NITROGEN FERTILIZATION AND LONG-TERM NO TILLAGE IMPACTS ON SOIL PROPERTIES AND DEEP SOIL C STORAGE UNDER IRRIGATION

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ABSTRACT

The net soil greenhouse gas mitigation potential of conservation agricultural management practices is strongly influenced by the direction and magnitude of soil organic C (SOC) change in deep soil layers (>6”). Deep SOC is typically old, highly processed, and consists of microbial products and root exudates associated with clay and other minerals. However, it can be susceptible to decomposition and priming from the addition of new, labile organic C. We examined long-term soil C dynamics (organic and inorganic) 13 years after conversion to no-tillage (NT) under varying nitrogen fertilizer rates (0 or 220 lbs a^{-1}). We present preliminary data from throughout the soil profile (0-4’) of $\delta^{13}C$ of SOC and SIC, ^{14}C, and organic and inorganic chemical composition by FTIR. Although there was surface (0-3”) accumulation of new, corn-derived-C, it was lost from the deeper soils (>3”). Nitrogen fertilizer had little effect on SOC and SIC except in the 0-3” layer. After NT adoption, deep soil C became older, from both δ^{13} SOC and ^{14}C data. Soil inorganic C increased at the two deepest depths, which was confirmed by FTIR. The δ^{13}SIC suggested disequilibrium of C sources with carbonate minerals after only 13 years. These results indicate that deep soil C (both organic and inorganic) is surprisingly dynamic and susceptible to loss, despite conservation management practices.

INTRODUCTION

The net soil greenhouse gas mitigation potential of conservation agricultural management practices in non-flooded systems is driven by changes in nitrous oxide emissions and soil carbon stocks. In many cases, net fluxes are strongly influenced by the direction and magnitude of soil organic C (SOC) changes in subsurface soil (>6”). Deep SOC is typically old, highly processed, and consists of microbial products and root exudates associated with clay minerals. However, it can be susceptible to decomposition and priming from the addition of new, labile organic C (such as dissolved organic C). After conversion to no-tillage (NT) for 11 years, we previously documented a net loss of 14-19 Mg C ha^{-1}, primarily from soils deeper than 1’ (Stewart et al. 2017). However, questions remain regarding the source and turnover of these soil C pools.

Nitrogen fertilizer could either promote SOC stabilization through greater plant productivity or C loss through stimulated microbial mineralization. In irrigated soils with carbonitic lithology, the addition of fertilizer could promote surface carbonate dissolution and reprecipitation in the soil profile. These effects have been observed over 50-100 years in some systems, but have typically involved comparing cultivated to non-disturbed soil profiles (Cihacek & Ulmer 2002).

Here, we examine the impact of long-term no-tillage on soil C dynamics (organic and inorganic) in more detail using $\delta^{13}C$, ^{14}C, and FTIR throughout the soil profile (0-4') 13 years after conversion to conservation NT.

MATERIALS AND METHODS

The study was located on a Fort Collins clay loam soil (fine-loamy, mixed, mesic Aridic Haplustalfs) with a 1 to 2% slope at the Agricultural Research Development and Education Center (ARDEC) (lat. 40° 39'6" N, long. 104° 59'57" W; 1535 m above sea level) near Fort Collins, CO. The study was initiated in 1999 and described in detail in Stewart et al. (2017) on a field that had previously been cropped under conventional tillage (CT) continuous corn for 6 yr. (moldboard plow, 6" depth). The study was a randomized complete block design under no-tillage (NT) continuous corn with five N rates and three field replicates with 10.7 by 15.2 m plots.

We report data for two N rate treatments 0, 220 lb a^{-1} from 2001 to 2014. N source was urea ammonium nitrate (UAN, 32–0–0) from 2001 through 2005 applied preplant in subsurface bands (2") with a liquid fertilizer applicator. In 2006, surface band (split applications) of a polymer-coated urea (ESN) was applied at corn emergence in May and dry granular urea N fertilizer was applied in mid-June. From 2007 to 2014, surface band applications of a polymer-coated urea near the corn row at emergence in May were used. Triple superphosphate (0–46–0) was applied in 1999 (56 kg P ha^{-1}), 2004 (28 kg P ha^{-1}), 2005 (53 kg P ha^{-1}), 2009 (20 kg P ha^{-1}), and 2010 (56 kg P ha^{-1}) to avoid P deficiency in corn.

Soil samples were collected in 2001, and 2014 using a GPS to relocate the sampling sites. One soil core (2" diameter) within each plot was collected in the fall after harvest, and separated into increments of 0-3", 3-6", 6"-1', 1'-2', 2'-3', 3'-4'. After 2mm sieving and large root removal, soils were air dried and finely ground for analysis. Soil total C, SOC and N concentration and $\delta^{13}C$ were analyzed with dry combustion mass spectrometry using methods described in Stewart et al (2019). Carbonates were removed before mass spec analysis using an 8 hr. acid fumigation in concentrated HCl vacuum atmosphere (Stewart et al., 2019). All analyses are expressed as oven dry weight (55°C).

The ^{14}C analyses were completed after carbonate removal. Samples were graphitized in the Carbon, Water and Soils Lab, USDA-Forest Service Northern Research Station Radiocarbon measurements were conducted at the Keck Carbon Cycle AMS Facility, Earth System Science Dept., UC Irvine.

The soil FTIR spectra of the dried and ground samples were obtained in diffuse reflectance mode with a Digilab FTS 7000 Fourier Transform spectrometer (Varian, Inc., Palo Alto, CA,) with a Pike AutoDIFF auto-sampler (Pike Technologies, Madison, WI). Resolution was 4 cm^{-1}, Spectral range was 10,000 - 4000 cm^{-1} for the NIR and 4000 - 400 cm^{-1} for the MidIR with 64 co-added scans per spectrum.

RESULTS AND DISCUSSION

Deep soil C is surprisingly dynamic in these semi-arid irrigated NT corn soils and susceptible to both redistribution and loss, despite conservation practices (Figure 1). Soil OC accrual was observed only in the surface horizon under the two N treatments, with the majority profile SOC loss below 6” (Figure 1a). Surface C accrual with deep soil C losses has recently been observed under conservation practices such as NT (Watts et al., 2020) and irrigated cover crops treatments (Tautges et al., 2019), suggesting that soil processes deep in the profile are more important than previously thought.

After only 13 years, there is also evidence of carbonate dissolution and redistribution through the soil profile, although this comprised a relatively small proportion of total SIC stocks (~kg C ha^{-1}). Carbonate was lost from the 1’-2’ depth and redistributed to the 2’-3’ and 3’-4’ depths (Figure 1b) with no effect of N fertilizer. Carbonate redistribution under agricultural management had been observed elsewhere and can comprise and significant proportion of total soil C stocks in irrigated semi-arid systems (Denef et al., 2008).

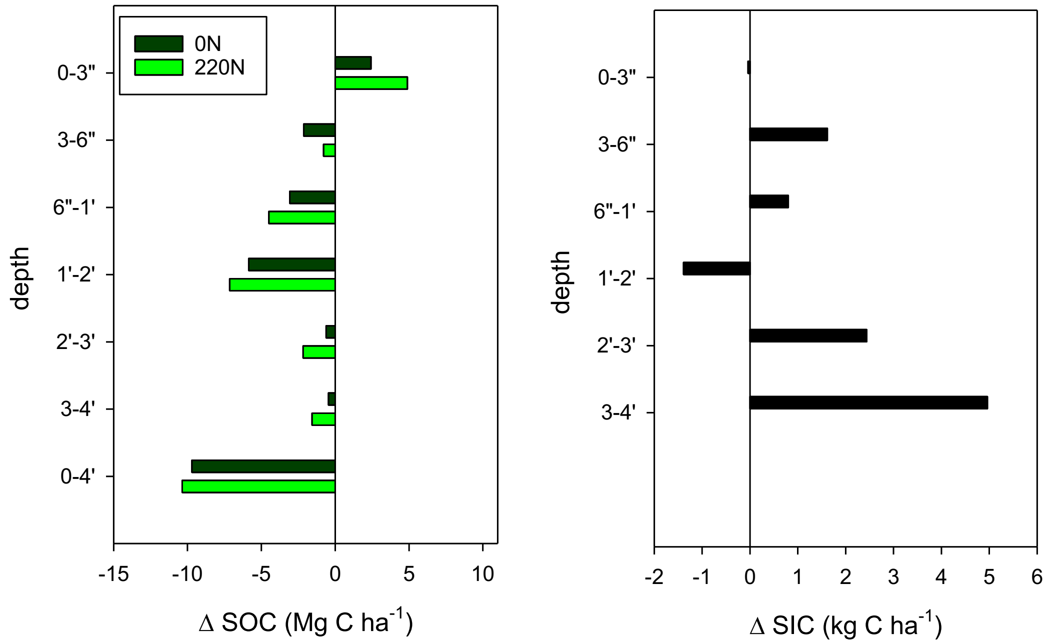

Figure 1. Change in (a) soil organic C (SOC) stock (Mg C ha^{-1}) by N rate (0 and 220 lbs a^{-1}) and (b) soil inorganic C (SIC) (kg C ha^{-1}) stocks (averaged over N rate) from 2001 to 2014 for the two N rates under irrigated no-tilled continuous corn.

depth	2001	2014	2001	2014
	^{14} C age (years BP)		δ ^{13}C	
0-3"	310	300	-18.18	-16.43
3-6"	385	825	-19.62	-18.33
6-12"	650	895	-19.74	-19.43
1-2'	3575	3930	-17.90	-18.86
2-3'	5930	4990	-18.24	-20.68
3-4'	9275	11600	-17.00	-23.72

Table 1. The ^{14} C age (years BP) and SOC δ^{13}C for the 220 lbs a^{-1} rate through the soil profile in 2001 and 2014.

After the adoption of NT, surface accumulation of new, corn-derived-C was evident by the less negative δ^{13}C and the loss of corn-derived C in the remaining 1-4' depths (Table 1). The ^{14}C data indicate a substantial shift from the 2001 baseline to older C and confirm the δ^{13}SOC results.

SOC age and δ^{13}C are known to increase with depth, but these relatively rapid changes are somewhat perplexing. Further research will be required to tease apart possible mechanisms but could include SOC decomposition at deeper depths (priming) from increased dissolved C or N flow. The addition of fresh C to deep soil horizons can result in a substantial loss of previously stable SOC (Fontaine et al., 2007). Increased surface SOC and a decreased SOC content at depth was also observed under irrigation with high-C waste-water (Jueschke et al., 2008). Another mechanism could be decreased C input from the upper soil layers (from lack of tillage). Residue C is placed deeper in the soil with conventional tillage (Angers and Eriksen-Hamel, 2008) and increases C inputs below the surface (Gregorich et al., 2009) where decomposition rates are slower compared to the surface (Leichty et al., 2018). A third possibility could be decreased root growth at depth under NT may also decrease corn-derived C inputs (Qin et al., 2005). Further studies will be required to look at these mechanisms of potential C loss.

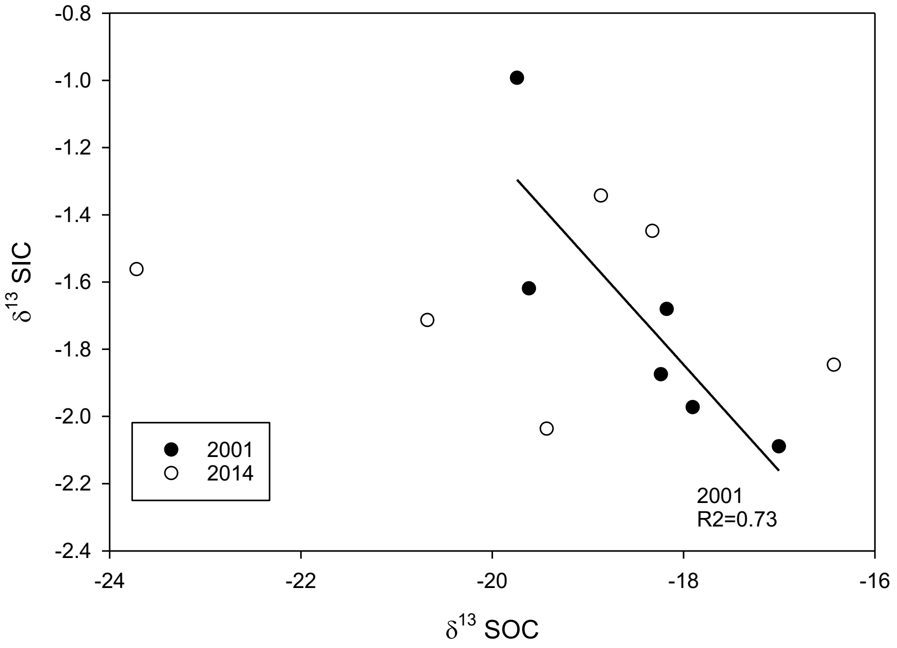

Figure 2. SIC δ^{13}C as a function of SOC δ^{13}C for the 232N rate through the soil profile in 2001 and 2014.

Inorganic C is a function of soil CO_2, which could have plant, soil, or lithological C sources. In 2001, the SIC δ^{13}C is closely related to SOC δ^{13}C, suggesting carbonate formation was in equilibrium with soil organic matter at each depth (Figure 2). However, in 2014, the lack of correlation suggests that the system is at disequilibrium and that other sources of CO_2 are the primary source for reprecipitated carbonate.

Agricultural management induced changes in water and pH levels have been found to increase inorganic C storage in cultivated versus native systems. This effect may depend on management and plant-mediated changes in water storage. Crop fallow treatments commonly practiced in this region store water and potentially move SIC down the profile along the wetting front (Cihacek & Ulmer 2002).

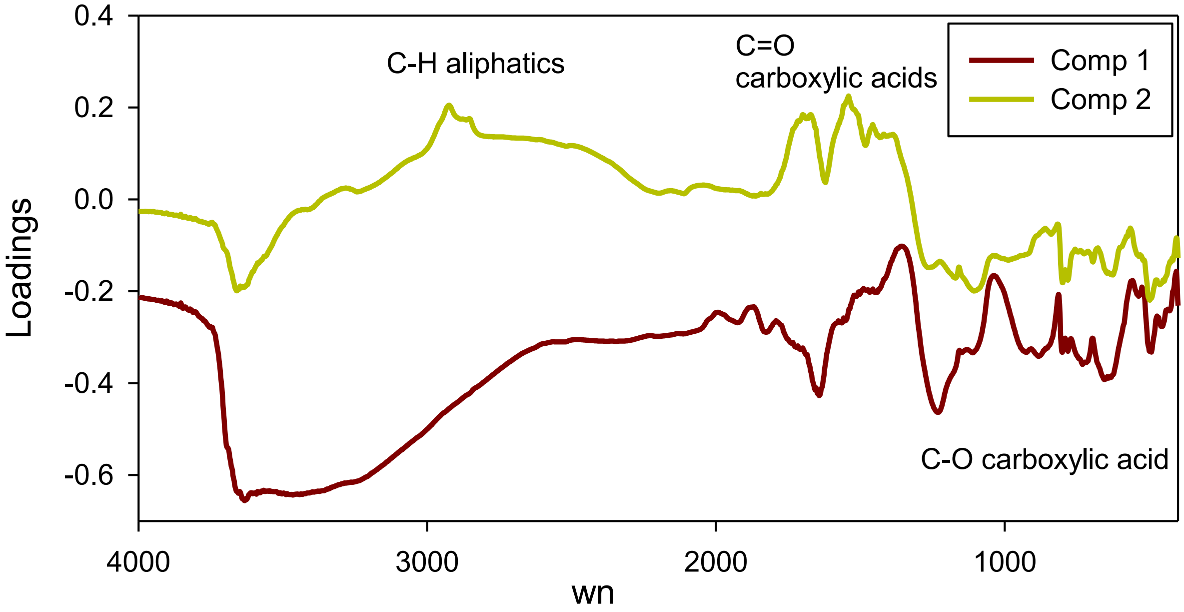

Figure 3. FTIR showed accumulation of new, corn-derived-C (aliphatics & double bonded carboxylic acids) in 2014 compared to 2001 (component 2), with the loss of single-bond carboxylic acids. Sampling times are resolved along component 2, with the 2014 samples having higher scores than the 2001.

FTIR spectra confirm surface accretion of plant-derived waxes (aliphatics) and lignin phenols (carboxylic acids) with the conversion from CT to NT (Figure 3). However, fewer effects in chemical composition were observed deeper in the soil profile. This suggests that the change in soil C stocks at depth was not a function of a change in SOC chemistry. Deep soil C is highly microbially processed with a low C:N ratio. Changes in hydrology with NT may have changed the amount of C delivered and C cycling, not chemistry. Soil inorganic C increased slightly at the two deepest depths between 2001 and 2014, which was confirmed by the FTIR (data not shown).

Together these preliminary data suggest that NT management can affect both organic and inorganic C in a relatively short period of time and that the effects of N fertilizer were modest when the entire soil profile was considered. No tillage maintains surface residue cover, which can directly and indirectly alter soil hydrology. In addition, SOC increases soil aggregation, maintains root channels and promotes soil faunal activity. Wet/dry cycles promote the turnover of aggregates and the release of dissolved organic C and N. This change in hydrology and C source could change both organic and inorganic C stocks and signatures. Irrigation could deliver water high in dissolved organic C and N deeper in the soil profile, stimulating microbial decomposition and loss of previously stabilized SOC stocks.

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