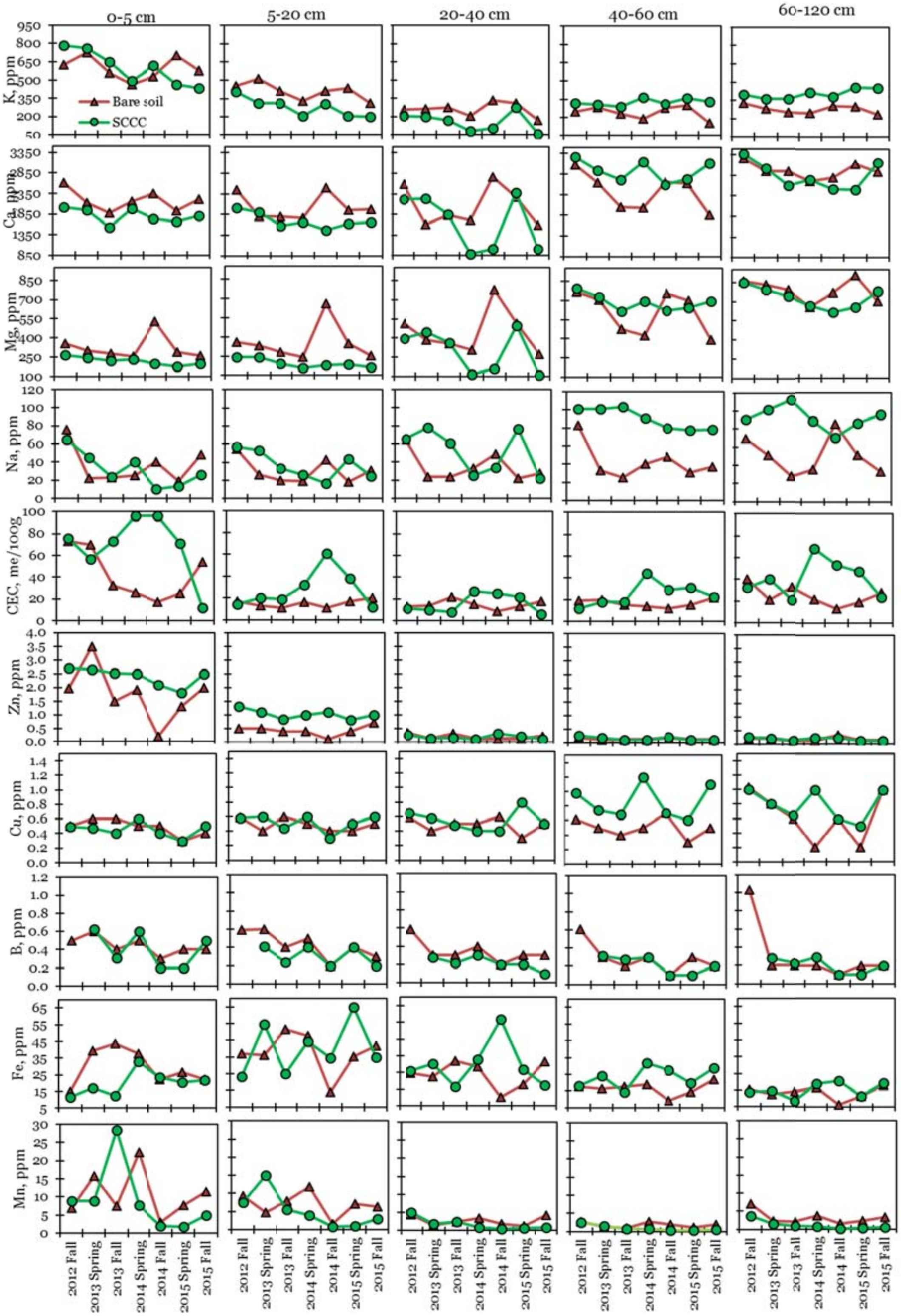


Figure 20. Soil Exchangeable Bases K, Ca, Mg and Na; CEC, Micronutrients Zn, Cu, B, Fe and Mn in SCCC plots as affected by no till and cover cropping, and bare soil in filed F1 from 2012-2015.

CONCLUSIONS

The effect of cover crops in no till seed maize/soybean production system on soil exchangeable bases and soil micronutrients from spring 2014 to fall 2015 has been studied in Beaver Crossing (Seward County), Nebraska, U.S.A. In addition, effect of cover crops in field F1 has been studied from 2012-2015. The results of this study indicates that cover crops in seed maize/soybean cropping system in south eastern Nebraska had differing effects on soil chemical attributes. Cover crops in seed maize/soybean (SCCC) had a significant effect on soil exchangeable K in 0-5 cm soil profile. Cover crops did not affect exchangeable K concentration below the 5 cm depth as there was no significant difference among the treatments below this depth. Exchangeable Ca concentrations were unaffected by any land cover treatment imposed in this study. Our finding suggests that incorporating cover crops in no till seed maize/soybean cropping system (SCCC), might help in maintaining the exchangeable Mg concentration better than no cover crop treatment (SC), especially in 20-40 cm soil profile. No significant differences in Na concentration were observed between the treatments except 20-40 cm soil depth where bare soil did not show any increase or decrease in Na concentration as compared to the study inception, whereas, there was 32%, 31% and 29% decrease in CC, SC and SCCC treatment, respectively. Cover cropping has significant effects on CEC at 5-40 cm soil depth. At 5-20 cm soil depth, CEC in SCCC treatment was significantly higher (14.2 me/100g) than SC treatment (11.6 me/100g) whereas was significantly lower than CC (13.7 me/100g) and bare soil (12.6 me/100g) at 20-40 cm soil profile. At 5-20 cm soil depth, SCCC treatment had increased the CEC by 8.4% as compared to study inception whereas, bare soil, CC and SC treatment had reduced it by 10% 4.1% and 21%, respectively. Cover cropping in seed maize (SCCC) reduced the concentration of micronutrients in top 0-5 cm soil. There was an increase in Zn and Cu concentration ranging from 6% to 33% in 5-40 cm as well, whereas, B and Mn concentration decreased at all depths for SCCC treatment. Overall, cover crops (SCCC) have the potential in maintaining the optimum levels of Zn, B, Fe and Mn in 0-5 cm soil profile as compared to SC treatment. Due to the short duration of the study, it is not known that how long these effects on soil properties will persist. Further research should investigate the long term impacts of cover crops on these selected soil properties.

REFERENCES

Clark, A. 2008. *Managing cover crops profitably*. DIANE Publishing.

Cruse, R., G. Yakle, T. Colvin, D. Timmons and A. Mussleman. 1983. Tillage effects on corn and soybean production in farmer-managed, university-monitored field plots. *Journal of Soil and Water Conservation* 38(6): 512-514.

Dick, W. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of America Journal* 47(1): 102-107.

Eckert, D. 1991. Chemical attributes of soils subjected to no-till cropping with rye cover crops. *Soil Science Society of America Journal* 55(2): 405-409.

Eckert, D. 1988. Rye cover crops for no-tillage corn and soybean production. *J. Prod. Agric*. 1:207-210.

Fink, R. J. and D. Wesley. 1974. Corn yield as affected by fertilization and tillage system. *Agronomy Journal* 66(1): 70-71.

Ketcheson, J. 1980. Effect of tillage on fertilizer requirements for corn on a silt loam soil. *Agronomy Journal* 72(3): 540-542.

Kuo, S., U. Sainju and E. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. *Soil Science Society of America Journal* 61(1): 145-152.

Lal, R. and B. Stewart. 1995. Managing soils for enhancing and sustaining agricultural production. *Soil management: experimental basis for sustainability and environmental quality. CRC, Boca Raton*1-9.

Lal, R., A. Mahboubi and N. Fausey. 1994. Long-term tillage and rotation effects on properties of a central Ohio soil. *Soil Science Society of America Journal* 58(2): 517-522.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am.J.42, 421-428.

Liu, X., X. Liao, Y. Zhang, F. Zhang and Y. Huang. 2001. Effects of Rice-based cropping system on distribution of manganese in the profile of paddy soil derived from red earth. *Acta Ecologica Sinica* 22(9): 1440-1445.

McCracken, D. V., M. S. Smith, J. H. Grove, R. L. Blevins and C. T. MacKown. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. *Soil Science Society of America Journal* 58(5): 1476-1483.

McVay, K., D. Radcliffe and W. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Science Society of America Journal* 53(6): 1856-1862.

Moschler, W., G. Shear, D. Hallok, R. Sears and G. Jones. 1967. Winter cover crops for sod-planted corn: Their selection and management. *Agronomy Journal* 59(6): 547-551.

Rees, H., T. Chow, D. Walker and A. Smith. 1999. Potential use of underseeded barley to increase carbon inputs to a loam soil in the New Brunswick potato belt. *Canadian Journal of Soil Science* 79(1): 211-216.

Sharma, V., S. Irmak. 2016a. Effect of cover cropping on selected soil properties.

Wagger, M. 1989. Cover crop management and nitrogen rate in relation to growth and yield of no-till corn. *Agronomy Journal* 81(3): 533-538.

Wei, X., Hao, M., Shao, M., & Gale, W. J. (2006). Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization. Soil and Tillage Research, 91(1), 120-130.

SECTION V: EFFECT OF COVER CROPS ON SOIL QUALITY. SOIL PHYSICAL PROPERTIES – FIELD CAPACITY, PERMANENT WILTING POINT, SOIL WATER HOLDING CAPACITY, INFILTRATION, BULK DENSITY, AND HYDRAULIC CONDUCTIVITY

INTRODUCTION

A considerable renewal interest in the use and management of cover crops among farmers in Mid-west have been seen in recent years. Farmers look to cover crops as an important component for fertility management and nutrient cycling. Cover crops are the plants seeded in the fields for the purpose of improving or maintaining ecosystem quality. Historically, cover crops were grown to provide supplement nitrogen (N) to the soil for subsequent crop but with the declining costs of synthetic nitrogen fertilizers, the use of legume cover crops in the cropping systems has declined. In addition to supplying N to the subsequent cash crop, cover crops also provides additional organic matter input to the soil which leads to improved soil organic matter, soil physical properties and soil infiltration characteristics (Macrae and Mehuys, 1985; Patrick et al., 1957; Williams, 1966). However, systems including cover crops in their rotations not always increase soil organic matter. For instance, Van der Linden et al (1987), in 20 years of green manure application, observed very little change in soil organic matter content, but a significant changes in soil physical and biological properties were observed. Cover crops with deep roots can be particularly effective in increasing soil water storage capacity (Reeves 1994; Reeves, 1997). They also improve soil's capacity to carry machines and improve field accessibility by utilizing water and holding together soil structural units (Kankanen, et al., 1998). Wagger and Denton, (1989) reported lesser impact of cover crops on soil porosity and hydraulic conductivity than does the wheel traffic.

Including cover crops into the agronomic row crop rotation (i.e., maize-soybean cropping system) may have positive, neutral, or negative impacts on soil-water storage, depending on environmental and climatic conditions as well as management practices. Cover crops possibly will enhance recharging of soil-water through their potential influence on increased soil infiltration rates. Many studies also have shown that soil-water storage under cover crops and fallow vary widely. Wilson et al. (1982) used double ring infiltrometer and observed improved infiltration, soil structure and porosity under cover crops compared to fallow. They also observed decreased bulk density in the top 0-10 cm soil depth. Increased infiltration rate was observed by Touchton et al. (1984) using 0.6 m ring infiltrometer in cover cropped plots as compared to fallow for no tillage cotton. Increased infiltration could be attributed to the mulch effect of cover crops that protects the soil. Cover crops increase soil infiltration (McVay et al., 1989), soil-water retention (Colla et al., 2000), reduce soil evaporation, and increase solar energy harvest (radiation use efficiency) and carbon flux into the soil. Colla et al. (2000) observed increased soil water holding capacity and soil permeability in cover cropped plots as compared to the conventional cropping system of 4-yr rotation in Sacramento Valley, California. They showed 0.028 m^3 m^{-1} infiltration during 3-h of irrigation event in conventional treatment and a greater infiltration rate of 0.062 m^3 m^{-1} in cover-cropped systems. Odhiambo and Bomke (2007) compared soil-water content in the winter cover crops with bare soil plots in the early spring in British Columbia, Canada. They found that the soil water content in the cover crop treatment was significantly higher in the top soil (0 - 20 cm) possibly due to cover crops reducing soil evaporation and increasing infiltration rate. In a 3-yr study conducted in Iowa, Qi et al. (2011) showed that winter rye planted in maize and soybean maintained higher soil-water storage when compared to the plots with only maize and soybean with no cover crop.

On the other hand, in a long-term (1999-2014) field experiments in San Joaquin Valley, California, Mitchell et al. (2015) found that net soil-water storage increase during the period January to March (the primary growing period for cover crops in California) by 48 and 43 mm in 2013 and 2014, respectively, for the fallow system, whereas, in the cover crop mixture plots, there was no additional water storage. Islam et al. (2006) investigated the effect of cover cropping systems on water balance variables (recharge and ET) in the Central Valley of California, and found a generally higher rye cover crop ET_a (140 mm from November to March) as compared to fallow (110 mm during same period). Ewing et al. (1991) reported that crimson clover cover crop depleted the soil-water in the upper 0.15 m by 28% more in 1985 and 55% more in 1986 than the fallow treatments. Until now, there have been few studies of cover crop production and its effects on soil physical properties in Mid-west regions. Also, aforementioned studies indicate that the effect of cover crops in conserving soil moisture as well as their effect on soil properties varies substantially with the climatic conditions as well as number of years of cover crop establishment. Moreover, sub-humid continental climate in eastern half and a semi-arid climate in the western half of the state, make Nebraska more susceptible to both excess and shortage of rainfall, thus makes it challenging for farmers to incorporate cover crops into the cropping system for improving soil physical properties without any strong research support.

The specific objective of this study is to investigate the effect of growing cover crops in seed maize or soybean rotation under no tillage on field capacity (FC), permanent wilting point (PWP), soil water holding capacity (SWHC), bulk density and soil hydraulic conductivity (K_{fs}) of soil.

MATERIAL AND METHODS

Site Description, experimental setup and cultural practices

A 4-year experiment was conducted during 2012-2015 period on three large scale farmer production fields (F1-BREBS field, F2-West Field and F3- East field) in Seward County near Beaver crossing, Nebraska, USA. All three research fields are located within 3.0 km distance (Figure 1). These fields are center-pivot irrigated seed maize-cover crop rotation fields with different cover crop mixes and no-till practice. All three fields have been panted with cover crops since 2002. Predominant soil at the F1 field is Hasting silt loam, which is a well-drained loamy upland soil with available water capacity of 126 mm m^{-1} in the top 0.90 m (average field capacity: 32% vol and permanent wilting point: 20% vol). The other two fields have very similar silt loam soils (Butler and Muir silt loam) with available water holding capacity of 142 mm m^{-1} in top 0.90 m. The long-term (1996-2015) average annual rainfall for this region is 599 mm. Annual rainfall during the course of this study was 304 mm, 518 mm, 855 mm and 679 mm for 2012, 2013, 2014 and 2015, respectively. The experimental treatments comprise of four land covers: (i) cover crop mixtures planted without seed maize residue from previous crop (CC), (ii) cover crop mixtures planted in seed maize residue (SCCC), (iii) seed maize residue only without any cover crops (SC) and (iv) bare soil (Bare soil) without any residue and cover crops. Four plots (one for each treatment) of 6 m* 6 m were established in each field. The cover crop treatment (CC) in this research represented the conditions when there is only cover crop in the plot without any seed maize residue from the previous crop (i.e., no crop was planted in these plots during the seed-maize growing season). The SCCC treatment represented the conditions where cover crops are planted in the seed-maize residue after harvest or broadcasted within the maize plants around physiological maturity before harvest. The SCCC treatment represents the actual production system that growers typically practice in the Midwest. The SC treatment corresponds to condition where there is no cover crop after seed maize harvest and only seed maize residue existed in the plot. Bare soil treatment refers to the bare soil plot in the field with no seed maize, cover crop or any other crop cultivated for several years. For the cover cropped plots (CC and SCCC), cover crop mixes (more than one cover crop) were used in all fields over except F2 field in 2012-2013 and F1 field in 2013-2014 cover crop season, where only single cover crop species was grown. Cover crop mixtures ensured good soil cover across variety of conditions as different cover crops may respond differently to varying soil, management and weather conditions. Information about cover crop mixtures, cover crop planting dates, seed maize planting and harvesting dates, cover crop termination dates, and some of the other agronomic management practices and dates for three fields for three growing seasons is presented in Table 1. All the plots in three fields were maintained throughout the research period. It was made sure that during the seed maize or soybean planting, CC and bare soil plots do not get any seed. In addition, bare soil and SC plots were covered with tarp whenever cover crop seeds were broadcasted so that these plots do not get any cover crop seeds. Weeds and other unwanted plants like volunteer corn were manually uprooted on regular basis from all the plots.

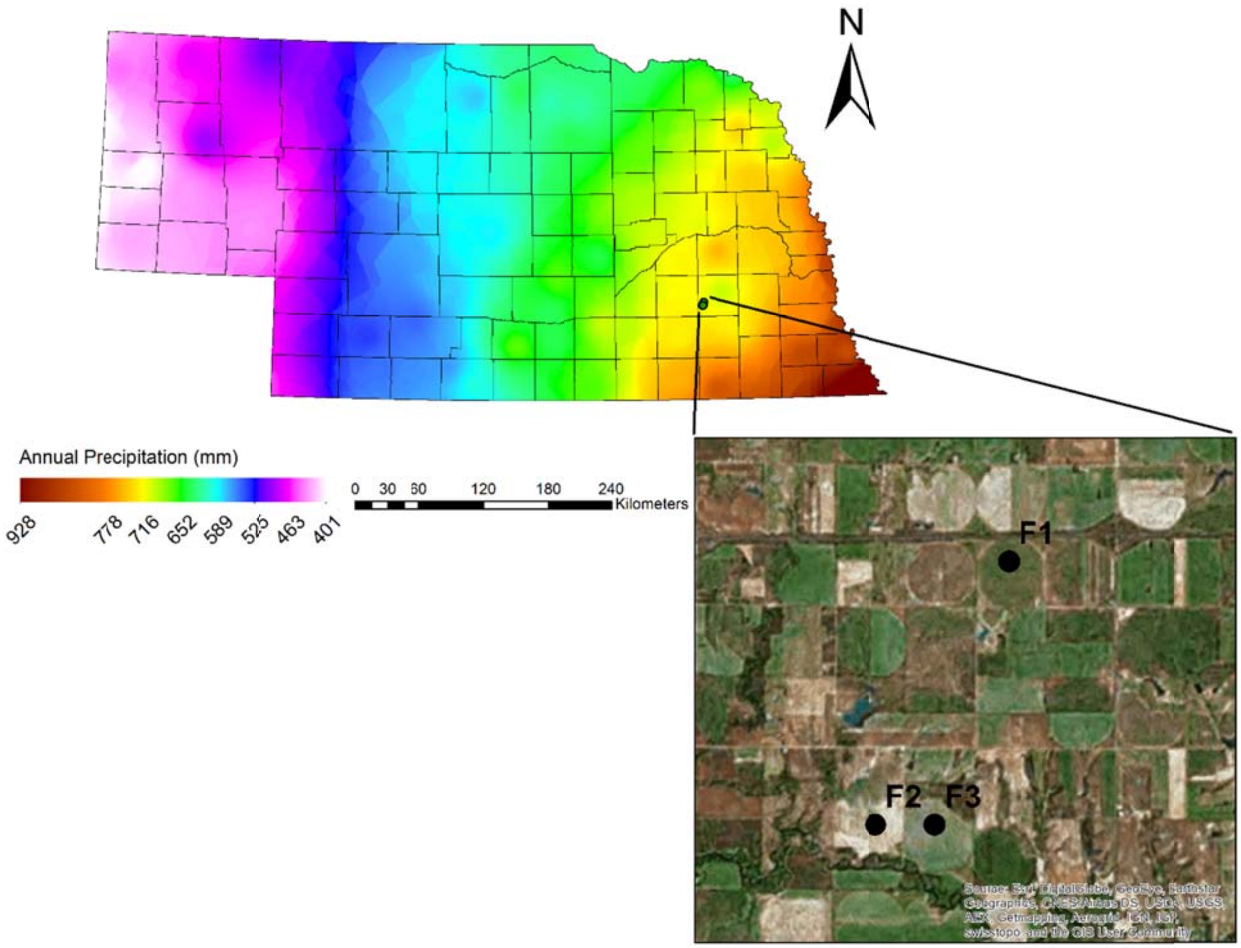


Figure 21. Location of three research fields with annual precipitation variation in the state of Nebraska, USA.

Table 34. Management information for three research fields for (2012-2013, 2013-2014, 2014-2015 and 2015-2016) cover crop growing seasons.

2012-2013

Management	F1	F2	F3
Seed maize planting	22-Apr-12	29-Apr-12	30-Apr-12
Seed maize harvesting	21-Aug-12	28-Aug-12	28-Aug-12
CC planting	8-Sep-12	30-Aug-12	28-Aug-12
Method of CC planting	Drill	Drill	Broadcast
CC type	Winter pea, Common vetch, Hairy vetch, Cereal rye, Oats, Nitro- radish, and rapeseed	Forage sorghum	Turnip, Radish, and Ethiopian cabbage
CC termination date	30-Apr-13	Winter kill	Winter kill

2013-2014

Management	F1	F2	F3
Seed maize planting	11-May-13	1-Jun-13	24-May-13
Seed maize harvesting	2-Oct-13	10-Oct-13	9-Oct-13
CC planting	13-Oct-13	14-Aug-13	11-Aug-13
Method of CC planting	Drill	Broadcast	Broadcast
CC type	Cereal rye	Turnip, Radish	Turnip, Radish, millet, and Winter pea
CC termination date	6-May-14	Winter kill	Winter kill

2014-2015

Management	F1	F2	F3
Seed maize planting	17-May-14	8-May-14	7-May-14
Seed maize harvesting	26-Sep-14	25-Sep-14	25-Sep-14
CC planting	7-Aug-14	10-Aug-14	9-Aug-14
Method of CC planting	Broadcast	Broadcast	Broadcast
CC type	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage	Turnip, Radish, and Ethiopian cabbage
CC termination date	Winter kill	Winter kill	Winter kill

2015-2016

Management	F1	F2	F3
Soybean planting	13-May-15	3-May-15	2-May-15
Soybean harvesting	7-Oct-15	3-Oct-15	10-Oct-15
CC planting	no cover crop	5-Oct-15	no cover crop
Method of CC planting		Drilled	
CC type		Cereal rye	
CC termination date			

F1: BREBS station field, F2: West Field, F3: East Field, CC: Cover Crop

Soil Sampling, experimental procedures and data analysis

Soil physical property measurements (FC and PWP) were made on the soil cores taken from each plot twice a year. FC and PWP were measured for 5 depths (0-5, 5-20, 20-40, and 40-60). All physical property determinations were based on two samples per plot. The FC and PWP of soil samples was measured from 2013-2015 for field F1, however, for F2 and F3 fields, measurements were carried out for 2014 and 2015 only (twice a year) from each plot. Two cores per plot were collected and sent to the laboratory for FC and PWP analysis. Soil water holding capacity (SWHC) was estimated as the amount of water held between field capacity and the wilting point between 0-0.6 m depth. Bulk density and infiltration measurements were done only for F1 field.

Bulk density was measured two times, one at the beginning of the experiment in 2013 and one at the end in 2016 from two treatments (SCCC and bare soil) at two depths (0-15 cm and 15-30 cm). The volume of the probe used to collect the samples for bulk density was 154 cm^3. The collected samples were placed in plastic lined bags, and transported to the laboratory for bulk density measurements. Five samples from each plot were taken each year. Bulk density was calculated on an oven-dry (105 ^oC) basis.

Infiltration tests to calculate field hydraulic conductivity were carried out using two methods: mini-disc infiltrometer and ring infiltrometer in 2013, 2014 and 2015.

Mini-Disc Infiltrometer

Two measurements from each plot were taken using mini-disc infiltrometer in all three years. Mini-disc infiltrometer (Decagon Devices, Inc., Washington, USA) measures unsaturated hydraulic conductivity of soil at tensions between -0.5 cm and 6 cm (figure 2). It consists of two chambers: upper chamber controls the suction and lower chamber stores the water for infiltration. At the bottom, a porous, sintered, stainless steel disk is present. Measurements were recorded every 30 sec interval as recommended for silt loam soil for up to 60 mins. The suction of 2 cm was selected each time. Hydraulic conductivity was determined using the method proposed by Zhang (1997). Cumulative infiltration vs time was measured and then fitted with the following function:

$$I = C_1 t + C_2 \sqrt{t} \quad (1)$$

where, C_1 and C_2 are parameters related to hydraulic conductivity and soil sorptivity respectively, I is the cumulative infiltration and t is the time.

The hydraulic conductivity of the soil K was calculated as follows:

$$K(h) = \frac{C_1}{A} \quad (2)$$

where, C_1 is the slope of the curve of the cumulative infiltration vs. the square root of time, and A is a value relating the van Genuchten parameters (van Genuchten, 1980) for 12 soil texture classes to the radius of the disk and applied tension.

Figure 22. Mini Disk Infiltrometer for estimation of unsaturated hydraulic conductivity K(h).

Ring Infiltrometer

Five measurements per plot were taken using single ring infiltrometer in 2013 and 2014 from each treatment. In 2015, double ring infiltrometer (Figure 3) was used to measure saturated hydraulic conductivity of the soil. For the calculations of saturated hydraulic conductivity (K_{fs}) from infiltration capacity obtained from single ring infiltrometer test, procedure reported by Nimmo et al., 2009 was followed. According to this procedure, K_{fs} was calculated as:

$$K_{fs} = \frac{L_G}{t} \ln[\frac{L_G + \lambda + D_o}{L_G + \lambda + D}] \qquad (3)$$

where, L_G is the ring-installation scaling length and calculated as:

$$L_G = C_1 d + C_2 b \qquad (4)$$

where, C_1 and C_2 are empirically determined constants with values of 0.993 and 0.578, respectively (Reynolds and Elrick, 1990), b is the ring radius, d is the ring insertion depth, t in equation 3 is the time during which the ponded depth falls from its initial value of D_o to D. λ is an index of how strongly water is driven by capillary forces in a particular soil. The value of λ was taken as 0.25 m as suggested in Nimmo et al., 2009. K_{fs} from double ring infiltrometer was calculated using modified Philip's equation (Philip, 1977) as:

$$i(t) = St^{\frac{1}{2}} + At \qquad (5)$$

where, i(t) is cumulative infiltration, S represents sorptivity of soil , and coefficient A characterizes long-term infiltration which approximates hydraulic conductivity.

Comparison of field measured soil properties for SCCC treatment (the actual producer's practices in the field since 2002) has been done with natural resource conservation service (NRCS) web soil survey data to evaluate the long-term impact of cover crops on soil physical properties.

Statistical analysis of the data was conducted using analysis of variance procedure (SAS Institute, Inc., 2003) and comparisons among means were made using a least significant difference (LSD) at P<0.05 and P<0.1. For FC and PWP, analysis was treated as randomize complete block design with fields as blocks and four treatments (cover types) in each block.

Each year was analyzed separately. Since, bulk density and hydraulic conductivity was measured only for field F1, t-test was used to determine the differences between the treatments.

Figure 23. Double ring infiltrometer for measuring saturated hydraulic conductivity.

RESULTS AND DISCUSSION

Field Capacity, Permanent Wilting point and Soil water holding capacity

Field capacity (FC) and permanent wilting point (PWP) of four land cover treatment at 0-5, 5-20, 20-40 and 40-60 cm soil depth from 2014 sprig to 2015 fall are shown in figure 4a to 4h. No significant differences in FC and PWP were observed among the four treatments in 2014 spring, 2014 fall and 2015 spring. However, in 2015 fall, PWP at 5-20 and 20-40 cm and FC at 20-40 cm in SC treatment was significant lower than bare soil treatment ($P<0.05$) (Table 2). Maximum FC and PWP for all treatments except bare soil in 2015 fall was observed at 40-60 cm soil depth. Maximum FC and PWP value among all treatments was observed to be 39.96 % vol. and 25.5% vol., respectively, for SC treatment in 2015 fall. For 0-5 cm soil depth, we observed an increase in PWP from 2014 spring to 2015 for all treatments, however, FC for all treatments had decreased. Soil water holding capacity (SWHC) at 0.60 m soil profile for four land cover treatments is shown in figure 5. No significant differences were observed between the treatments at any time (Table 3). Though not significant, there was 6% increase in SWHC in CC treatment from 2014 spring to 2015 fall whereas, 4%, 2% and 6% decrease was observed for SCCC, bares soil and SC treatment, respectively. Also, comparing SCCC and SC treatment, for first two season (2014 spring and 2014 fall), SWHC in SCCC treatment was less than SC, however, in 2015 spring and 2015 fall, it was higher than SC treatment. At the end of the experiment in 2015 fall, maximum SWHC in 0.6m soil profile was observed in SCCC treatment (92.16 mm) (Table 3).

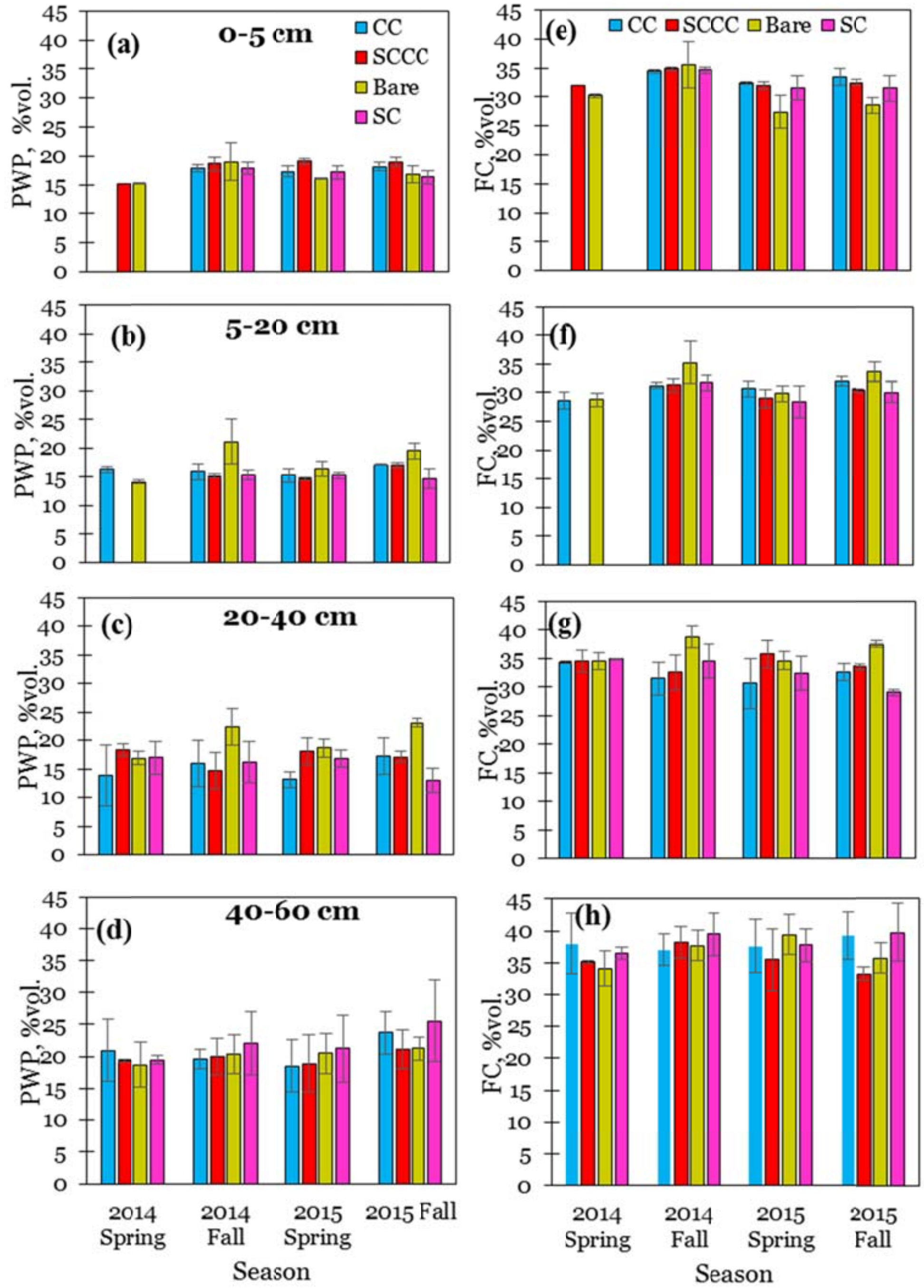


Figure 24. Permanent wilting point (a-d) and field capacity (e-h) of four land for 0-5, 5-20, 20-40 and 40-60 cm soil depth from 2014 spring to 2015 fall.

Table 35. Permanent wilting point and field capacity of four land for 0-5, 5-20, 20-40 and 40-60 cm soil depth from 2014 spring to 2015 fall.

Depth, cm	Season	PWP, %				FC, %			
		CC	SCCC	Bare	SC	CC	SCCC	Bare	SC
0-5	2014 Spring		15.21	15.23			32.08	30.25	
	2014 Fall	17.87	18.68	18.99	17.84	34.43	34.90	35.58	34.68
	2015 Spring	17.33	19.07	16.12	17.17	32.36	32.01	27.44	31.49
	2015 Fall	18.13	18.91	16.75	16.31	33.39	32.46	28.53	b31.46
5-20	2014 Spring	16.30		14.10		28.65		28.80	
	2014 Fall	15.92	15.12	21.10	15.39	31.23	31.29	35.30	31.72
	2015 Spring	15.29	14.61	16.36	15.27	30.67	29.01	29.83	28.40
	2015 Fall	17.10ab	17.05ab	19.51a	14.63b	31.96	30.46	33.67	30.21
20-40	2014 Spring	13.89	18.35	16.89	17.00	34.29	34.57	34.54	34.86
	2014 Fall	16.02	14.74	22.32	16.15	31.46	32.58	38.84	34.61
	2015 Spring	13.17	18.05	18.67	16.82	30.62	35.72	34.59	32.42
	2015 Fall	17.26ab	17.15ab	23.07a	12.96b	32.51ab	33.60ab	37.54a	29.11b
40-60	2014 Spring	20.96	19.39	18.65	19.40	37.98	35.22	34.08	36.46
	2014 Fall	19.64	19.94	20.31	22.00	37.03	38.12	37.64	39.52
	2015 Spring	18.47	18.85	20.47	21.21	37.59	35.51	39.38	37.74
	2015 Fall	23.72	21.07	21.25	25.51	39.28	33.33	35.78	39.76

Means for treatments in the same row and season followed by the same letter are not significantly different at the 5% level.

The expected increase in SWHC with inclusion of cover crops in the cropping system was not evident from this study primarily due to the reason that study period was very short. Usually, the larger period of several years is required to return the amount of residues in order to achieve the higher level of organic matter, thus SWHC.

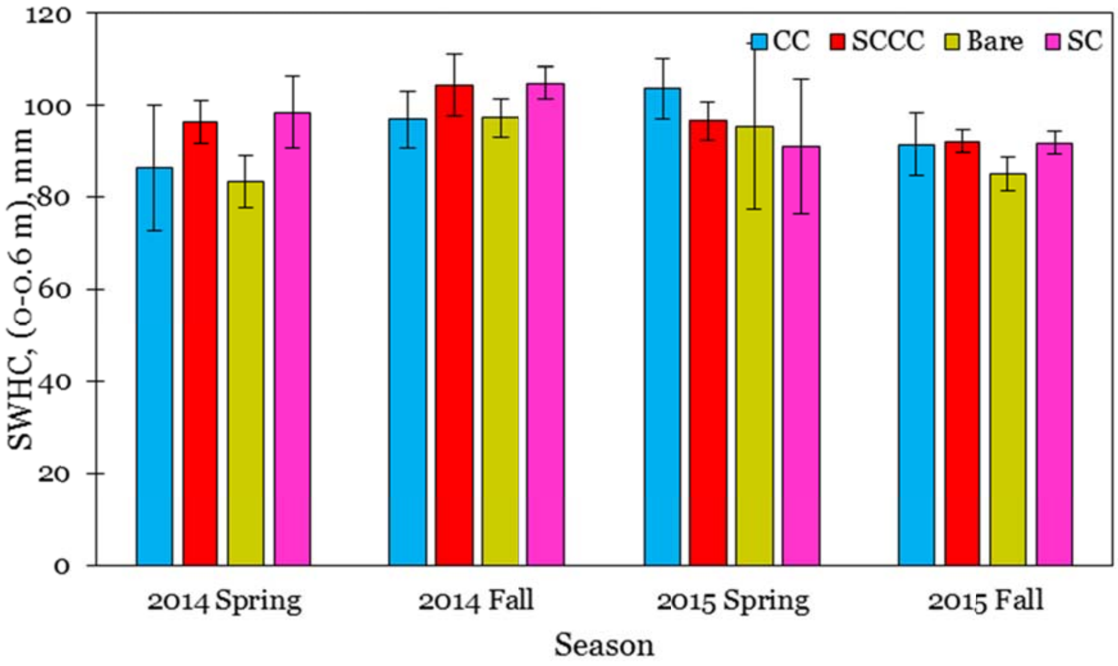


Figure 25. Soil water holding capacity at 0.60 m soil profile for four land cover treatments.

Table 36. Soil water holding capacity at 0.60 m soil profile for four land cover treatments.

	SWHC, mm			
Season	CC	SCCC	Bare	SC
2014 Spring	86.48	96.40	83.26	98.54
2014 Fall	96.93	104.42	97.30	104.86
2015 Spring	103.72	96.73	95.54	91.09
2015 Fall	91.54	92.17	85.13	91.76

Table 37. Bulk Density for 0-15 cm depth as affected by cover crops for 2013 and 2016 growing season.

Treatment	2013 ρ_b (g cm^{-3})	2016
SCCC	1.44 (0.04)a	1.44 (0.01)a
Bare	1.44 (0.01)a	1.46 (0.03)a

Bulk density and Hydraulic conductivity

With the incorporation of cover crops in cropping system, no increase or decrease in bulk density was observed from 2013 to 2016 at 0-15 cm soil depth (Table 4). DISCUSS BULK DENSITY IN 2013-2016 AS COMPARED TO NRCS DATA.. Not significant, but there was a slight increase in bulk density (0.02 g cm^{-3}) in bare soil from 2013 to 2016, however SCCC treatment maintained the bulk density of soil to same level as it was at the beginning of the experiment. This might be due to the reason that in this short duration (2013-2016), increase in organic matter content due to cover crops was not enough (0.03% unit increase) (Sharma and Irmak, 2017; Part I, Companion paper, this issue) to make any change in bulk density as bulk density is highly negatively correlated to organic matter (De Kimpe et al., 1982). Similar results were shown by Wagger and Denton 1989, where no increase in bulk density was observed in untrafficked hairy vetch treatment from 1980 to 1985 in top 2.5 to 10 cm.

The hydraulic conductivity values exhibited inter-annual variation for the same treatments and there were no significant differences between the land cover treatments in saturated hydraulic conductivity as measured by ring infiltrometer ($p<0.05$) in 2013, 2014, or 2015 (Figure 6). The hydraulic conductivity of SC treatment remained similar (decreased by 6%) from 2013 to 2015; however, for SCCC treatment K_{fs} has increased by 50%. There was 46% decrease in CC treatment and 32% decrease in bare soil treatment from 2013 to 2015. This shows that treatment with seed corn residue and cover crops (SCCC), helped in increasing the K_{fs} of soil due to more organic matter than other treatments. However, in CC treatment, which remained bare during seed maize growing season did not have enough residue that would increase K_{fs}. This means cover crops in combination with seed maize helped in increasing the infiltration rate of soil. Among all treatments, bare soil and CC treatment showed lowest K_{fs} in 2015 where as SC treatment showed the highest value.

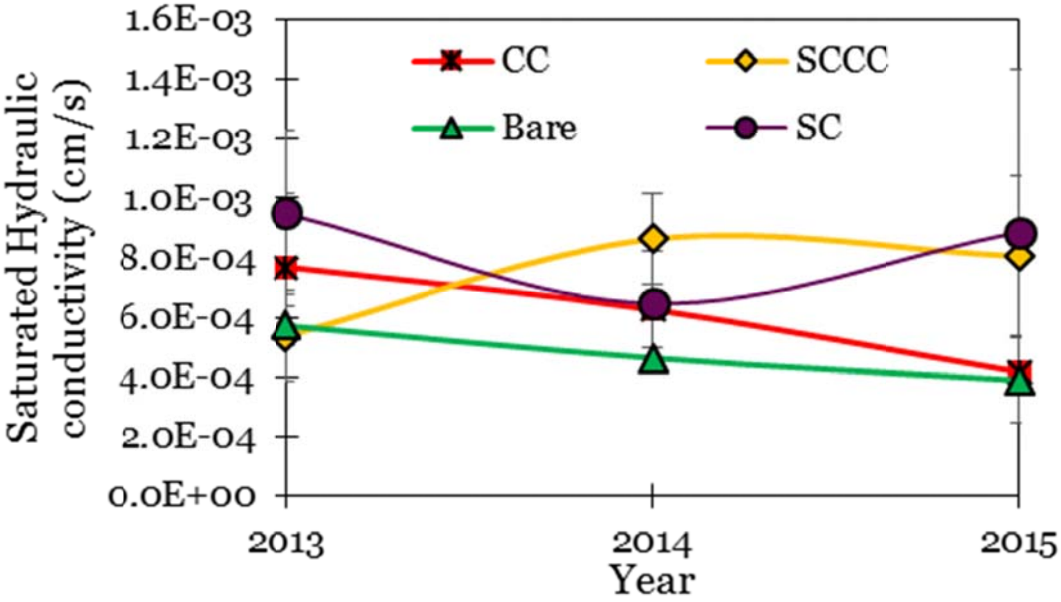


Figure 26. Saturated hydraulic conductivity of four land cover treatments as measured by Ring-infiltrometer from 2013 to 2015.

For all treatments, unsaturated hydraulic conductivity has increased from 2013 to 2015 (figure 7). Lowest unsaturated hydraulic conductivity has been observed in 2014 for all treatments except SC which might be due to an experimental error. This decrease in all treatments can be attributed to higher rainfall in that year which led to higher water table and consequently reduced the infiltration rate. In 2015, highest unsaturated hydraulic conductivity was observed in CC treatment whereas, lowest was observed in bare soil treatment.

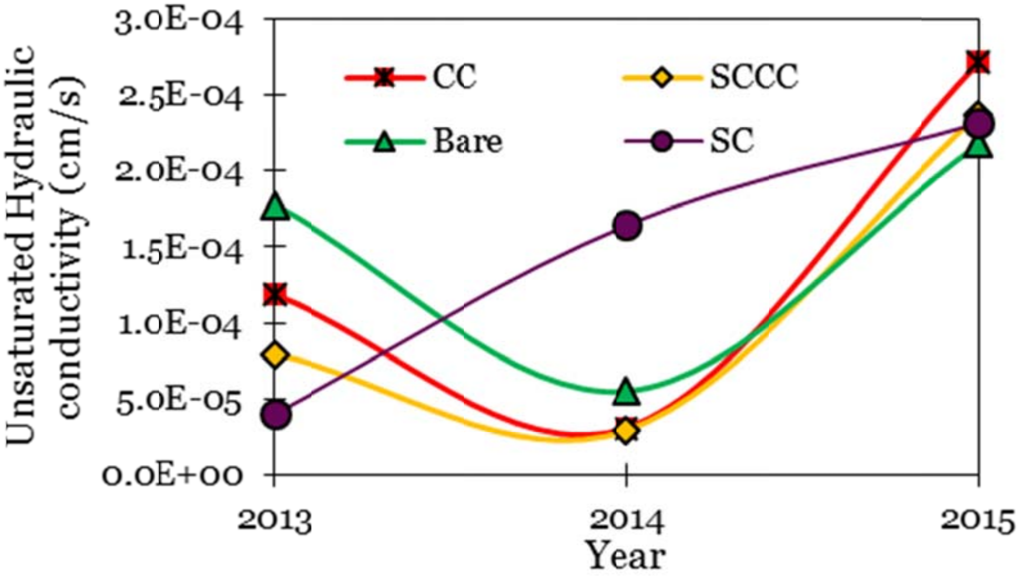


Figure 27. Unsaturated hydraulic conductivity measured by Mini-Disc infiltrometer for four land cover treatments from 2013 to 2015.

Table 38. Saturated hydraulic conductivity of four land cover treatments as measured by Ring-infiltrometer from 2013 to 2015.

Treatment	2013 K_{fs} (cm/s)	2014	2015
CC	0.000769	0.000626	0.000417
SCCC	0.000537	0.000864	0.000806
Bare	0.000572	0.000464	0.000389
SC	0.000950	0.000647	0.000889

Comparison with NRCS measured soil properties

The comparison of field measured FC, PWP and SWHC for SCCC treatment (the actual producer’s practices in the field since 2002) with natural resource conservation service (NRCS) web soil survey data is presented in figure 8. From figures 8a to 8d and 8e to 8h, it is clear that there is an increase in FC and PWP in field measured data as compared to NRCS at 0-5 cm soil depth. On three field average 5 % increase in FC and 20% increase in PWP was observed for this depth. Also, on average, SWHC at 0-60 cm soil depth was 0.6 mm lower than NRCS value. This might be due to an increase in both FC and PWP at this depth, which makes SWHC for field measured data and NRCS data approximately same. Similarly, Jamison (1953) found an increase in aggregation of soil due to an increase in organic matter to result in decreased available water. They found that this result was due to an increase in moisture retention at permanent wilting point (-15 bar).

On three field average basis (Figure 8l) field measured SWHC at all depths was less than NRCS values expect 20-40 cm where it was 4 mm higher. The reason behind no to very little increase in SWHC with adoption of cover crops for more than 10 years might be the fact that there is a significant correlation between organic matter content and available water only in the soil of medium-low clay content (13 to 20%) (Macrae and ma; Jamison and Kroth, 1958). They found that with more than 15% clay, other factors were dominant in determining available water. Since, the soils at the study site have clay content more than 19% (except 0-30 cm in F1), one can expect no change in SWHC with inclusion of cover crops (organic matter).

A decrease of 0.06 g/cc in bulk density was observed when compare to NRCS values for 0-15 cm soil depth. According to literature, the effect of a one percentage unit change of soil organic matter on bulk density ranged from 0.07 to 0.14 g/cc (Shaykewich and Zwarich, 1968). Since, for top 0-5 cm soil for the study site, 0.3% unit increase in organic matter was observed only from 2013- 2015 (Sharma and Irmak, 2017; Part I, Companion paper, this issue) which shows that inclusion of cover crop has a positive impact in decreasing the bulk density of soil if cover crops were grown for longer periods.

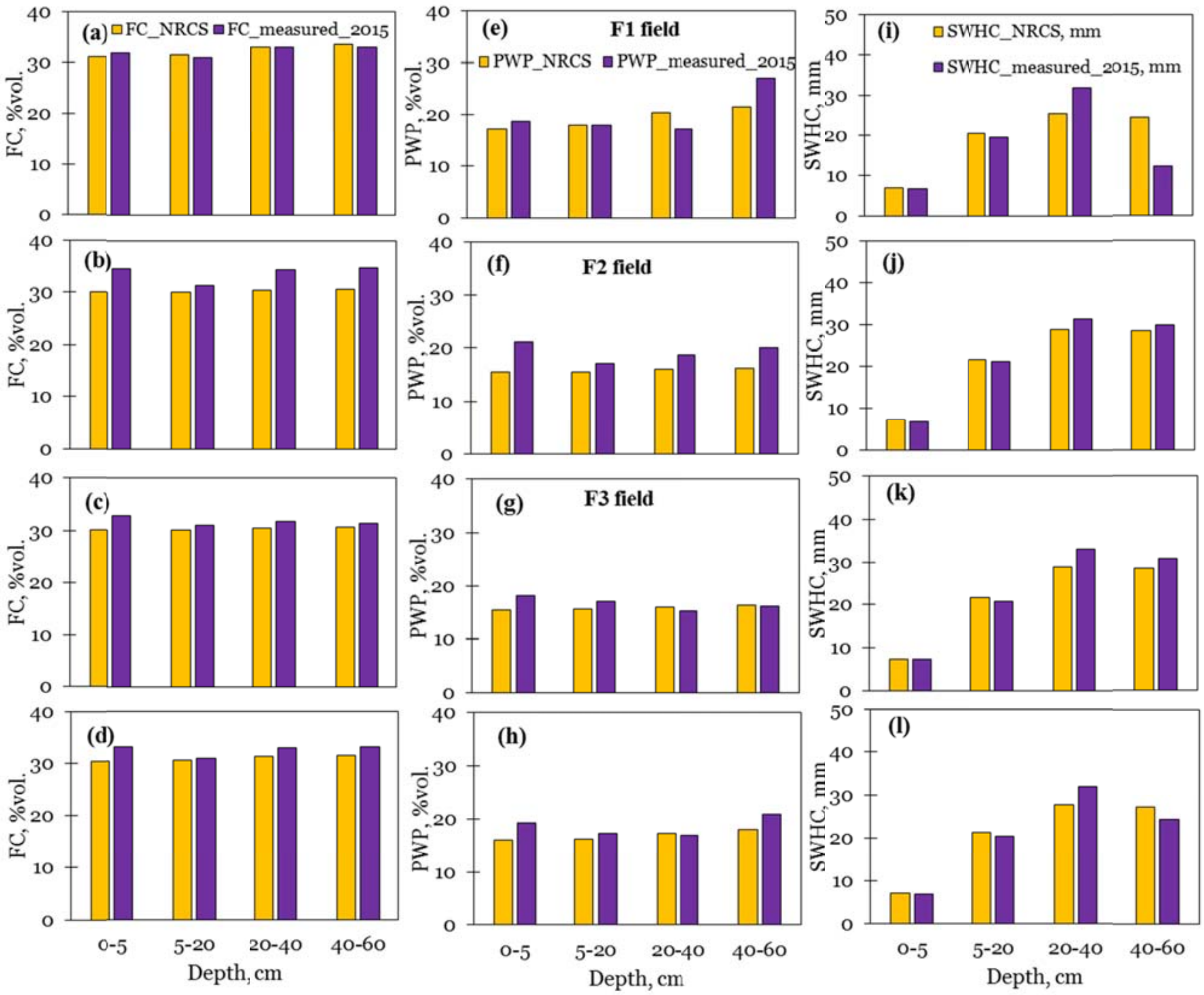


Figure 28. Comparison of field measured field capacity (a-d), permanent wilting point (e-h) and soil water holding capacity (i-l) with NRCS data at 0-5, 5-20, 20-40 and 40-60 cm soil depth for field F1 (a, e and i), F2 (b, f and j), F3 (c, g and k) and average of three fields (d, h and l).

SUMMARY

Field capacity, permanent wilting point, soil water holding capacity, bulk density and hydraulic conductivity of four land cover treatments [CC (cover crop without seed maize); SCCC (seed maize followed by cover crop); bare soil (bare soil without any residue cover); and SC (seed maize without cover crop)] were quantified and compared near Beaver Crossing in eastern Nebraska, USA. Also, comparison of field measured soil properties for SCCC treatment was made with NRCS web soil survey data in order to understand the long term impact of cover crops on soil physical properties. Results of this study showed no significant differences in FC and PWP among the four treatments in 2014 spring, 2014 fall and 2015 spring. However, in 2015 fall, PWP at 5-20 and 20-40 cm and FC at 20-40 cm in SC treatment was significant lower than bare soil treatment ($P<0.05$). Though not significant, there was 6% increase in SWHC in CC treatment from 2014 spring to 2015 fall whereas, 4%, 2% and 6% decrease was observed for SCCC, bares soil and SC treatment, respectively. At the end of the experiment in 2015 fall, maximum SWHC in 0.6m soil profile was observed in SCCC treatment (92.16 mm). Similarly, no significant increase or decrease was observed in bulk density and hydraulic conductivity of soil, however, not significant, there was a slight increase in bulk density (0.02 g cm^{-3}) in bare soil from 2013 to 2016, yet SCCC treatment maintained the bulk density of soil to same level as it was at the beginning of the experiment. Hydraulic conductivity of SC treatment remained approximately same (decreased by 6%) from 2013 to 2015, however, for SCCC treatment K_{fs} has increased by 50%. This shows that treatment with seed corn residue and cover crops (SCCC), helped in increasing the K_{fs} of soil due to more organic matter than other treatments. Comparing field measured data with NRCS data on three field average, there was 5% increase in FC and 20% increase in PWP. Also, a decrease of 0.06 g/cc in bulk density was observed when compare to NRCS values for 0-15 cm soil depth. From the above results, we concluded that cover cropping altered several very important soil physical properties even in a very short period (though not significantly). Further research is required with longer durations of experimentation to investigate the long term effects of cover cropping on soil physical properties.

REFERENCES

Colla, G., J. P. Mitchell, B. A. Joyce, L. M. Huyck, W. W. Wallender, S. R. Temple, T. C. Hsiao and D. D. Poudel. 2000. Soil physical properties and tomato yield and quality in alternative cropping systems. *Agron J.* 92(5): 924-932.

Decagon Devices, Inc., (2005). Minidisk infiltrometer, User's manual.

Ewing, R. P., M. G. Wagger and H. P. Denton. 1991. Tillage and cover crop management effects on soil water and corn yield. *Soil Sci. Soc. of Amer. J.* 55(4): 1081-1085.

Islam, N., W. W. Wallender, J. Mitchell, S. Wicks and R. E. Howitt. 2006. A comprehensive experimental study with mathematical modeling to investigate the affects of cropping practices on water balance variables. *Agric. Water Manage.* 82(1): 129-147.

Jamison, V. C. 1953. Changes in Air-Water Relationships Due to Structural Improvement of Soils. *Soil Sci.* 76:143.

Jamison, V. C. and E. M. Kroth. 1958. Available Moisture Storage Capacity in Relation to Textural Composition and Organic Matter Content of Several Missouri Soils. *Soil Sci. Soc. Amer*. Proc. 22:189.

Kankanen, H., A. Kangas, T. Mela, U. Nikunen, H. Tuuri and M. Vuorinen. 1998. Timing incorporation of different green manure crops to minimize the risk of nitrogen leaching. *Agric and Food Sci in Finland.* 7(5-6): 553-567.

Kimpe, C. D., M. Bernier-Cardou and P. Jolicoeur. 1982. Compaction and settling of Quebec soils in relation to their soil-water properties. *Canad. J. Soil Sci.* 62(1): 165-175.

MacRae, R. J. and G. R. Mehuys. 1985. The effect of green manuring on the physical properties of temperate-area soils. In *Advan. in Soil Sci.,* 71-94. ed. Anonymous , Springer.

McVay, K. A., D. E. Radcliffe and W. L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Sci. Soc. Amer. J.* 53(6): 1856-1862.

Mitchell, J. P., A. Shrestha and S. Irmak. 2015. Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. *J. of Soil and Water Conser.* 70(6): 430-440.

Nimmo, J. R., K. M. Schmidt, K. S. Perkins and J. D. Stock. 2009. Rapid measurement of field-saturated hydraulic conductivity for areal characterization. *Vadose Zone J.* 8(1): 142-149.

Odhiambo, J. and A. A. Bomke. 2007. Cover crop effects on spring soil water content and the implications for cover crop management in south coastal British Columbia. *Agric. Water Manage.* 88(1): 92-98.

Patrick, W. H., C. B. Haddon and J. A. Hendrix. 1957. The effect of longtime use of winter cover crops on certain physical properties of Commerce loam. *Soil Sci. Soc. Amer. J.* 21(4): 366-368.

Philip, J. E.: The theory of infiltration: 1. The infiltration equation and its solution. *Soil Sci.* 83: 1957. 345-357.

Qi, Z., M. J. Helmers and A. L. Kaleita. 2011. Soil water dynamics under various agricultural land covers on a subsurface drained field in north-central Iowa, USA. *Agric. Water Manage.* 98(4): 665-674.

Reeves, D. W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Res.* 43(1): 131-167.

Reeves, D. W. 1994. Cover crops and rotations. *Advan.in Soil Sci.* Crops Residue Management. 125-172.

SAS (2003) SAS ver. 9.3. SAS Institute Inc., NC, USA.

Reynolds, W. D. and D. E. Elrick. 1990. Ponded infiltration from a single ring: I. Analysis of steady flow. *Soil Sci. Soc. of Amer. J.* 54(5): 1233-1241.

Sharma, V., S. Irmak. 2016a. Effect of cover cropping on selected soil properties (in progress).

Shaykewich, C. F. and M. A. Zwarich. 1968. Relationships Between Soil Physical Constants and Soil Physical Components of Some Manitoba Soils. *Canad. J. Soil Sci.* 48:199.

Touchton, J. T., D. H. Rickerl, R. H. Walker and C. E. Snipes. 1984. Winter legumes as a nitrogen source for no-tillage cotton. *Soil and Tillage Res.* 4(4): 391-401.

Van der Linden, A., J. A. Van Veen and M. J. Frissel. 1987. Modelling soil organic matter levels after long-term applications of crop residues, and farmyard and green manures. *Plant and Soil*. 101(1): 21-28.

Van Genuchten, M.T. 1980. A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. *Soil Sci. Soc. of Amer. J.* 44(5). 892-898.

Wagger, M. G. and H. P. Denton. 1989. Influence of cover crop and wheel traffic on soil physical properties in continuous no-till corn. *Soil Sci. Soc. of Amer. J.* 53(4): 1206-1210.

Williams, W. A. 1966. Management of nonleguminous green manures and crop residues to improve the infiltration rate of an irrigated soil. *Soil Sci. Soc. of Amer. J.* 30(5): 631-634.

Wilson, G. F., R. Lal and B. N. Okigbo. 1982. Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded Alfisol. *Soil and Tillage Res*. 2(3): 233-250.

Zhang, R. (1997) Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. *Soil Sci. Soc. of Amer. J.* 61, 1024-1030.

Our NRCS-CIG Cover crop project has received two recognitions:

"**Second place award**" at the 2015 ASABE Annual International Conference for the research paper titled "S*oil water dynamics and evapotranspiration of cover crop mixtures in seed maize-cover crop rotation fields (by V. Sharma and S. Irmak).*" Presented by the ASABE-AABFEIO. The award has been instituted to recognize excellence among members in the conduct and presentation of research related to agricultural, food and biological engineering. July 29, 2015. New Orleans, LA.

“**First Place Award in Poster Presentation Competition**” for the poster titled “Soil-water dynamics, evapotranspiration and single and basal crop coefficients of cover crop mixtures in seed maize-cover crop rotation fields (by V. Sharma and S. Irmak).” 6th DWFI Conference. October 23, 2014. Seattle, WA.

The project data, information, and accomplishements have been disseminated to the growers and agricultural professionals in numerous public education programs. Some of the presentations include, but not limited to:

1. Sharma, V., and S. Irmak. July 16, 2014. Energy balance fluxes, evapotranspiration, and crop coefficients of cover crop mixtures. *Montreal, Canada*. 45 people.
2. Sharma, V., and S. Irmak. October 20, 2014. Soil-water dynamics, evapotranspiration and single and basal crop coefficients of cover crop mixtures in seed maize-cover crop rotation fields (poster). 6th DWFI Conference. *Seattle, WA*, 80 people.
3. J. Mitchell, T. Hsiao, A. Shrestha, and S. Irmak. November 4, 2014. Cover crop biomass production and water use in California’s San Joaquin Valley. ASA-CSSA-SSSA Annual International Conference (invited). *Long Beach, CA*, 70 people.
4. Irmak, S. November 24, 2014. Irrigation engineering, evapotranspiration, and cover crop research update. SCAL Advisory Committee meeting. *Clay Center, NE*. 21 people.
5. Sharma, V., and S. Irmak. July 27, 2015. Cover crop evapotranspiration and crop coefficients. ASABE Annual Conference. *New Orleans, LA*. July 26-29, 2015. *35 people*.
6. Irmak, S., and V. Sharma. August 19, 2015. Cover crop water use and crop coefficients. South Central Agricultural Laboratory Field Day. *Clay Center, NE. 130 people*.
7. Irmak, S. February 23-4, 2016. Cover crop evapotranspiration, crop coefficients and impact(s) on soil water storage. Central Plains Irrigation Conference. *Kearney, NE*. 75 people (**repeated in two sessions**).
8. Irmak, S. March 10, 2016. Cover crop evapotranspiration and crop coefficients. NAWMN Annual Conference. *York, NE.* 55 people.
9. Barker, J. B., A.T. Mohammed, D.M. Heeren, R.W. Elmore, C.A. Shapiro, S. Irmak, K. Koehler-Cole, T.M. Shaver, H. Blanco-Canqui and C.A. Francis. April 12, 2016. Impact of cover crops on soil moisture available for the primary crop. Spring Research Fair, *Lincoln, NE*.

Picture 1. The Bowen ratio-energy balance tower in the seed corn field after detasseling in Field 1. – July 2, 2012

Picture 2. A Watermark data logger in the male seed corn row, immediately after the male row had been cut and the cover crop seed had been broadcast. Also note the early weed development. – July 17, 2012

Picture 3. Weed growth in the row where the male corn had been removed during the corn senescence in Field 1. – August 1, 2012

Picture 4. Cover crop growth in the row where the male corn had been removed in Field 1. – August 1, 2012

Picture 5. Seed corn harvest and cover crop distribution in Field 1. The cover crop was predominately growing in the row where the male corn had been removed, though there was some growth between female rows. – August 21, 2012

Picture 6. An area of heavy cover crop cover in Field 1. – August 21, 2012

Picture 7. Ethiopian cabbage, turnip, and radish cover among some weeds and corn stubble and residue in Field 1. – August 28, 2012

Picture 8. The sorghum-Sudan barely grew before a killing frost in Field 2. – October 16, 2012

Picture 9. The king of the radishes in Field 3. – October 16, 2012

Picture 10. The stalky Ethiopian cabbage in Field 3. – October 16, 2012

Picture 11. A plump turnip in Field 3. – October 16, 2012

Picture 12. Millet in the mix in Field 3. Other rows are greening-up more, however, the cover crop is still predominately in the old male rows. – October 16, 2012

Picture 13. Snow and runoff on the edge of Field 3. – January 17, 2013

Picture 14. Watermark sensors in snow cover at Field 1. – February 1, 2013

Picture 15. The Bowen ratio energy balance system (BREBS) installed at the primary site records hourly water balance, energy balance, and microclimate parameters year-round.

Picture 16. Turnip, radish, and Ethiopian cabbage cover crop mix broadcast into seed corn, primary field, summer 2012.

Picture 17. Sorghum Sudangrass growth before fall frost, fall 2012.

Picture 18. Three fields have a four-plot Watermark sensor set-up for measuring the differences in soil water between plots of (1) cover crop only, (2) seed corn and cover crop, (3) seed corn only (not pictured), and (4) bare soil (not pictured). This picture is of a primarily turnip mix in fall 2013.

Picture 19 and 20. Cover crop in the primary field in spring 2013. The cover consists of the fall planted crops that overwintered, including cereal rye, hairy vetch, and winter pea.

Picture 21. Spring-terminated cover crop in the primary field, spring 2013.

Picture 22. Seed corn emerged into cover crop residue, primary field, spring 2013.

Picture 23. Turnip emergence into seed corn stand, summer 2013.

Picture 24. Primarily turnip cover crop in seed corn prior to harvest, fall 2013.

Picture 25. View of the height of the turnip, radish, millet, and winter pea cover crop only plot from the bare plot, summer 2013.

As the project leader, Dr. Suat Irmak expresses his appreciation his research team members who helped in this project.

Respectfully submitted,

Suat Irmak