Geoderma 209–210 (2013) 262–272

Contents lists available at SciVerse ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Land use and management effects on soil organic matter fractions in Rhodic Ferralsols and Haplic Arenosols in Bindura and Shamva districts of Zimbabwe

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ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form 11 June 2013
Accepted 28 June 2013
Available online 31 July 2013

Keywords:
Soil density fractionation
Soil management
Soil organic matter
Soil carbon sequestration
Soil nitrogen
Tillage

ABSTRACT

Soil organic carbon (SOC) is a major attribute of soil quality that responds to land management activities which is also important in the regulation of global carbon (C) cycling. This study evaluated bulk soil C and nitrogen (N) contents and C and N dynamics in three soil organic matter (SOM) fractions separated by density. The study was based on three tillage systems on farmer managed experiments (conventional tillage (CT), ripping (RP), direct seeding (DS)) and adjacent natural forest (NF) in Haplic Arenosols (sandy) and Rhodic Ferralsols (clayey) of Zimbabwe. Carbon stocks were significantly larger in forests than tillage systems, being significantly lower in sandy soils (15 and 14 Mg C ha^{-1}) than clayey soils (23 and 21 Mg C ha^{-1}) at 0–10 and 10–30 cm respectively. Nitrogen content followed the same trend. At the 0–10 cm depth, SOC stocks increased under CT, RP and DS by 0.10, 0.24, 0.36 Mg ha^{-1} yr^{-1} and 0.76, 0.54, 0.10 Mg ha^{-1} yr^{-1} on sandy and clayey soils respectively over a four year period while N stocks decreased by 0.55, 0.40, 0.56 Mg ha^{-1} and 0.63, 0.65, 0.55 Mg ha^{-1} respectively. SOM fractions were dominated by mineral associated heavy fraction (MaHF) which accounted for 86–93% and 94–98% on sandy and clayey soils respectively. Tillage systems on sandy soils had the smallest average free light fraction (fLF) and occluded light fraction (oLF) C stocks (25.3 ± 1.3 g m^{-2} and 7.3 ± 1.2 g m^{-2}) at 0–30 cm when compared with corresponding NF (58.4 ± 4 g m^2 and 18.5 ± 1.0 g m^{-2}). Clayey soils, had the opposite, having all fLF C and N in tillage systems being higher (80.9 ± 12 g C m^{-2} and 2.7 ± 0.4 g N m^{-2}) than NF (57.4 ± 2.0 g C m^{-2} and 2.4 ± 0.3 g N m^{-2}). Results suggest that oLF and MaHF C and N are better protected under DS and RP where they are less vulnerable to mineralisation while fLF contributes more in CT. Thus, DS and RP can be important in maintaining and improving soil quality although their practicability can be hampered by unsupportive institutional frameworks. Under prevailing climatic and management conditions, improvement of residue retention could be a major factor that can distinguish the potential of different management practices for C sequestration. The exploitation of the benefits of RP or DS and the corresponding sustainability of systems need support for surface cover retention which should also be extended to conventional tillage.

1. Introduction

Land use practices in agro ecosystems affect the storage of soil organic carbon (SOC) and nitrogen (N). Soil organic matter (SOM) represents a large, dynamic and complex terrestrial reservoir of carbon (C) in the form of organic compounds derived from plant, animal or microbial biomass (Baldock, 2009). The rates of C release from the soil varies with land use type, climate and the soil matrix. Several studies have shown that significant amounts of C were lost from the soil as carbon dioxide (CO_2) when forests were converted to agriculture (Food and Agriculture Organisation, 2010; IPCC., 2000), as a result of the release of physically protected soil C (Denef et al., 2007; McConkey et al., 2003; Six et al., 1999). Despite this loss, agriculture is inevitably required to enhance food security in the developing countries which are threatened by food shortages (Food and Agriculture Organisation, 1996).

In this regard, conservation agriculture (CA) has been recommended as a means of C accumulation and soil quality enhancement (Álvaro-Fuentes et al., 2008; Chivenge et al., 2007b; Dercon et al., 2010; Ken and Johnson, 1993) and has been proposed as a means of sustainable land use management (Food and Agriculture Organisation, 2010). In southern Africa, the reasons for the success of conservation farming have been clearly outlined (Andersson and Giller, 2012; Marongwe et al., 2011). However, the success of some conservation farming practices such as no-tillage in C storage depends on the quality and quantity of organic residue inputs (de Moraes Sá et al., 2011) and the degree of soil disturbance.

Abbreviations: SOM, soil organic matter; SOC, soil organic carbon; CF, conventional tillage; RP, ripping; DS, direct seeding; fLF, free light fraction; oLF, occluded light fraction; MaHF, mineral associated heavy fraction.

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0016-7061/$ – see front matter
http://dx.doi.org/10.1016/j.geoderma.2013.06.025

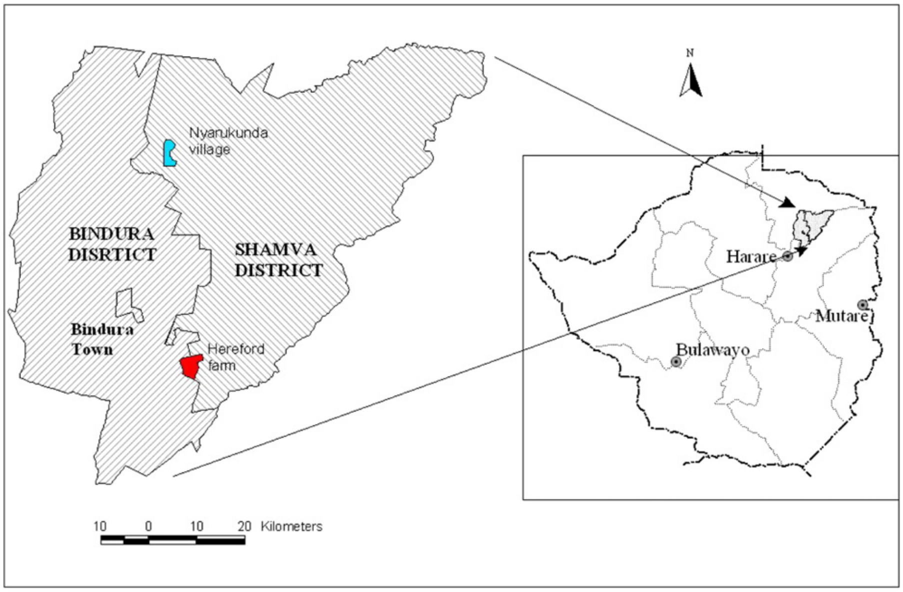

Fig. 1. Map of Zimbabwe showing location of Shamva and Bindura districts.

No tillage or minimal tillage practices may affect SOC stocks, although some studies have shown that no-tillage increases SOC concentrations only in the upper layers of some soils with no significant differences with conventional farming when considering the whole profile (Blanco-Canqui and Lal, 2008; Poirier et al., 2009). Soil organic C may be present in the soil as either 1) relatively fresh (labile) SOM not protected by the soil matrix, as 2) SOM physically protected in aggregates (occluded), or as 3) SOM adsorbed onto mineral surfaces (chemically stabilised) (Dalal and Mayer, 1986). Although land management systems such as tillage may not have an effect on bulk SOC and N, they may have an effect on individual SOM fractions (Von Lützow and K gel-Knabner, 2009). Moreover, changes in SOM fractions may provide insight into the effects of tillage practices on SOC stabilisation (Marín-Spiotta et al., 2008; von Lützow et al., 2007).

Isolation of these functional pools can be done by density or size separation. Density fractionation is often coupled with ultrasonic dispersion to give three mutually exclusive fractions: free light fraction (fLF) extracted before the breakdown of aggregates; occluded light fraction (oLF) isolated after ultrasonic disruption and mineral associated fraction (MaHF) recovered in the remaining heavy precipitate which is considered as stable (Gregorich et al., 2006; Poirier et al., 2005). Evidence of differences in residence time of fLF and oLF has been shown (Golchin et al., 1994; Gregorich et al., 2006) and confirmed by radio C dating (Baisden et al., 2002; Swanston et al., 2005). The mineral-associated heavy fraction contains more processed materials with a slower turnover rate and a higher degree of chemical protection (Hassink, 1995).

Table 1
Bulk soil chemical and physical soil properties at 0–10 cm depth before establishment of three tillage systems at sites selected for the study at Nyarukunda and Hereford study areas.
Source: International Maize and Wheat Improvement Centre (2005/2006).

Characteristic		Shamva–Nyarukunda (Sandy soils)			Bindura–Hereford (Clayey soils)		
	Tillage	CT	RP	DS	CT	RP	DS
pH (Ca Cl_2)		5.2	4.9	5.0	5.4	5.5	5.6
BD (g cm^{-3})		1.33	1.33	1.33	1.2	1.2	1.2
SOC (g kg^{-1})		3.60	4.8	4.1	13.40	13.40	14.7
TON (g kg^{-1})		0.7	0.7	0.8	1.6	1.7	1.6
C:N ratio		5.1	6.9	5.1	8.4	7.9	9.2
P (mg kg^{-1})		16.3	15.8	13.5	26.7	30.5	31.0
ex K (cmol/kg)		0.2	0.3	0.2	0.5	0.6	0.6
ex Ca (cmol/kg)		1.3	1.0	1.0	8.5	8.9	8.6
ex Mg (cmol/kg)		0.7	0.3	0.2	4.6	3.7	5.0
TEB (cmol/kg)		2.5	1.7	1.6	14.0	13.6	14.7
BASE SAT %		70	60	35	64	63	75
Clay %		4	5	4	22	23	26
Silt %		7	7	8	20	20	20
Sand %		89	87	89	58	57	54

CT = conventional tillage, RP = ripping, DS = direct seeding.

Soil organic C and N in density fractions are important attributes of the quality of a soil and associated impacts of land management systems. The applicability and feasibility of density fractionation has not been fully exploited in Zimbabwean soils. Some studies in Zimbabwe focused on crop production and soil organic matter fractions in aggregate sizes and have revealed that physically separated SOM fractions change with aggregate size (Chivenge et al., 2007b; Nyamadzawo et al., 2009). Despite the importance of SOC storage in the light fraction, there is little information about size, composition and stability of free and occluded light fractions in sandy and clayey soils of Zimbabwe. In addition, research on experimental stations has not provided the required information on C sequestration potential since it does not represent farmer's conditions (Giller et al., 2011).

In this study, active collaboration with farmers in the research plots provided a true picture of small holder farmers' condition which can result in the transfer of technologies to their own fields. The native forests in the area are mainly miombo woodlands which are subjected to annual wild fires and are utilised by local communities for timber and non-timber forest products. We therefore aim to evaluate the effects of land management systems on: 1) bulk soil C and N contents and 2) the C and N dynamics of three fractions, (*i.e.* the free light fraction (fLF), occluded light fraction (oLF) and mineral associated heavy fraction (MaHF)) on farmer managed tillage experiments on sandy and clayey soils. In order to assess the effect of agricultural land use, irrespective of treatment, on SOC and N contents, samples were also collected from adjacent natural forests to show the C benefits of not clearing more land for agriculture. Agricultural land is mostly a product of deforestation of these native forests.

2. Material and methods

2.1. Study site

This research was carried out at two experimental locations; Hereford in Bindura district (17°42′ S; 31°44′ E) and Nyarukunda in Shamva district (17°00′S; 31°43′E) (Fig. 1) which were established in