# SOIL CARBON AND AGROECOSYSTEM BENEFITS OF CONSERVATION MANAGEMENT AND PERENNIAL BIOENERGY CROP PRODUCTION

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## ABSTRACT

Conservation agricultural management practices and perennial bioenergy crops can increase soil organic C (SOC) stocks on marginal soils yet the time necessary to observe these benefits, as well as the upper limit of C storage is not known. Co-benefits often associated with SOC accumulation are positive effects on water and nutrient retention, soil microbial biomass (SMB) and diversity and soil structure, resulting in better soil quality. We measured a variety of soil properties and soil quality indicators including SOC, aggregate stability, SMB-C, bulk density (BD), soil volumetric water content ($\theta_v$) at field capacity (FC) and wilting point (WP), and available water (FC – WP) during a 16-year bioenergy study. N fertilizer (0, 60, 120, and 180 kg N ha$^{-1}$) and harvest management on switchgrass (*Panicum virgatum* L., harvested at Aug. and post-frost) and no-tilled corn (NT-C, *Zea mays L.*, with and without 50% stover removal)) established on a marginal soil in the western U.S. Corn Belt. We present changes in surface (0-30 cm) soil properties after 16 years. Surface soils have not achieved equilibrium and continue to accrue SOC. Soil OC, microbial biomass, and aggregation increased over time. Available water increased with increasing SOC, but the effect was small and unlikely meaningful for plant growth. The impacts of conservation management practices on water capture and infiltration may be much larger than the water storage impact. Our results suggest that perennial systems need long-term measurements to accurately quantify bioenergy impacts on the soil resource and in contrast to model predictions, soil C accrual and soil quality benefits persist for decades post land-use conversion.

## INTRODUCTION

Conversion of marginally productive crop lands to perennial biofuel crops has the potential to produce cellulosic biofuel feedstock and increase soil carbon (C) stocks while reducing erosion, fertilizer use, and greenhouse gas (GHG) emissions (Adler et al., 2007; Jin et al., 2019; Mitchell et al., 2016). Switchgrass can increase soil C stocks due to its perennial, deep-rooted growth form (Garten et al., 2010; Stewart et al., 2016) and increase soil aggregation and reduce erosion potential compared to corn (*Zea mays* L.). In this study, we track the impact of N fertilizer and harvest effects on continuous switchgrass (Cave-in-Rock), rotational switchgrass (Liberty), and NT-corn on surface soil properties. We measured several soil quality indicators and properties (aggregate stability, SMB, SOC, available soil water) over the 16-year study.

## MATERIALS AND METHODS

### Site & Experimental Design

The 16-year rainfed bioenergy experiment is located at the University of Nebraska's Eastern Nebraska Research, Extension, and Education Center (ENREEC) (latitude 41.151, longitude 96.40) in Saunders County, 50 km west of Omaha, NE (details in Stewart et al., 2016, Jin et al. 2019). The mean annual temperature is 9.16°C and the mean annual precipitation is 63.5 cm. The experiment included two similar soils; a Yutan silty clay loam (fine-silty, mixed, superactive, mesic Mollic Hapludalf) and a Tomek silt loam (fine, smectitic, mesic Pachic Argiudoll) with a slope less than 2%.

The study design compares bioenergy crop species (corn and two switchgrass cultivars), N fertilizer rates and harvest practices. It is a randomized complete block split-split plot experimental design that was established with two cultivars of switchgrass (Liberty, Cave-in-Rock), and NT-C.

Three N fertility treatments were randomly assigned within the main plots and were different for switchgrass and NT-corn. Subplots are 30 m long × 18 m wide and are separated by 15 m wide alleys. From 2000-2014, N fertilizer on the CIR switchgrass were 0, 60, and 120 kg N $ha^{-1}$ and on NT-C were 60, 120, and 180 kg N $ha^{-1}$. For Liberty, in 2014 N fertilizer was the same as for CIR. The 0N rate was used as a low input treatment only for switchgrass. Harvest treatments (no residue removal (NRR) or 50% residue removal (RR) for corn and August or post-frost harvest for switchgrass), were established by splitting plots lengthwise into 9 m wide sub-subplots after the 2001 soil sampling.

### Soil Sampling & Analyses

Soils were sampled by excavating the 0–5, 5–10, and 10–30 cm depths using a flat-bladed shovel in July 1998, May 2001, April 2004, May 2007, and April 2014 as described by Stewart et al. (2014). Soils were packed on ice, and transported to Fort Collins, CO and refrigerated or seran coated and shipped to Lincoln, NE. All plant material <2 mm was hand-picked from the soil. Moist subsamples were retained for microbial biomass and soil moisture content (105 °C). An additional subsample was oven-dried at 55 ºC, ground to pass through a 0.2-mm sieve, and stored in glass containers for C analysis.

Soil microbial biomass was determined in duplicate using the incubation-fumigation method on moist soils (Follett et al., 2007). Briefly, soil moisture was adjusted to -0.05 MPa and the soils incubated at 30 ºC for 10 days. Soils were fumigated using distilled chloroform at day 10 and incubated for an additional 10 days. Soil $CO_2$ was trapped in 1M NaOH base traps and titrated with an excess of HCl.

Soil total C and N concentration and $\delta^{13}C$ were determined using a Europa Scientific carbon nitrogen analyzer with a Solid/Liquid Preparation Module (Dumas combustion sample preparation system) coupled to a Europa 20-20 stable isotope analyzer continuous flow isotope ratio mass spectrometer (Europa Scientific Ltd., Crewe, England). Carbonates were observed in only a few samples and were removed prior to analyses for organic C with addition of 0.03 M $H_3PO_4$, dried at 55 ºC and ground (Follett *et al.,* 1997). All analyses are expressed as oven dry weight (55°C).

Bulk density, aggregate stability, water content at field capacity (-33 kPa), water content at wilting point (-1500 kPa) were performed at the NRCS Kellogg Soil Survey Laboratory in Lincoln, NE using established methods (USDA-NRCS, 2004). Soil bulk density was determined using the Saran-coated clod method 3B1. Soil clods were cut from the excavated soil material to a suitable size (average of about 210 $cm^3$), coated immediately with Saran F310, hung to dry, then placed in NRCS chambered boxes and transported to the laboratory. Mass and volume were determined after desorption to 33 kPa, and after drying at 110ºC. A correction was made for mass and volume of rock fragments and the Saran F310 coating with the BD value reported for <2 mm (<0.079 in) soil fabric (NRCS, 2004). Wet soil aggregate stability (method 3F1a1a) was determined on dry soils sieved to 2mm and subsequently wet-sieved on a 0.5 mm sieve and expressed as a percent soil mass (USDA-NRCS, 2004). Available water (AW) was calculated as the difference between FC and WP. Calculations of changes in AW were made on a volumetric ($\theta_v$) basis.

Data were analyzed using a repeated measures design with split-split plot experimental units in SAS version 9.3 (Cary, NC). Fixed main treatment effects were crop, N×crop and harvest×crop with replicate, replicate×crop and replicate×N×crop considered random effects. Variables were tested for homogeneity of variance, normalcy and when necessary, log transformed to meet these criteria.

## RESULTS AND DISCUSSION

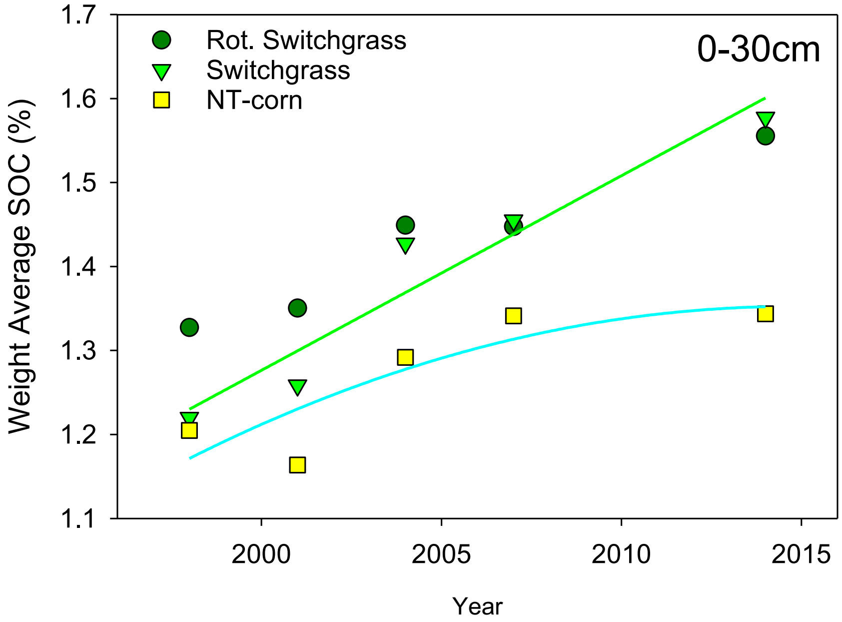

**Figure 1.** Main crop effects for soil organic carbon (SOC) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

The benefits of best management practices, NT and perennial cropping, were evident in soil quality indicators compared to historic long-term conventional tillage management. Soil OC (Figure 1), microbial biomass (Figure 2), and aggregation (Figure 3) increased over time under all best management practices over the 16-year study. In fact, the greatest increase in SOC content, soil aggregation and SMB-C and the strongest decrease in soil bulk density under switchgrass were observed in the last 7 years of the study, emphasizing the importance of long-term studies in SOC research (Peterson et al., 2012). Main N and harvest effects were not observed, and so we present only main crop effects.

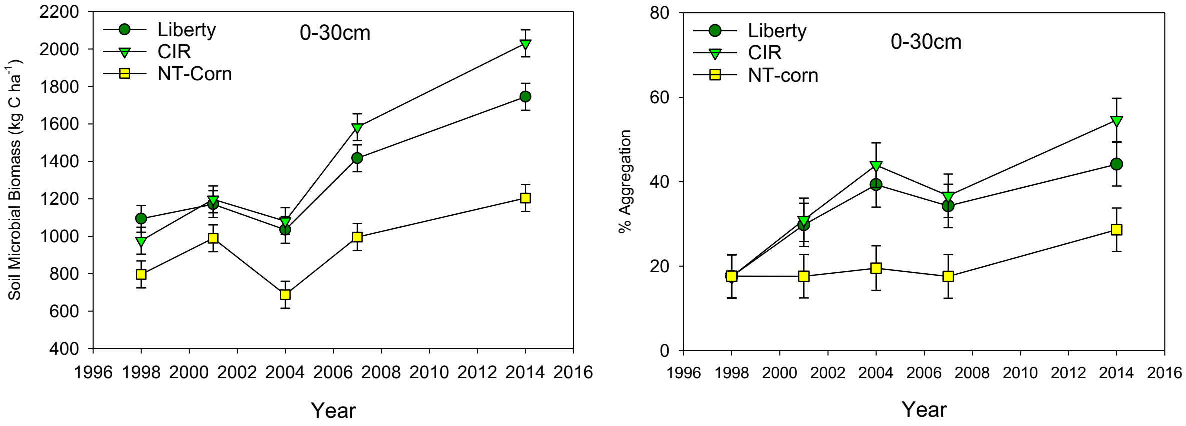

**Figure 2.** Main crop effects for soil microbial biomass (kg C ha$^{-1}$) (left panel) and % aggregation (right panel) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

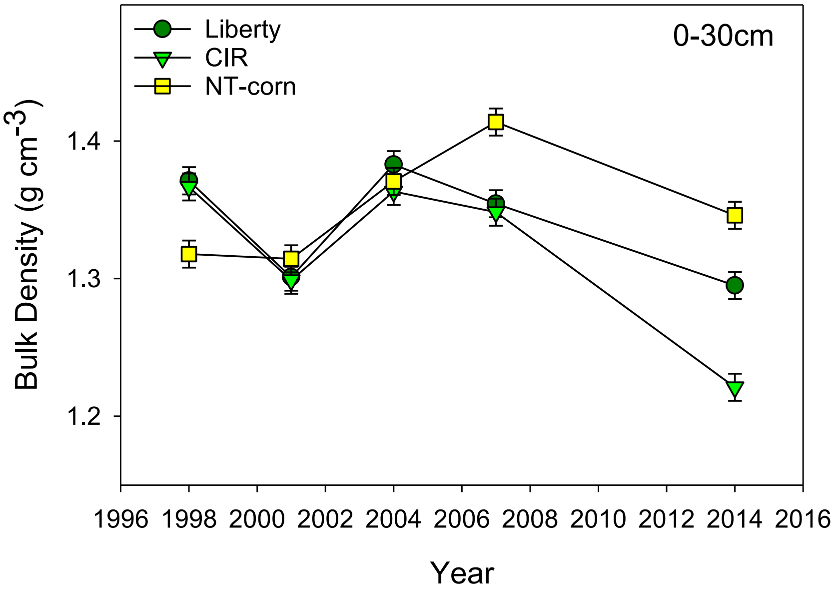

**Figure 3.** Main crop effects for a) soil microbial biomass (kg C ha$^{-1}$) and % aggregation b) for two switchgrass cultivars (Liberty, Cave-in-Rock) and NT-Corn in the 0-30 cm depth. Error bars represent standard error of the mean (n=3).

NT-corn increased SMB-C 51%, Liberty 60%, and CIR 108% compared to baseline (Figure 2). The two switchgrass cultivars had more SMB-C in 2014 (CIR 2030.3 g SMB-

C ha$^{-1}$, and Liberty 1745.1 g SMB-C ha$^{-1}$) compared to NT-Corn (1204.2, $p<0.0001$, Figure 2). NT-corn increased aggregate stability 62%, Liberty 151%, and CIR 212% compared to baseline for 0-30cm depth (Figure 2). Averaged across N and harvest, switchgrass soils had almost double the aggregate stability (50%) compared to NT–C (27%).

Averaged over depths and N treatments, both cultivars of switchgrass decreased bulk density 10-15% over the 16 years ($p<0.0001$, Figure 3). NT-corn increased bulk density until 2007 and then decreased to slightly above baseline in 2014.

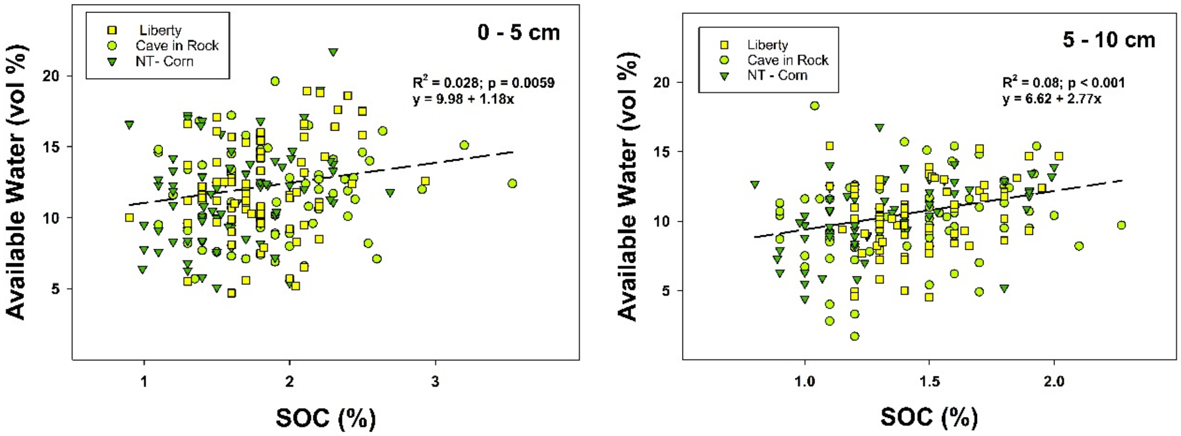

**Figure 4.** Available soil water ($\theta_v$) versus SOC (%) for the 0 – 5 cm depth (left panel), and the 5 – 10 cm depth (right panel). Slopes and intercepts did not differ between crops. Note the difference of scales for the x-axis.

Due to the increase in SOC %, we expected an increase in available soil water. On average, a 1% increase in SOC increased available water (vol %) by ~ 1.2 in the 0 - 5 cm depth and 2.8 in the 5 -10 cm depth, with no differences in the slopes or intercepts between crop treatments (Figure 4). Although statistically significant, this effect is fairly small (e.g., equivalent to an increase of 1.2 and 2.8 mm of water per 100 mm of soil). These results are similar to those reported by Minasny and McBratney (2018). However, the impacts of conservation management practices on water capture and infiltration may be much larger than the water storage impact.

Switchgrass has the potential for long-term soil C gain due to its large root biomass and slower decomposition compared to NT-corn. Soil quality indicators did show greater increases under switchgrass. Soil microbial biomass increased 3% per year under NT-corn and 7% per year under switchgrass in the 0-30 cm depth. Soil aggregate stability increased 4% per year under NT-corn and 13% per year under switchgrass. Bulk density did not change under NT-corn, but decreased 1% per year under switchgrass in the 0-30 cm depths. Long-term studies will be required to measure these changes, since after 16 years we were only beginning to see crop species differences in SOC storage in the surface soils.

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