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Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils

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Abstract

Residue retention and reduced tillage are both conservation agricultural management options that may enhance soil organic carbon (SOC) stabilization in tropical soils. Therefore, we evaluated the effects of long-term tillage and residue management on SOC dynamics in a Chromic Luvisol (red clay soil) and Areni-Gleyic Luvisol (sandy soil) in Zimbabwe. At the time of sampling the soils had been under conventional tillage (CT), mulch ripping (MR), clean ripping (CR) and tied ridging (TR) for 9 years. Soil was fully dispersed and separated into 212–2000 μm (coarse sand), 53–212 μm (fine sand), 20–53 μm (coarse silt), 5–20 μm (fine silt) and 0–5 μm (clay) size fractions. The whole soil and size fractions were analyzed for C content. Conventional tillage treatments had the least amount of SOC, with 14.9 mg C g^{-1} soil and 4.2 mg C g^{-1} soil for the red clay and sandy soils, respectively. The highest SOC content was 6.8 mg C g^{-1} soil in the sandy soil under MR, whereas for the red clay soil, TR had the highest SOC content of 20.4 mg C g^{-1} soil. Organic C in the size fractions increased with decreasing size of the fractions. In both soils, the smallest response to management was observed in the clay size fractions, confirming that this size fraction is the most stable. The coarse sand-size fraction was most responsive to management in the sandy soil where MR had 42% more organic C than CR, suggesting that SOC contents of this fraction are predominantly controlled by amounts of C input. In contrast, the fine sand fraction was the most responsive fraction in the red clay soil with a 66% greater C content in the TR than CT. This result suggests that tillage disturbance is the dominant factor reducing C stabilization in a clayey soil, probably by reducing C stabilization within microaggregates. In conclusion, developing viable conservation agriculture practices to optimize SOC contents and long-term agroecosystem sustainability should prioritize the maintenance of C inputs (*e.g.* residue retention) to coarse textured soils, but should focus on the reduction of SOC decomposition (*e.g.* through reduced tillage) in fine textured soils.

Keywords: Particulate organic matter; Soil organic carbon; Tillage; Residue management; Conservation tillage; Tropical agro ecosystems

1. Introduction

Soil organic matter (SOM) is an important determinant of soil fertility, productivity and sustainability, and is a useful indicator of soil quality in tropical

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agricultural systems where nutrient poor and highly weathered soils are managed with little external input (Feller and Beare, 1997; Lal, 1997). The dynamics of SOM are influenced by agricultural management practices such as tillage, mulching, removal of crop residues and application of organic and mineral fertilizers.

Removal of crop residues from the fields is known to hasten soil organic carbon (SOC) decline especially when coupled with conventional tillage (Yang and Wander, 1999; Mann et al., 2002). This is a common practice in most communal areas of Zimbabwe, where crop residues are removed from the fields for use as fodder or grazed *in situ*. Mann et al. (2002) reviewed a number of studies where additions of stover resulted in greater increases in SOC than if stover was removed. They also found that the mean residence time of original SOC is substantially lengthened if stover is not harvested. Soil organic C decreased by 75% after 15 years of no-till maize cropping with residue removal on a Nigerian Alfisol following forest clearing while residue return had twice as much SOC than residue removal (Juo et al., 1996). When the effects of hoeing and ploughing were compared, with or without manure, greater soil organic C, C mineralization and crop yields were found when manure was applied, and with hoeing being superior to ploughing (Mando et al., 2005a). Their study also indicated that the use of manure can counter the negative effects of tillage. The use of grass mulch was also shown to reduce annual soil loss by up to 5 t ha^{-1} compared with no surface residue application in a study conducted in Zimbabwe on a clay loam (Hudson, 1957).

Tillage plays an important role in the manipulation of nutrient storage and release from SOM, with conventional tillage (CT) inducing rapid mineralization of SOM and potential loss of C and N from the soil. A global analysis of 67 long-term experiments indicated that on average a change from CT to no-till (NT) can sequester 57 ± 14 g C m^{-2} $year^{-1}$ (excluding NT in wheat fallow systems) with peak sequestration rates being reached within 5–10 years after conversion (West and Post, 2002). By contrast, Six et al. (2002a,b) found a general increase in soil C contents of $\approx 325 \pm 113$ kg C ha^{-1} $year^{-1}$ under NT compared with CT for both tropical and temperate systems. They also reported that, on average, C turnover was 1.5 times slower in NT compared with CT.

The amount of SOM loss due to tillage is dependent on the clay content of the soil. In general, greater SOM loss is observed in coarse textured than fine textured soils, primarily due to lack of physical protection of organic matter in sandy soils (Hassink, 1995; Feller and Beare, 1997). In fine textured soils, clay- and silt-sized particles with high surface activity may chemically stabilise SOM and form the building blocks for aggregates, thereby inducing physical protection of SOM by occlusion in aggregates, especially micro-aggregates (Six et al., 2000). Soil disturbance through tillage is a major cause of reduction in the number and stability of soil aggregates and subsequently organic matter depletion (Six et al., 2000). The greater part of the smallholder farming areas of Zimbabwe is dominated by coarse textured soils (Grant, 1981).

Type and length of tillage practice, and soil texture influence the amount of SOC present in the soil, the rate of SOC turnover, and its distribution among size fractions (Cambardella and Elliott, 1992; Six et al., 2002a,b; Feller and Beare, 1997). Tillage reduces SOM in all size fractions, but particulate organic matter (POM) is much more readily lost than other fractions (Cambardella and Elliott, 1992; Six et al., 1999). In continuously cultivated soils the decrease in SOC is primarily due to a loss of POM in sandy soils and of clay-associated C in clayey soils (Feller and Beare, 1997). Inputs of C also tend to increase SOC by mainly accumulating it as POM in the sand-size fraction in sandy soils whereas in clayey soils it accumulates both in the sand- and clay-size fractions (Feller and Beare, 1997). Silt-associated SOM is more stable and does not readily change with management (Christensen, 1992; Six et al., 2001).

The objective of this study was to assess the effects of disturbance (*i.e.* tillage) and C input (*i.e.* crop residue return) on SOC content and its distribution across size fractions in two soils differing in texture. We hypothesized that (i) SOC content would increase with decreasing tillage intensity in the order tied ridging (TR) > clean ripping (CR) > CT, (ii) returning crop residues would result in greater SOC contents than removing residues, and (iii) SOC dynamics are more responsive to tillage disturbance in the clay soil as aggregates are disrupted to release protected SOC, while in the sandy soil C input differences would result in bigger differences in SOC content.

2. Materials and methods

The two experiments used in this study were established in the 1988/1989 season at the Institute of Agricultural Engineering (IAE) in Harare (17°43′S; 31°06′E; 1500 m above sea level) and the Domboshawa Training Centre (DTC) (17°35′S; 31°10′E; 1550 m above sea level) approximately 30 km NE of Harare (Nyagumbo, 1997). The IAE site is on red clay soil (clay = 59%; silt = 20%; sand = 21%) derived from