# Impact of conservation tillage on soil organic carbon storage in Washtenaw County, MI

by

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## Abstract

Although tillage has been used to prepare agricultural soils for centuries, many modern farmers are shifting away from traditional tillage because it degrades soil fertility over time. Soil organic carbon (SOC), a common indicator of soil quality, is associated with improvements in aggregate structure, cation exchange capacity, base saturation, available water capacity, and other soil properties. Increased SOC storage has also been suggested as a strategy for mitigation of anthropogenic $CO_2$. As an alternative to intensive tillage systems which diminish SOC, forms of conservation tillage such as chisel plowing (CP) and no tillage (NT) are increasing in popularity in the United States. To understand how forms of conservation tillage influence SOC storage, six farms in Washtenaw County, MI under CP and NT management were sampled to a depth of ~0.5 m and assessed for SOC content. Summed across all depths, NT fields contained 30% less SOC relative to CP. However, the influence of tillage on SOC varied by depth, which was revealed through a significant tillage by depth interaction. For example, NT stored 50% of total SOC in the 0-15 cm depth interval, whereas CP stored only 38% of total SOC in the 0-15 cm depth. The largest difference between tillage types by depth was at 15- 30 cm, wherein CP contained 2.8 times more SOC than NT. Overall, the results indicate that NT stores a greater proportion of SOC near the soil surface, but does not store significantly more total SOC than CP. Finally, variations in intensity of tillage impact are likely to vary with local climate and soil characteristics. It is highly recommended, therefore, that future studies on the relative impacts of NT and CP on SOC include sample comparisons of both above and below plow depth in addition to documentation of local climate and soil characteristics.

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## Introduction

For many centuries, worldwide agricultural production has depended on forms of tillage to control past crop residue, competing vegetation, incorporate soil amendments, and prepare the seedbed for planting. Conventional tillage practices such as moldboard plowing, however, have been linked with soil organic carbon (SOC) depletion (Bowman et al. 1990, Ussiri and Lal 2009). Although there are many different methods of measuring soil quality (Karlen et al. 1997), SOC is often utilized as a key indicator of soil fertility due to its beneficial effects on numerous soil properties (Wander and Drinkwater 2000). For instance, high levels of SOC are associated with increased cation exchange capacity, base saturation, and available water capacity (de Moraes Sa et al. 2009, Dell et al. 2008). As SOC increases, soil aggregate stability also increases, and soils with highly stable aggregate structures are less prone to erosion and runoff (Dell et al 2008, Devine et al 2011).

Existing research also demonstrates that eliminating agricultural tillage presents an opportunity to sequester anthropogenic $CO_2$ into SOC (Jarecki and Lal 2003, West and Marland 2002, Paustian et al. 2000). For example, Houghton (1999) estimated that land conversion to agricultural uses from 1850 to 1990 resulted in a cumulative emission of 124 Pg C, which is about one-half the amount that was released from the combustion of fossil fuel over this period. Additionally, Lee et al. (1993), predicted that converting tilled corn and soybean farms in the U.S. Corn Belt to NT could sequester $3.3 \times 10^6$ tons of C per year for the next 100 years.

As an alternative to traditional and intensive forms of tillage, no-till management involves planting crops in the residue of previous crops without disturbing the mineral soil surface. No-tillage (NT) is widely recommended as a strategy to improve SOC content and reduce erosion, minimize agricultural energy use, and decrease CO2 emission to the atmosphere, among other benefits (USDA NRCS 2011). It has also been shown to increase the residence time of C in soil as compared to tillage systems as a result of superior aggregate structure (Six et al.1998), thereby representing a potential mitigation strategy for sequestering anthropogenic $CO_2$ (Jarecki and Lal 2003, West and Marland 2002, Paustian et al. 2000). Approximately 35% of cropland in the U.S. planted to eight major crops was managed by NT in 2009 and the percentage of cropland being managed by no-till increased by approximately 1.5% per year from 2000-2007 (USDA ERS 2010). The frequency of moldboard plowing in the U.S. has also dropped in the recent past, with the proportion of cropland tilled by this method decreasing from 28% to 8% between 1988 and 1995 (Hrubovcak et al. 1999).

Although NT presents many benefits, it can also cause significant challenges (especially in early stages of adoption) including nutrient stratification (Robbins and Voss 1991), soil compaction (Blanco-Canqui and Lal 2007), and yield decreases on poorly drained soils (Lal et al. 1989). Additionally, the cost of purchasing new planting equipment and increased dependence on herbicides associated with NT can limit its adoption and can have negative environmental impacts (McRobert et al. 2010). As an alternative, less strict forms of conservation tillage, such as chisel plowing (CP), are often utilized in order to alleviate drawbacks associated with no-till while retaining the soil quality benefits of reduced tillage. Conservation tillage is defined as any tillage and planting system that leaves at least 30% of the soil surface protected by plant residue after planting (Hrubovcak et al. 1999); both NT and CP are included in this category.

NT and CP both maintain higher soil quality as compared to moldboard plowing because moldboard plowing cuts and inverts soils to the deepest depth; it also leads to the highest SOC losses as a result of aeration and increased decomposition (Duiker and Beegle 2006, Olson et al. 2005, Ussiri and Lal 2009). However, recent disagreements have arisen regarding impacts of tillage on SOC beneath the plow depth. Many conclusions about the SOC storage potential of NT compared to tillage practices rely on data from only the upper 30 cm of soil profiles (Baker et al. 2007, Yang et al. 2008, Blanco-Canqui et al. 2011), which provides an incomplete view of the soil profile that may lead to inaccurate conclusions about relative impact of tillage systems on SOC storage. For example, Angers and Eriksen-Hamel (2008) found that NT samples above the plow depth contained significantly more SOC than moldboard plow soils, but beneath the plow depth (21-35 cm), moldboard plow soils contained significantly more SOC than NT samples. In Angers and Eriksen-Hamel 2008, gains in NT surface SOC were not completely offset by gains at depth from moldboard plowing. In other cases, however, the deep profile values led to total SOC values under moldboard plow treatment that were equal to or higher than NT (Angers et al. 1997, Carter 2005, Dolan et al. 2006, VandenBygaart et al. 2003). For this reason, SOC gain in NT surface soils must take into account losses at depth when compared to total SOC storage of plowed soils.

Additionally, the degree of SOC stratification increases as tillage is reduced, with a greater percentage of SOC residing at the surface in NT systems, relative to moldboard plow and chisel plow systems (Gal et al. 2007, Duiker and Beegle 2005, Angers et al. 1997, Syswerda et al. 2011). High stratification of SOC at the soil surface could be interpreted as an indication of high soil quality, because the soil surface is primarily where soil erosion, water infiltration, and nutrient loss occur, and SOC improves resistance to water erosion, water infiltration, and nutrient retention (Franzluebbers 2002, Blanco-Canqui et al. 2009).

SOC storage characteristics between CP and NT are less distinct than between MP and

NT, but in general CP is seen as an intermediate between moldboard plowing and NT. Reicosky (1997) found that $CO_2$ loss is inversely related to intensity of soil disturbance, suggesting that CP is more effective at maintaining SOC than moldboard plowing but less effective at maintaining soil quality than NT. Duiker and Beegle 2006 also demonstrated that CP systems stored an amount of SOC which was in between that of NT and moldboard plowing. Stavi et. al (2011), however, found that only one year of conservation tillage every 3-4 years in an otherwise NT corn-soybean system brought about decreases in total SOC and crop yields, suggesting that long-term NT is more successful at maintaining soil fertility than CP. In contrast, however, Dolan et al. (2006), Angers et al. (1997), and Olson et al. (2005) found no significant difference among the total SOC content of CP and NT treatments when the SOC levels were summed for 0-50 cm, 0-60 cm, and 0-75 cm, respectively. Additionally, Varvel and Wilhelm (2011) and Duiker and Beegle (2005) found a significantly higher amount of SOC beneath the plow layer under CP as compared to NT, suggesting that CP can store high amounts of SOC at depth in a similar way to moldboard plowing.

A better understanding of the distribution and content of SOC in NT soil profiles as compared to CP soil profiles is needed in order to make accurate predictions about the influence of conservation tillage on SOC sequestration potential and soil quality. With this goal in mind, samples of agricultural soil under both types of management were collected from around northeastern Washtenaw County, MI at various depth intervals and analyzed for SOC content. The key aims of this study were to determine whether there was a significant difference between (1) the total SOC content of CP and NT samples as well as (2) the vertical distribution of SOC for the CP and NT samples. It was expected that (1) NT samples would have a significantly higher total SOC content than the CP samples and (2) NT samples would display a significantly higher degree of SOC stratification than the CP samples, with a greater percentage of SOC near the soil surface.

## Methods

### *Selection of Sampling Sites*

Six farms in northeastern Washtenaw County, Michigan were selected for soil sampling through a combination of soil map analysis and telephone surveys with farmers about management practices. All six sampling locations spanned a total area of approximately 90 square kilometers around the city of Ann Arbor. The sites included five corn-soybean-wheat rotation farms and one corn-soybean rotation farm. Half of the sites were in no-till management for at least five years prior to sampling and the other half were chisel-plowed for at least five years prior to sampling. This length of time was selected because agricultural soil typically takes a minimum of 3-5 years to show the effects of tillage practices (West and Post 2002). Longer term tillage history was not gathered. Only soils mapped in the Miami Loam Series (2-6% slopes) were selected for sampling in order to minimize variation among soil characteristics. Although variations in drainage manipulation, nitrogen fertilization, and cover crops between sites could impact SOC levels, these factors were assumed to be similar.

### *Field Sampling*

Soil samples were collected in October 2013 from all six sites. To gather soil for SOC analysis from each location, a composite sample was taken from 5 separate sampling holes with a bucket auger in the following depth intervals: 0-5, 5-15, 15-30, and 30-50 cm. A plant litter residue sample was also collected from the soil surface, providing a total of 5 depth increments. Sampling sites were established with one central hole and four additional holes spaced approximately 6 meters away in all four cardinal directions. All six sampling locations were situated at approximate mid-slope positions within each field, because variations in topography can have a strong influence on the accumulation of SOC (Senthilkumar et al. 2009b, VandenBygaart et al. 2002). One bulk density sample was also taken with a mallet and metal core at the 0-10 cm (surface layer) near the central sampling location at each site. All samples were stored in sealed plastic bags and air-dried before analysis within three weeks of collection.

*Laboratory Analysis*

In early November 2013, a modified version of the Walkley-Black procedure (Schumacher 2002) was employed in order to determine soil organic carbon content of the composited samples gathered by depth. This method utilizes potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid ($H_2SO_4$) to oxidize soil organic matter, wherein the amount of reduced dichromate ion is proportional to organic matter content. For each sample, 5 grams of air-dried soil was mixed with 10 mL of 1 N $K_2Cr_2O_7$ and 20 mL of conc. $H_2SO_4$, and then mixed with 100 mL of deionized water once the solutions cooled. Solutions were left overnight to settle and the percent transmittance (T) of all solutions was measured with a spectrophotometer at 620 nm. Five C standards, prepared by dissolving sucrose in deionized water, were also measured to develop a regression model of the log T and carbon content.

In addition, a subsample of each composite soil sample was weighed, then oven-dried, and weighed again in order to calculate an air dry: oven dry ratio. Bulk density samples were also weighed and bulk density was calculated based on oven-dry weight and core volume. The

SOC values were then converted to Mg C $ha^{-1}$ using bulk density. Mean total SOC was calculated for each sampling site by summing SOC values across sampling depths, then averaging values across all three sampling sites for each tillage system (Fig. 1A). Similarly, mean SOC was calculated by averaging SOC values across sampling depths at each sampling site, then averaging values across all three sampling sites for each tillage system (Fig. 1B). Surface stratification ratios were calculated by dividing near-surface SOC (0-15 cm) by total SOC (0-50 cm) (Table 1).

*Statistical Analyses:*

Statistical analyses were completed through a two-way ANOVA, which examined the main effects of tillage and depth as well as their interactions on SOC. A separate one-way ANOVA model was used to test whether differences in mean total SOC between CP and NT treatments were significant. Significance for all statistical analyses was determined at $\alpha = 0.05$.

## Results

Tillage did not have a significant main effect on total SOC ($P = 0.141$; Fig. 1A), but it did have a significant main effect on mean SOC ($P = 0.012$; Fig. 1B). Regardless, CP was approximately 1.4 times greater than NT for both measures. Depth also had a significant main effect on SOC ($P <. 0001$).

Tillage and depth interacted significantly to influence SOC ($P = 0.004$; Fig. 2). At the surface level, NT systems had 2.1 times the amount of carbon stored as crop residue in comparison to CP. At 0-5 cm, NT contained a slightly higher amount of SOC than CP (difference of < 0.1 Mg/ha). At 5-15 cm, NT contained 1.3 times less SOC than CP. The largest difference in SOC between tillage types was at 15-30 cm, where CP contained 2.8 times more SOC than NT. At 30-50 cm, NT contained 1.2 times less SOC than CP. Overall, NT sites had higher near-surface stratification ratios, with 50% of total SOC stored in the 0-15 cm depth interval in comparison to 38% of total SOC stored in the 0-15 cm depth for CP (Table 1).

## Discussion

In all terrestrial ecosystems, net SOC content is continually modified by tradeoffs between carbon-containing biomass inputs and carbon losses as a result of soil respiration and erosion (Senthilkumar et al. 2009b). In agricultural ecosystems specifically, tillage has been found to promote soil C loss at a faster rate and store less total SOC than NT systems primarily because mechanical soil mixing increases soil respiration rates (Gregorich et al. 1998, Stavi et al. 2011, Duiker and Beegle 2006). However, recent studies have revealed that in some cases CP and moldboard plowing can store more total SOC than NT due to higher SOC storage at deeper depths in the soil profile (Baker et al. 2007, Yang et al. 2008, Blanco-Canqui and Schlegel 2011). In support of those recent conclusions, the results presented in this study indicate that NT stores a slightly larger amount of total SOC near the soil surface, but does not store significantly more total SOC in relation to CP because of higher SOC storage beneath the maximum plow depth.

The significant interaction between tillage and depth on SOC content indicates that surface SOC measurements cannot be generalized to represent the entire profile. When SOC means were compared by depth across both tillage types, the interval at 15-30 cm exhibited the highest standard deviation (14), since soil mixing occurred and deposited organic matter at this depth in CP but not in NT. The largest difference in SOC between tillage types was at 15-30 cm, wherein CP contained 2.8 times more SOC than NT. This difference contributed greatly to the higher total SOC content of CP.

For CP, SOC is more stable in deeper layers because microbial respiration declines exponentially with depth (Eilers et al. 2012) and crop residue is continually plowed under and stored at 15-30 cm. When fresh organic matter in the form of crop residue is mixed in, less diverse and populous communities of microbes deeper in the soil (below maximum plow depth) generate lower respiration rates than more populous communities near the surface would. In contrast, crop residue under NT remains near the soil surface without being mechanically mixed into deeper mineral soil.

Increased N fertilizer incorporation at the bottom of the plow layer in CP systems may also slow the rate of SOC decomposition at depth. For example, Alvarez (2005) found that carbon sequestration increases with the addition of nitrate to agricultural systems. Dolan et al. (2006) also noted under moldboard plowing and CP, there was a correlation between areas of the soil profile beneath the plow depth with elevated SOC and high levels of N. Experimental N enrichment has also been shown to increase the SOC storage capacity of forest soils (Eisenlord et al. 2012).

At 0-5 cm, NT contained a slightly higher amount of mean SOC than CP (difference of <0.1 Mg/ha). These results contrast with evidence of high near-surface SOC stratification typically associated with NT (Gal et al. 2007, Duiker and Beegle 2005, Angers et al. 1997, Syswerda et al. 2011). Although NT stored 50% of total SOC in the 0-15 cm depth interval as compared to 38% for CP, the difference between these values is smaller than expected considering conclusions of other studies comparing MP and CP. The lack of pronounced near-surface stratification in this study may be due to the relatively short length of time that NT was carried out prior to sampling at the chosen sites, an error in choosing sampling intervals, or influence of local climate. Two out of the three NT farms sampled in this study had been managed by no-tillage for five years prior. Previous studies demonstrate that it may take as long as eight years before any significant changes associated with NT emerge (Lopez-Fando and Pardo 2011), so it may have been too soon to detect stratification in these systems. Additionally, narrower sampling intervals, such as the 0-2 cm interval used in Blanco-Canqui et al. (2009), have detected significantly higher levels of SOC near–surface stratification under NT systems as compared to CP. The 0-5 cm sampling interval utilized in this study, therefore, may have failed to account for SOC stratification at smaller intervals near the surface. Another explanation for the relatively small amount of near-surface SOC stratification under NT could be the relatively cool climate of Washtenaw County. Because decomposition rates are slower in cooler climates (< 20°C), crop residue at the soil surface in the sites sampled may take a longer time to restore SOC pools than in regions with warmer air temperatures (> 20°C) (Ogle et al. 2005).

Furthermore, variation in conclusions about the relative influence of CP and NT on total SOC storage is largely attributable to differences in local climate and soil characteristics between studies. This is because rates of SOC loss are dependent upon air temperature and soil moisture as well as initial SOC level (Mann, 1986). Expected rates of SOC loss due to conversion from natural to agricultural ecosystems are larger in the tropics than in temperate regions and soils naturally high in SOC are expected to have higher rates of CO2 loss than soils naturally low in SOC (Mann, 1986). The region surrounding the city of Ann Arbor, Michigan observed in this study has a relatively cool, moist climate, with a mean temperature of 10.7°C and 92.7 cm of total precipitation in 2013 (Annual Climatological Summary 2014). Because tillage has a stronger impact on SOC in warm, moist climates than in cool, dry climates (Ogle et al. 2005), smaller differences in SOC loss at the soil surface between NT and CP may have occurred than would be expected in warmer, moister climates. Additionally, the soils included in this study were all composed of a silt loam texture in upper horizons and clay loam in lower horizons. Current research shows that NT may impact SOC storage in soil with high silt and clay contents (finer-textured) more dramatically than sandy soils (coarser-textured) because of their greater physical protection of SOC (Senthilkumar et al. 2009a, Hao and Kravchenko 2007, Hassink 1994, and Angers et al. 2007). Likewise, Needelman et al. (1999) detected a stronger impact of NT on SOC storage under lower rather than higher sand contents. As a result, variation in the relative influence of CP and NT on SOC storage is expected among different soil textures.

Overall, my results indicate that NT stores a greater percentage of SOC near the soil surface, but does not store significantly more total SOC than CP, as a result of evident SOC storage beneath the maximum plow depth. Given the significant interaction between tillage and depth, it is vital that depth is considered when making conclusions about the impacts of tillage on total profile SOC. It is also vital that local climate and soil characteristics are considered when drawing conclusions about the impact of tillage on SOC storage because of their influence on soil respiration rates. In summary, the key factors of sampling depth, local climate, and soil characteristics must be evaluated in order to accurately predict tillage impacts on SOC storage and soil quality.

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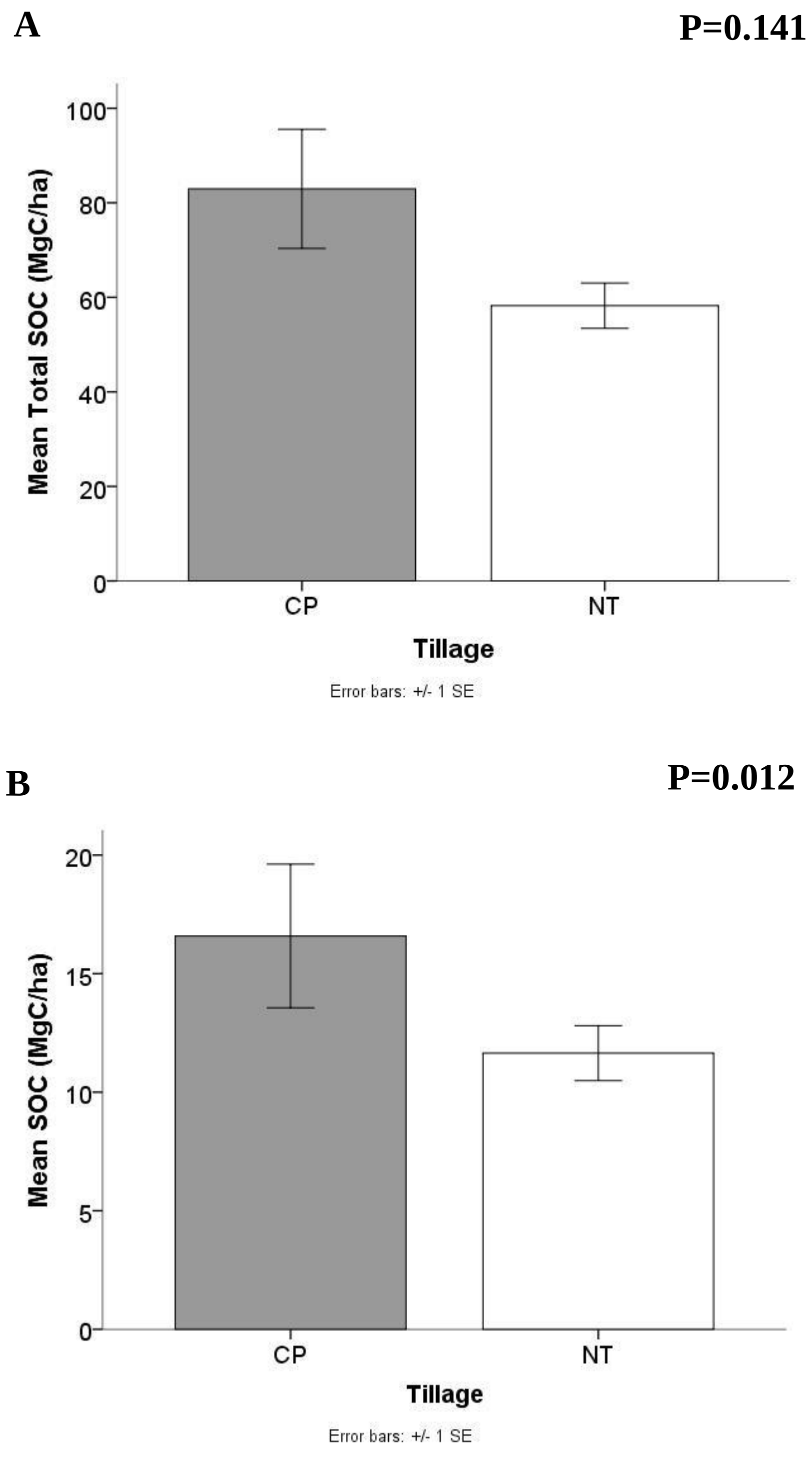


**Figure 1**: Mean total SOC (sum of SOC values across all depths) and mean SOC (average of SOC values across all depths) as influenced by tillage system. Values are means across all three sampling sites for each tillage system, with gray bars representing chisel plowing and white bars representing no-tillage. Two units of standard error are indicated by the length of each error bar.

**P=0.004**

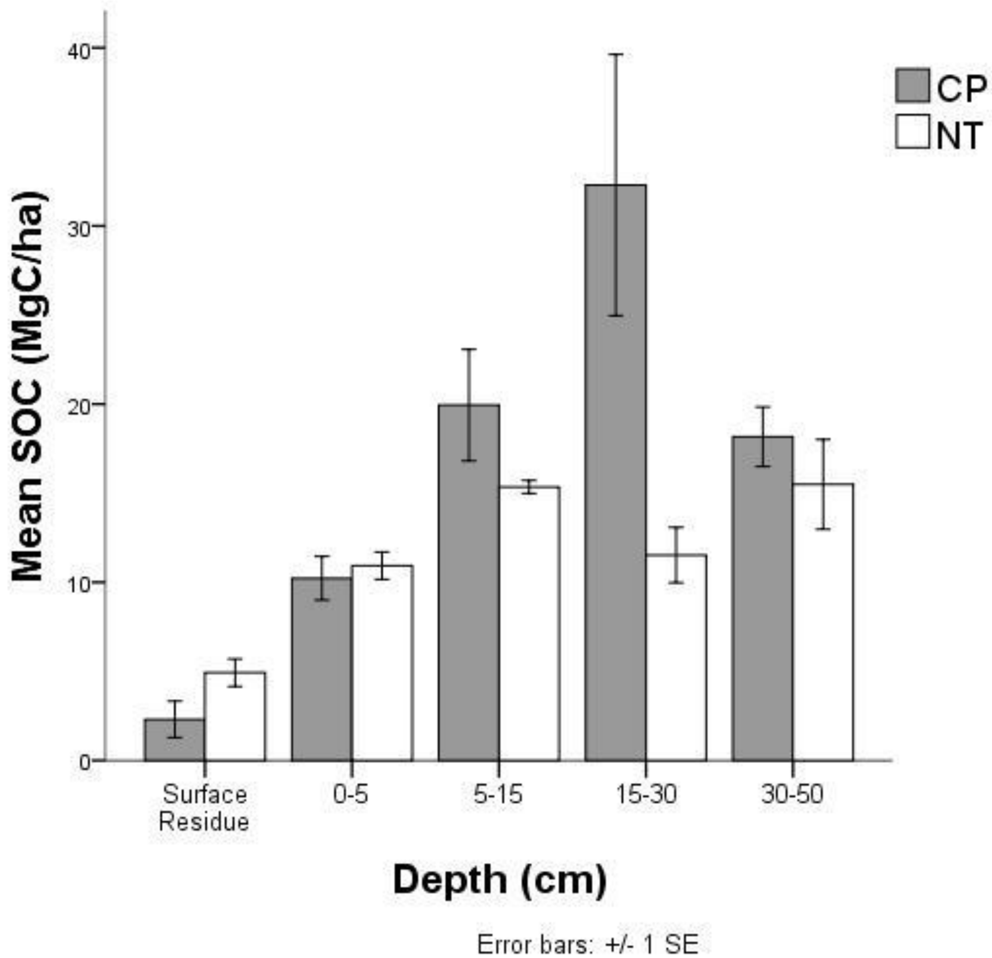


**Figure 2**: The interaction of tillage system and depth on SOC. Values are means across all three sampling sites for each tillage system, with gray bars representing chisel plowing and white bars representing no-tillage. Two units of standard error are indicated by the length of each error bar.

| | Near-surface SOC (0-15 cm) | Total SOC (0-50 cm) | Near-surface stratification ratio |
|---|---|---|---|
| **NT** | 27.03 | 61.19 | 0.442 |
| **NT** | 24.09 | 44.75 | 0.538 |
| **NT** | 27.74 | 53.98 | 0.514 |
| **CP** | 37.95 | 104.23 | 0.364 |
| **CP** | 29.68 | 79.66 | 0.373 |
| **CP** | 22.91 | 58.03 | 0.395 |

**Table 1**: SOC near-surface stratification ratios. All SOC values are reported in Mg/ha and were determined by dividing near-surface SOC by total SOC; NT mean =0.498 and CP mean=0.377.

## Chapter 2: Conclusions

- CP can sequester more total SOC than NT by storing SOC in a more stable form below plow depth. In consequence, future studies comparing the relative impacts of NT and CP on SOC storage should include comparisons of both above and below plow depth; failure to do so could lead to inaccurate predictions about NT as a climate change mitigation tool.
- NT stores a higher percentage of SOC than CP near the soil surface. Understanding how tillage impacts surface soil properties is an important step in determining how to optimize resistance to water erosion, water infiltration, and nutrient retention in agricultural soils.
- Local climate and soil characteristics must be considered when drawing conclusions about the impact of tillage on SOC storage. This is because warm, moist climates and soils with high silt and clay contents have been found to exhibit the greatest impact of tillage on SOC storage.