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Soil organic C and N distribution for wheat cropping systems after 20 years of conservation tillage in central Texas

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Abstract

Long-term conservation tillage and cropping intensity may alter the depth distribution of soil organic C and N. The objectives of this study were to investigate the impacts of conventional tillage (CT), no tillage (NT), and wheat cropping sequences on the depth distribution of dissolved organic C (DOC), soil organic C (SOC), and total N in a central Texas soil after 20 years. Soil was sampled for six depth intervals ranging from 0 to 105 cm. Conventional tillage consisted of disking, chiseling, ridging, and residue incorporation into soil, while residues remained on the soil surface for NT. The depth distribution of DOC was similar to SOC. Tillage impacts on DOC, SOC, and total N were primarily observed in surface soil (0–5 cm) under continuous wheat but also in subsurface soil depth intervals down to 55 cm for more intensive cropping sequences. On average, NT increased SOC, DOC, and total N compared to CT by 28, 18, and 33%, respectively. Soil organic C and total N were highest at 0–5 cm and decreased with depth to 30–55 cm, below which few tillage or cropping sequence effects were observed. The depth distribution of SOC and total N indicated treatment effects below levels of the maximum tillage depth, while intensive cropping increased SOC and total N for NT compared to CT to a greater depth than for monoculture wheat. High intensity cropping sequences, coupled with NT, resulted in the highest soil organic matter levels in subsurface soils, demonstrating the importance of subsurface C and N storage for potential mitigation of greenhouse gases.

Keywords: C sequestration; Dissolved organic C; Soil organic matter; Tillage

1. Introduction

Soil C and N sequestration potential can be enhanced by utilization of management practices such as conservation tillage and intensive cropping systems. Impacts of tillage on soil organic matter in surface soils have been well documented, but results vary due to soil type, cropping systems, residue management, and climate (Paustian et al., 1997). Soil organic matter levels in the USA are often related to climatic patterns, and increase from warmer to cooler climates (Kern and Johnson, 1993). Long-term impacts of tillage and cropping sequences on C storage have been reported for surface soils in the southern USA (Franzluebbers et al., 1994; Wright and Hons, 2004, 2005), but seldom for subsurface soils. Conventionally tilled soils commonly exhibit less stratification of soil C and N with depth than soils under conservation tillage due to the mixing of crop residues and soil by tillage (Franzluebbers, 2002; Piovanelli et al., 2006). Soil organic C storage is often higher under NT than CT because of residue accumulation at the soil surface, but CT can potentially increase soil C levels in subsurface soils relative to NT as a result of lower organic matter decomposition rates (Ghidey and Alberts, 1993; Yang and Kay, 2001; Franzluebbers, 2002; Piovanelli et al., 2006). Other studies have shown that NT increases soil C levels compared to CT in subsurface soils (Dick and Durkalski, 1998).

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Dissolved organic C is an important C pool in soils and influences many chemical and biological processes (Chantigny, 2003; Marschner and Kalbitz, 2003), and may indicate short-term responses to crop management practices. Dissolved organic C generally decreases with depth due to retention by soil surfaces (Qualls and Haines, 1992). However, the contribution of crop residues and root exudates to the DOC pool is not entirely understood. Cropping systems have varying effects on soil C, N, and DOC pools by production of residues of variable quantity and quality (Xu and Juma, 1993; Lorenz and Lal, 2005). Roots may also be important C sources to soils which contribute to soil C sequestration (Hogberg and Hogberg, 2002), especially in the subsurface, where decomposition proceeds at slower rates (Franzluebbers, 2002; Lorenz and Lal, 2005). Thus, assessment of the distribution of soil C and N pools with depth may provide an accounting of sequestration potential.

Most studies related to cropping system and tillage impacts on soil C sequestration focus on the rhizosphere or surface soils. Tillage practices primarily influence surface soils, which causes stratification of residues and soil C that is dependent on the depth of tillage (Allmaras et al., 1996; Potter et al., 1998). Furthermore, impacts of cropping sequences and residues on C and N accumulation in surface and subsurface soils of the humid, temperate southern USA may indicate the potential of these soils for mitigation of greenhouse gases. Dissolved organic C may indicate short-term changes resulting from different crop management practices, while total SOC and total N indicate long-term effects. The objectives of this study were to determine the impacts of tillage and wheat cropping sequences on soil organic C and N distribution in a Weswood silty clay loam soil from 0 to 105 cm for a 20-year crop rotation and tillage study in central Texas.

2. Materials and methods

2.1. Site description

A field experiment was initiated in 1982 in Burleson County, Texas (30°32′N, 94°26′W) on a Weswood silty clay loam (fine-silty, mixed, superactive, thermic Udifluventic Haplustepts) (Eutric Cambisols FAO classification). The soil had pH 8.0, and 115 g sand kg^{-1}, 452 g silt kg^{-1}, 310 g clay kg^{-1}, and 94 g $CaCO_3$ kg^{-1} at 0–15 cm. Long-term average annual rainfall is approximately 980 mm and temperature is 20 °C. Soil bulk density for this site was not affected by tillage regime and averaged 1.43, 1.69, and 1.67 g cm^{-3} for 0–5, 5–15, and 15–30 cm, respectively.

The experimental design was a split-split plot with cropping sequence as the main plot, tillage as the split plot, and N fertilizer rate as the split-split plot, although only the optimal N rate for crop production was tested in this study. Field plots measured 4-m wide by 12.2-m long and were replicated four times. Three cropping sequences were established under both CT and NT, and included a grain sorghum [*Sorghum bicolor* (L.) Moench]-wheat (*Triticum aestivum* L.)-soybean [*Glycine max* (L.) Merr.] rotation (SWS), a wheat–soybean doublecrop, and a continuous wheat monoculture. The SWS rotation resulted in three crops every two years while the wheat–soybean doublecrop had two crops every year. Sorghum was sowed in 1-m wide rows in March and harvested in August, followed by wheat in winter and soybean the following summer. Soybean was sowed in 1-m wide rows in early June and harvested in October. Wheat was planted in 0.18-m wide rows in November and harvested in May, followed by the soybean crop for wheat–soybean. For CT under wheat, soil was disked three to four times after harvest. Conventional tillage in sorghum and soybean consisted of disking to 10–15 cm after harvest, chiseling to 25 cm, a second disking, and ridging prior to winter. Conventional tillage sorghum and soybean also received one to three in-season cultivations annually for weed control, and sorghum stalks were shredded for both tillage regimes. Under NT, no soil disturbance except for planting, and residues remained on the soil surface. Nitrogen, as NH_4NO_3, was subsurface applied preplant at 90 kg N ha^{-1} for sorghum. Wheat received 68 kg N ha^{-1}, with half surface broadcast shortly after emergence and half in late February. Soybean received 15 kg P ha^{-1} banded preplant with no added N.

2.2. Soil sampling and analysis

Triplicate soil cores (5 cm diameter) were taken from field plots in August 2002 after wheat harvest and sectioned into six depth intervals (0–5, 5–15, 15–30, 30–55, 55–80, and 80–105 cm). Samples from respective depths in each plot were then combined, dried at 50 °C for 7 days, and passed through a 2-mm sieve. Soil organic carbon was measured using a modified Mebius method (Nelson and Sommers, 1982). Briefly, 0.5 g soil was digested with 5 ml of 1.0 N $K_2Cr_2O_7$ and 10 ml of H_2SO_4 at 150 °C for 30 min, followed by titration with standardized $FeSO_4$. Soil total N was measured by Kjeldahl digestion (Gallaher et al., 1976) with NH_4-N analyzed colorimetrically (Technicon Industrial Systems, 1977). Dissolved organic C was extracted with distilled water (25 °C) (1:4 soil:water) by shaking for 1 h, followed by centrifugation and vacuum filtration through 0.45 μm filters (Wright et al., 2005). Extracts were analyzed for DOC by persulfate oxidation using a Model 700 Total Organic Carbon Analyzer (O.I. Analytical, College Station, TX).

The depth distribution of DOC, SOC and total N fit a logarithmic model. Analysis of variance (ANOVA) for a split–split plot was performed to determine main effects of cropping sequence, tillage regime, and soil depth interval (CoStat Statistical Software, 2003). Moreover, ANOVA was used for determination of differences between tillage regime and cropping sequence for each soil depth interval. All significant treatment effects were determined using the LSD at $P < 0.05$, and correlation coefficients were calculated at $P < 0.05$.

3. Results

3.1. Dissolved organic C

Tillage impacts on DOC were observed not only for surface soils, but for subsurface soils under intensive cropping (Fig. 1). No tillage significantly increased DOC compared to CT at 0–5 cm for continuous wheat, but at depths to 30 cm for wheat–soybean and 80 cm for SWS. At 0–5 cm, DOC was 28, 38, and 36% higher for NT than CT for wheat–soybean, SWS, and continuous wheat, respectively. On average, DOC significantly decreased with each successive deeper interval from 0 to 105 cm, from a high of 216 mg C kg^{-1} at 0–5 cm to 48 mg C kg^{-1} at 80–105 cm. Dissolved organic C did not vary among cropping sequences, with the exception of DOC being lowest for continuous wheat at 0–15 cm depths. Soil DOC exhibited a logarithmic decrease with depth for all treatments, although NT showed a more pronounced decrease than CT. Dissolved organic C was significantly correlated with SOC ($r = 0.95$) and total N ($r = 0.96$).

3.2. Soil organic C

The depth distribution of SOC was significantly impacted by tillage and cropping sequence (Fig. 2). Under CT, an approximately linear decrease in SOC from the 0–5 to 30–55 cm depth intervals occurred for all three cropping sequences, from an average high of 11.3 g C kg^{-1} at 0–5 cm to 2.3 g C kg^{-1} at 30–55 cm. The average decrease between these two depths was 0.18, 0.24, and 0.23 g C kg^{-1} cm^{-1} for continuous wheat, wheat–soybean, and SWS, respectively. Under NT for all cropping sequences, however, SOC was significantly highest at 0–5 cm and decreased to 5–15 cm, did not change from 5–15 to 15–30 cm, then significantly decreased to 30–55 cm. No further decreases with depth occurred except for SWS. Throughout 0–105 cm, SOC averaged 28% higher under NT than CT.

Tillage effects on SOC were most evident in surface soils for monoculture crops, but also in subsurface soils for intensive cropping sequences, even at depth intervals below the maximum tillage depth of 25 cm. No tillage significantly increased SOC relative to CT only from 0 to 5 cm for continuous wheat, from 0 to 30 cm for wheat–soybean, and from 0 to 55 cm for SWS. Thus, similar to DOC (Fig. 1), tillage impacts on SOC varied with cropping intensity, as a higher cropping intensity increased SOC levels in lower soil depths to a greater extent for NT than CT.

3.3. Soil total N

The distribution of soil total N with depth was similar to SOC (Fig. 3). Tillage significantly influenced the distribution of total N in surface soils for monoculture wheat, and in subsurface soils for more intensive cropping sequences. Total N under CT decreased linearly with depth from the 0–5 to 30–55 cm depth intervals for all cropping sequences, with average decreases of 18, 23, and 20 mg N kg^{-1} cm^{-1} for continuous wheat, wheat–soybean, and SWS, respectively. Throughout 0–105 cm, however, total N distribution exhibited a logarithmic decrease with depth. Under NT, total N significantly decreased from 0–5 to 5–15 cm, did not change from 5–15 to 15–30 cm depths, and then significantly decreased to the 30–55 cm depth. Similar trends were also observed for SOC (Fig. 2). Soil total N was not influenced by tillage or cropping sequence below the 30–55 cm depth. Throughout 0–105 cm,

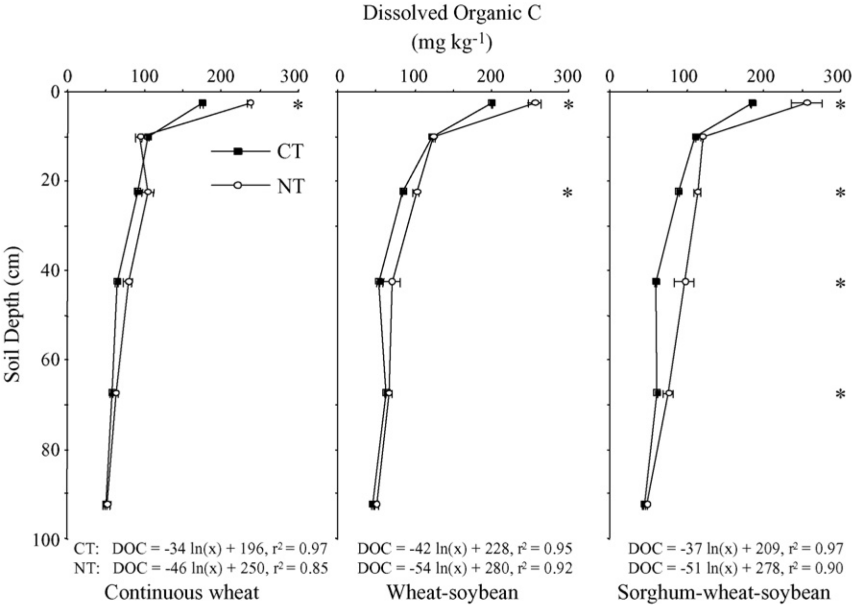

Fig. 1. Dissolved organic C (DOC) under no tillage (NT) and conventional tillage (CT) for a sorghum–wheat–soybean rotation, wheat–soybean doublecrop, and continuous wheat monoculture. Soil depth intervals were 0–5, 5–15, 15–30, 30–55, 55–80, and 80–105 cm. Error bars represent standard error of means. *Significant differences between tillage regimes at $P < 0.05$. For equations describing depth distribution, (x) denotes soil depth (cm).

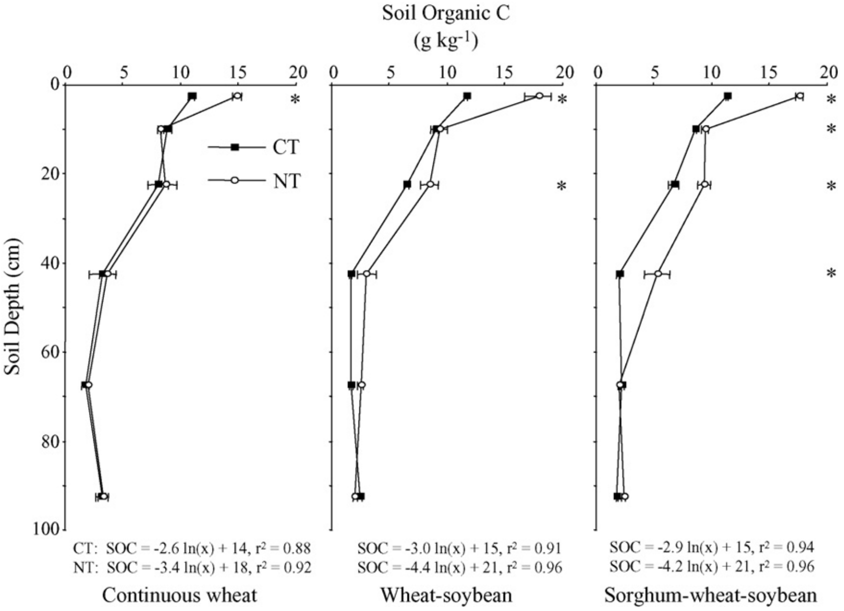

Fig. 2. Soil organic C (SOC) under no tillage (NT) and conventional tillage (CT) for a sorghum–wheat–soybean rotation, wheat–soybean doublecrop, and continuous wheat monoculture. Soil depth intervals were 0–5, 5–15, 15–30, 30–55, 55–80, and 80–105 cm. Error bars represent standard error of means. *Significant differences between tillage regimes at $P < 0.05$. For equations describing depth distribution, (x) denotes soil depth (cm).

total N was 33% significantly higher under NT than CT, and 515% greater at 0–5 cm than 80–105 cm. Soil total N was significantly correlated with SOC ($r = 0.99$).

Tillage effects on total N were more evident for intensive cropping sequences. No tillage significantly increased total N at 0–5 cm for all cropping sequences, and for wheat–soybean and SWS from 15 to 50 cm depth intervals. Soil total N seldom differed as a result of cropping sequence, except at 0–5 cm where continuous wheat exhibited the lowest concentrations. Soil C:N was not influenced by cropping sequence, but was significantly higher under CT (11.2) than NT (10.8) (data not shown). Soil C:N was also significantly highest for the 15–30 cm depth, followed by 30–105 cm depth intervals, while the 0–15 cm depth intervals were lowest.

3.4. Proportion of soil organic C as dissolved organic C

The proportion of SOC as DOC was not influenced by tillage or cropping sequence from 0 to 30 cm (Fig. 4). However, CT generally had a higher proportion at depths

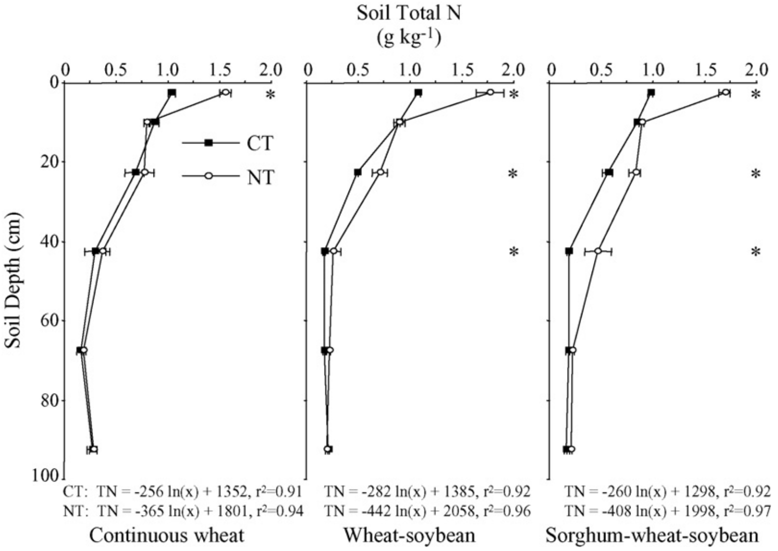

Fig. 3. Soil total N (TN) under no tillage (NT) and conventional tillage (CT) for a sorghum–wheat–soybean rotation, wheat–soybean doublecrop, and continuous wheat monoculture. Soil depth intervals were 0–5, 5–15, 15–30, 30–55, 55–80, and 80–105 cm. Error bars represent standard error of means. *Significant differences between tillage regimes at $P < 0.05$. For equations describing depth distribution, (x) denotes soil depth (cm).

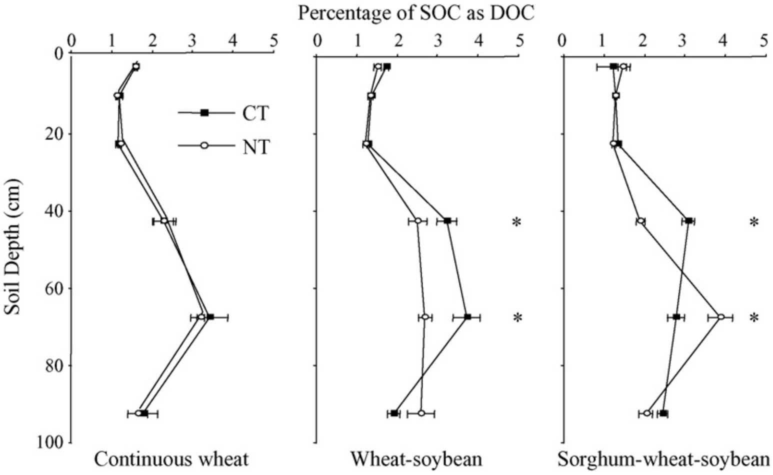

Fig. 4. The proportion of soil organic C (SOC) as dissolved organic C (DOC) under no tillage (NT) and conventional tillage (CT) for a sorghum–wheat–soybean rotation, wheat–soybean doublecrop, and continuous wheat monoculture. Soil depth intervals were 0–5, 5–15, 15–30, 30–55, 55–80, and 80–105 cm. Error bars represent standard error of means. *Significant differences between tillage regimes at $P < 0.05$.

from 30 to 80 cm for wheat–soybean and SWS. The proportion of SOC as DOC did not change with depth from 0 to 30 cm, but significantly increased from 30 to 80 cm, then decreased to 105 cm for all cropping sequences. Overall, continuous wheat had the significantly lowest proportion of SOC as DOC, while CT was 7% greater than NT. The proportion of SOC as DOC significantly increased with depth from 1.6% at 0–5 cm to 3.3% at 55–80 cm.

4. Discussion

High cropping intensity and residue production contributed to higher soil C and N levels compared to monoculture wheat. In related studies, higher soil C and N storage for intensive cropping systems than monocultures occurred in surface soils (Wright and Hons, 2004, 2005), and was related to crop residue inputs of 741, 907, and 555 g m^{-2} for SWS, wheat–soybean, and continuous wheat, respectively (Franzluebbers et al., 1995a). However, crop residue production did not differ between tillage regimes. Sorghum, wheat, and soybean produced an equivalent quantity of residues (524 g m^{-2}) under monoculture (Franzluebbers et al., 1995a), thus the residue production rates, and ultimately C and N storage, reflected the influence of cropping intensity. However, in this study, impacts of cropping sequence were evident not only in surface soils but at lower depths. Lower production of crop residues under continuous wheat relative to more intensive cropping sequences (Franzluebbers et al., 1995a) explain lower SOC under CT in subsurface soils. Higher SOC and total N from 0 to 55 cm under NT than CT demonstrate the importance of conservation tillage for C and N retention in subsurface soils.

Crop species may have also influenced soil C and N levels through production of residues of varying quality. The residue N content did not differ between tillage regimes, and averaged 6.2, 6.2, and 12.9 mg N g^{-1} for sorghum, wheat, and soybean residues, respectively (Franzluebbers et al., 1995a). Even though wheat–soybean and SWS produced more residues than continuous wheat, they also produced residues having higher N contents (Franzluebbers et al., 1995a), which likely enhanced their turnover rate in soil. Wheat residues produced under monoculture had lower N contents than cropping systems using soybean (Franzluebbers et al., 1995a) which may have depressed organic matter decomposition and contributed to similar soil organic matter levels as high-intensity cropping sequences, even though these had significantly higher total residue inputs. These factors may explain the lack of differences in soil C and N levels between cropping sequences under CT. Crop residues persist longer at the soil surface under NT, thus differences in soil C and N levels between cropping sequences were more apparent compared to CT. Organic matter turnover, mineralizable C, and soil microbial biomass were greater for high-intensity sequences than for monoculture crops (Franzluebbers et al., 1995a,b; Salinas-Garcia et al., 1997). This suggests that higher crop residue inputs from intensive cropping sequences were offset by enhanced organic matter degradation, especially for CT. Stimulation of residue and organic matter decomposition under CT masked the effects of cropping sequence on soil C and N levels, but under NT, greater effects of cropping sequence were observed. Thus, both residue quantity and quality served important roles in C and N accumulation in these soils.

Residues returned to subsurface soils by tillage promote the turnover of organic materials. Thus, SOC and total N under CT, although concentrations were generally equivalent to those under NT, were likely more labile since CT subsurface soils contained recently deposited plant residues. These factors may have important implications for C and N sequestration when soil conditions become more favorable for organic matter degradation, as would occur during future tillage operations or changes in cropping systems. Thus, the long-term stability of soil organic matter under CT may be dependent on maintenance of current crop management practices.

Dissolved organic C levels in soils were dependent on both cropping intensity, which influenced the quantity and quality of crop residues, and tillage, which impacted residue placement in soils. In the long-term, vegetation type and quantity of organic residues are the main factors influencing the amount and composition of DOC (Chantigny, 2003). Soil DOC was twice as high under crops that produced more residues (Lundquist et al., 1999). Likewise, in this study, DOC was greater for intensive cropping sequences than continuous wheat at 0–5 cm. Placement of residues near the soil surface under NT resulted in the highest DOC, but levels significantly decreased with depth. Dissolved organic C in subsurface soils may be a result of decomposition of crop residues (Zsolnay, 1996; Lundquist et al., 1999) or translocation from surface soil (Kalbitz et al., 2000). Since the proportion of SOC as DOC increased with depth (Fig. 4), enhanced residue decomposition by tillage or vertical movement of DOC likely increased the size of the DOC pool relative to SOC in subsurface soils. The depth distribution of DOC, SOC, and total N was impacted by tillage regime, as concentrations were higher in surface soils for NT than CT, and for subsurface soils under intensive cropping. The use of CT did not increase SOC and total N in subsurface soils to levels greater than NT, suggesting that burial or incorporation of residues did not contribute to greater soil C and N accumulation for this soil. Even though SOC and total N exhibited management effects down to 55 cm, tillage operations only occurred in the top 35 cm of soil.

5. Conclusions

Management practices, such as NT and high intensity cropping sequences, played important roles in subsurface C and N accumulation. Dissolved organic C dynamics and distribution were closely linked to SOC. Soil organic C and total N were highest in surface soil and decreased with depth to 30–55 cm, below which few tillage or cropping impacts occurred. Depth distribution of SOC and total N indicated treatment effects below the levels of the maximum tillage depth. Intensive cropping sequences contributed to higher soil organic matter levels under NT than CT in subsurface soils, but not for monoculture cropping. Thus, a combination of NT and intensive cropping resulted in the highest C and N levels in subsurface soils. For monoculture wheat, effects of tillage on soil C and N were observed only at 0–5 cm. For more intensive cropping sequences under NT, decreasing fallow periods and increasing crop residue production increased soil C and N levels to the 55 cm depth. Long-term benefits of intensive cropping and conservation tillage may include protection of SOC and total N in subsurface soils. Thus, estimates of effects of conservation tillage practices on greenhouse gas mitigation in the southern USA should account for subsurface C and N.

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