^{13}C AND ^{15}N CHANGES IN SOIL ORGANIC MATTER FRACTIONS AS AFFECTED BY TILLAGE AND CROPPING SEQUENCE

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INTRODUCTION

Management factors for enhancing C sequestration in agricultural ecosystems involve increasing crop residue inputs and decreasing soil organic matter (SOM) decomposition. Many studies show that conservation tillage, especially no tillage (NT), along with increased cropping intensity, can increase soil C sequestration (West and Post, 2002). The use of ^{13}C natural abundance techniques, coupled with physical and/or chemical fractionation, has provided additional insight into SOM turnover for cases where an appropriate change in vegetation from C_3 to C_4 or vice versa has occurred. Studies have reported that discrimination may also occur during decomposition of SOM by soil microbes, although it is less compared to that from C_3 or C_4 vegetation. Thus, the ^{13}C distribution of SOM mirrors the turnover of plant residue, in addition to management and environmental effects. Our study evaluated effects of cropping sequence and tillage on ^{13}C and ^{15}N in physically- and chemically-separated soil organic matter pools.

MATERIALS AND METHODS

Sampling. Soil samples from a 20-year study near College Station, TX were collected to a depth of 50 mm in May and August 2002 after wheat and sorghum harvest, respectively. The soil is Weswood silt loam (Udifluventic Haplustept) and the experimental design is a split-split plot within a randomized complete block. Tillage is the main plot, cropping sequence is the split plot, and N fertilization is the split-split plot. Four cropping sequences are used: continuous wheat (CW), a wheat-soybean double crop (WS), a rotation of soybean-wheat-sorghum (SWS), and continuous sorghum (CS). All samples were collected following wheat except for CS.

Fractionation. Size and density fractionations were conducted on soil samples to isolate SOC fractions described by Six et al. (2000). Soil (20 g) from the 0-to 50-mm layer was gently immersed in deionized water on top a 250-µm mesh screen and gently shaken with 50 glass beads. A continuous and steady water flow through the screen was used to ensure microaggregates were immediately flushed onto a 53-µm sieve. After all macroaggregates were broken, material on the 53-µm screen was sieved to ensure that the isolated microaggregates were water-stable. The inter-microaggregate POM retained with microaggregates on the sieve was isolated by density flotation in 1.85 g cm^{-3} sodium polytungstate. The fractionation resulted in the following C fractions: coarse, unprotected particulate organic matter (POM) (>250 µm); fine, unprotected POM (53 to 250 µm); protected POM (53 to 250 µm); protected <53-µm fraction; unprotected <53-µm fraction; resistant organic C (ROC) in the unprotected <53-µm fraction; ROC in the protected <53-µm fraction. A schematic of the fractionation scheme is provided in Fig.1.

Resistant organic C was measured after an 18-hr acid hydrolysis and washing with deionized water to neutral pH (Paul et al., 2001).

^{13}C, C, ^{15}N, and N analysis. Carbon, N, ^{13}C, and ^{15}N were analyzed using the method of Harris et al. (2001). Oven-dried samples were ground and homogenized to pass through a 150-µm sieve. Four or 40-mg soil samples depending on C and N concentration were weighed into silver capsules. Inorganic carbonate was removed by exposure to HCl atmosphere in a desiccator, with ^{13}C, %C, ^{15}N, and %N measured with an elemental analyzer (Carlo Erba EA-1108, Lakewood, NJ, USA) interfaced with a Delta Plus isotope ratio mass spectrometer (ThermoFinnigan, Bremen, Germany) operating in the continuous flow mode. Precision for the $\delta^{13}C$ measurements was < 0.1‰, while that for $\delta^{15}N$ was < 0.2‰ . $\delta^{13}C$ values were expressed relative to the V-PDB standard, and $\delta^{15}N$ values were expressed relative to atmospheric N_2.

RESULTS AND DISCUSSION

$\delta^{13}C$ in SOM Fractions

- Natural abundance of ^{13}C in soil from CW decreased in the order of silt and clay fraction, ROC > microaggregate > POM (Fig. 2). Results were similar to those observed by Boutton et al. (1993), who proposed that organic matter turnover rates appeared to decrease in the order of sand > silt > clay.

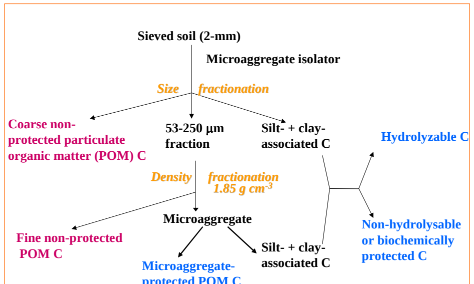

Fig. 1 Fractionation scheme to isolate microaggregate- associated C fractions. Adapted from Six et al. (2000).

- ROC of the protected silt and clay fraction of CW had lower ^{13}C values than that of the unprotected silt and clay free fraction.
- Due to similar ^{13}C values of soybean compared to wheat, a similar distribution was observed in soil from the WS double-crop.
- In contrast with CW, an almost opposite pattern was observed for CS, which might be expected since sorghum is a C_4 plant while wheat is C_3.
- Because POM is usually labile organic matter with a short mean residence time (several months), this fraction was most affected by wheat or sorghum residue input.

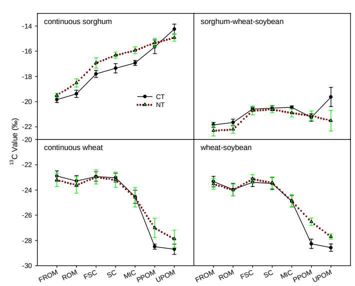

Fig. 2. $\delta^{13}C$ values of free resistant organic matter (FROM), resistant organic matter (ROM) protected by microaggregates, free fraction associated with silt and clay (FSC), silt- and clay-associated fraction (SC), microaggregates (MIC), protected particulate organic matter (PPOM), and unprotected particulate organic matter (UPOM) in continuous sorghum, continuous wheat, sorghum-wheat-soybean, and wheat-soybean rotations as affected by tillage. CT and NT represent conventional and no tillage. Error bars indicate standard deviation.

- Even for POM, higher ^{13}C values of unprotected POM compared to protected POM were observed (Fig. 2). These results indicated that while a small portion of recent crop residues was incorporated into more recalcitrant fractions, a much greater proportion was associated with labile fractions.
- A combined effect of C_3 and C_4 crops was observed in the SWS system (Fig. 2).
- Tillage effects on ^{13}C were observed primarily in the more labile pool, except with CS where NT enhanced ^{13}C even in more resistant fractions (Fig. 2). Compared to CT, greater ^{13}C values were observed in POM under NT, except in UPOM in CS and in the SWS rotation.

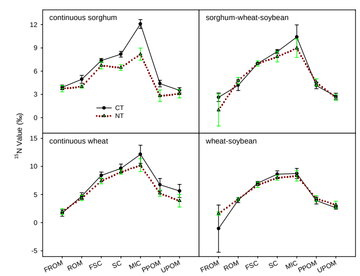

Fig. 3. $\delta^{15}N$ values of free resistant organic matter (FROM), resistant organic matter (ROM) protected by microaggregates, free fraction associated with silt and clay (FSC), silt- and clay-associated fraction (SC), microaggregates (MIC), protected particulate organic matter (PPOM), and unprotected particulate organic matter (UPOM) in continuous sorghum, continuous wheat, sorghum-wheat-soybean, and wheat-soybean rotations as affected by tillage. CT and NT represent conventional and no tillage. Error bars indicate standard deviation.

$\delta^{15}N$ in SOM Fractions

- In all cropping sequences, ROM and labile organic matter pools (protected or unprotected POM) had the lowest ^{15}N values (Fig. 3). All other fractions exhibited higher ^{15}N values than ROM and POM, with the microaggregate fraction being the most enriched.
- ^{15}N values under NT were lower than CT in most fractions of all cropping sequences.
- The enrichment of ^{15}N in crop residues often increases with decomposition of SOM, which was consistent with observed results of ^{13}C. These results indicated that microaggregate and silt- and clay-associated organic matter generally were more decomposed than ROM, or maybe ROM was biologically resistant because of its composition, but not necessarily because of its advanced status of decay.
- Unlike ^{13}C values, however, ^{15}N values were less affected by C_3 or C_4 crop.

Contribution of C from Sorghum (C_4)

- The contribution of C from sorghum in the various fractions (C_4) in CS increased in the order of ROM < SC < MIC < POM. No-till stored more current crop input than CT in most size fractions (Fig. 4).

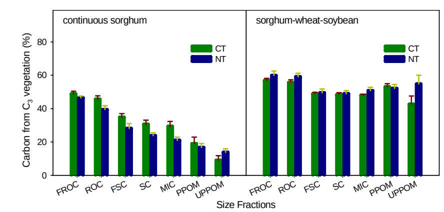

Fig. 4. Percentage of C from sorghum (C_4) in free resistant organic matter (FROM), resistant organic matter (ROM) protected by microaggregates, free fraction associated with silt and clay (FSC), silt- and clay-associated fraction (SC), microaggregates (MIC), protected particulate organic matter (PPOM), and unprotected particulate organic matter (UPOM) in continuous sorghum, continuous wheat, sorghum-wheat-soybean , and wheat-soybean rotations as affected by tillage. CT and NT represent conventional and no tillage. Error bars indicate standard deviation.

- In the SWS system, however, silt- and clay-associated fractions and microaggregates exhibited greater C from sorghum (C_4) than other fractions with ROM being the lowest. Carbon contribution of from sorghum to different fractions in SWS was less evident than in CS because sorghum represents only a fraction of total crop C input.

CONCLUSIONS

- ^{13}C in all size fractions was mainly affected by crop species. In continuous wheat, the natural abundance of ^{13}C decreased in the order of silt and clay fraction, ROM > microaggregate > POM.
- Continuous sorghum showed a reverse trend because it is a C_4 crop .
- Sorghum-wheat-soybean rotation showed a mixed pattern between CS and CW.
- Tillage effects on ^{13}C were observed primarily in the labile pools (protected and unprotected POM).
- ^{15}N values were the lowest in ROM and POM and were highest in microaggregates.
- C_3 and C_4 crops did not affect ^{15}N of different fractions.
- In general, ^{15}N was greater under NT than CT regardless of cropping sequence.
- Our study indicated that natural abundance of ^{13}C and ^{15}N is a useful tool for examining effects of cropping sequence and tillage on soil organic C and N turnover and distribution.

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