Geoderma 274 (2016) 1–9

Contents lists available at ScienceDirect

Geoderma

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

Long-term assessment of soil and water conservation measures (Fanya-juu terraces) on soil organic matter in South Eastern Kenya

Gustavo Saiz [a,*], Fredrick M. Wandera [b], David E. Pelster [b], Wilson Ngetich [c], John R. Okalebo [c], Mariana C. Rufino [d], Klaus Butterbach-Bahl [a,b]

[a] Institute Meteorology and Climate Research, Karlsruhe Institute of Technology, Garmisch-Partenkirchen 82467, Germany
[b] Livestock Systems and Environment, International Livestock Research Institute, Nairobi 30709-00100, Kenya
[c] Department of Soil Science, University of Eldoret, P. O. Box, 1125, Eldoret, Kenya
[d] Centre for International Forestry Research (CIFOR), PO Box 30677, Nairobi, Kenya

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 22 March 2016
Accepted 23 March 2016
Available online 8 April 2016

Keywords:
Semi-arid ecosystems
Soil water conservation
Climate-smart agriculture
Small household farms
Soil organic carbon
Stable isotopes

ABSTRACT

A comprehensive assessment of soil organic matter (SOM) dynamics in semi-arid agrosystems implementing soil and water conservation (SWC) measures is still lacking despite their extent, ecological and economic significance. Therefore, we assessed the long-term impact of a commonly used SWC technique (Fanya-juu terracing) on SOM-related properties in South Eastern Kenya. A soil sampling campaign was conducted in a replicated stratified random manner on three land uses that had been continuously managed for over 30 years. Samples were analyzed for organic carbon and nitrogen contents, $\delta^{13}C$, $\delta^{15}N$, pH and texture. Compared to sites implementing conventional agriculture, the establishment of SWC structures in this erosion-prone landscape resulted in the recovery of SOM levels comparable to those observed in neighboring semi-natural ecosystems. Sites under conventional agriculture practices contained 20 Mg C ha^{-1} (0.85 m), while sites with SWC measures and those hosting semi-natural vegetation stored above a third more. There were significant differences in soil C/N ratios as well as in $\delta^{13}C$ and $\delta^{15}N$ values between SWC cultivation practices classified according to the presence or absence of trees. The presence of woody vegetation in sites with SWC structures had a strong impact on the spatial variability of SOM-related properties. There was also a significant negative relationship between $\delta^{15}N$ values and C/N ratios across the different land uses. Our findings indicate the existence of contrasting SOM dynamics caused by vegetation-related effects, and provide suggestions for enhancing SOM storage in agricultural sites implementing SWC measures.

1. Introduction

Land degradation is a serious cause for concern in sub-Saharan Africa where it affects more than two-thirds of its land (Penny, 2009). This is having detrimental effects on ecological functions and has already led to significant losses of agricultural productivity (Biancalani et al., 2011). Overgrazing, vegetation removal, poor agricultural management and overexploitation are among the main causes of soil degradation in sub-Saharan Africa (Hammond, 1992; Oldeman et al., 1991). These problems are being exacerbated by the ever-increasing pressure on soil resources from growing population and the heavy reliance on an agriculture that is highly vulnerable to environmental change (Liniger et al., 2011; Marks et al., 2009). The implementation of sustainable land management practices may help to increase agricultural productivity, improve ecosystem functions and enhance resilience to adverse environmental impacts. Integrative approaches such as climate–smart agriculture (CSA) advocate for the implementation of agricultural practices and technologies aiming at increasing productivity in a sustainable manner (Lipper et al., 2014; Nyasimi et al., 2014). Indeed, small household farmers could effectively contribute to climate change mitigation through the adoption of agricultural practices that sequester carbon (C) and minimise emissions (Liniger et al., 2011). Soil organic matter (SOM) plays a crucial role on determining soil quality (Brady and Weil, 2007), and its enhancement may generate production, adaptation and mitigation benefits through the regulation of C, oxygen and plant nutrient cycling, thus promoting carbon sequestration and enhanced resilience to drought and flooding (Lipper et al., 2014). Soil degradation and/or high erosion rates have a detrimental effect on the numerous essential functions provided by SOM, posing major adverse economic and ecological consequences to livelihoods and the environment (Brady and Weil, 2007; Lal, 2004; Chappell et al., 2015). Given the significance of environmental degradation in sub-Saharan agricultural systems, efforts to revert the situation should focus on preserving two valuable and scarce natural assets, i.e. soil and water.

Abbreviations: (SWC), soil and water conservation; (SOM), soil organic matter; (SOC), soil organic carbon; (CSA), climate smart agriculture.

* Corresponding author.
E-mail address: gustavo.saiz@kit.edu (G. Saiz).

http://dx.doi.org/10.1016/j.geoderma.2016.03.022
0016-7061/

The implementation of soil and water conservation (SWC) techniques comprising structural, vegetative and agronomic measures have the potential to reduce both runoff water and soil erosion, and improve infiltration and soil fertility (Liniger and Critchley, 2007). An example of such measure is the 'Fanya-juu' terracing system, which consists of producing embankments along a slope by digging out ditches following contour lines and depositing the soil uphill to form a mound (Fig. 1). The use of these SWC measures has increased crop yields by about 25% in East Africa (Ellis-Jones and Tengberg, 2000; Liniger et al., 2011). Moreover, SWC measures may hold great potential for increasing SOM levels since the regions where these are implemented are often heavily degraded (Liniger and Critchley, 2007). In fact, the semi-arid regions of Africa have been reported as having the largest potential for soil organic carbon (SOC) sequestration in the World (Batjes and Sombroek, 1997; Marks et al., 2009; Saiz et al., 2012). The increase of SOC stocks at a given site can be achieved either through the reduction of factors promoting SOM mineralization and lateral exports (e.g. erosion, percolation), and/or by increasing SOM inputs and enhancing stabilization mechanisms (e.g. physical protection of SOM through stable aggregates). Sites with SWC measures commonly host agroforestry systems that combine crops, grazing lands and trees. Should these systems be sensibly managed through sustainable agronomic practices (e.g. improved tillage practices, use of cover crops, optimum dosage and timely application of fertilizer, etc.) they will likely result in greater SOC stocks (Liniger et al., 2011). Moreover, this would also contribute to CSA aims, as soils rich in SOM require lower chemical inputs to sustain agricultural productivity and may enhance vital ecosystem functions, such as the hydrological and nutrient cycles (FAO, 2013).

The detailed study of OM-related properties such as C/N ratio, δ^{13}C, and δ^{15}N in soil profiles may provide valuable information about the different processes affecting SOM pools on sites with contrasting land use. At the landscape scale, variations in land use, soil and vegetation type are the main factors affecting decomposition processes and the quantity and quality of SOM inputs (Feller and Beare, 1997; Silver et al., 2000; Chiti et al., 2014). While at the site scale, differences in local topography, vegetation cover and land management are among the main drivers behind potentially contrasting SOM dynamics (Peukert et al., 2012; Saiz et al., 2006). Soil ^{13}C and ^{15}N are natural tracers of C and nitrogen (N) cycling (Bird et al., 2004; Nardoto et al., 2014; Wang et al., 2013) that can be combined with C and N elemental analyses to interpret SOM transformation processes (de Freitas et al., 2015; Stevenson et al., 2010). However, fractionation effects such as those associated with microbial reprocessing and the edaphic-dependent physicochemical protection of SOM makes the judgment of the variation in δ^{13}C and δ^{15}N values of SOM difficult (Silver et al., 2000; Blagodatskaya et al., 2011; Rumpel and Kögel-Knabner, 2011).

A comprehensive assessment of SOM dynamics in sub-Saharan agricultural sites implementing combined SWC measures is still lacking despite their extent, ecological and economic significance. Specifically, the effect that long-term established SWC measures may have on SOM-related properties is not yet known. Moreover, there is no information about the impact that contrasting vegetation (grass vs woody) and highly heterogeneous, purposely-made, ground strata may have on SOM dynamics at sites implementing SWC measures. Therefore, our study takes advantage of long-term established agricultural sites managed under real farming conditions, which follows on a similar strategy adopted in Liu et al. (2015). We hypothesized that, compared to sites under conventional agriculture, the implementation of SWC measures in erosion-prone semi-arid agricultural fields lead to an increase in SOM levels due to the greater topsoil preservation and enhanced organic matter inputs. We also hypothesized that in those sites having SWC measures, the existence of well-defined ground strata may promote significant variations in SOM dynamics between the different locations, largely because of their differential regimes in the transport, accumulation and removal of SOM. Our last hypothesis proposes that the presence of woody vegetation in agricultural fields may have a strong effect on both the elemental and stable isotopic composition of SOC and N because of the reported differential SOM dynamics observed in mixed C_3/C_4 semi-natural ecosystems (Saiz et al., 2015a). The objectives of this study were to: (i) assess the impact of SWC structures on the spatial variability of SOM-related properties; (ii) evaluate the influence of specific SWC cultivation practices (classified according to the presence

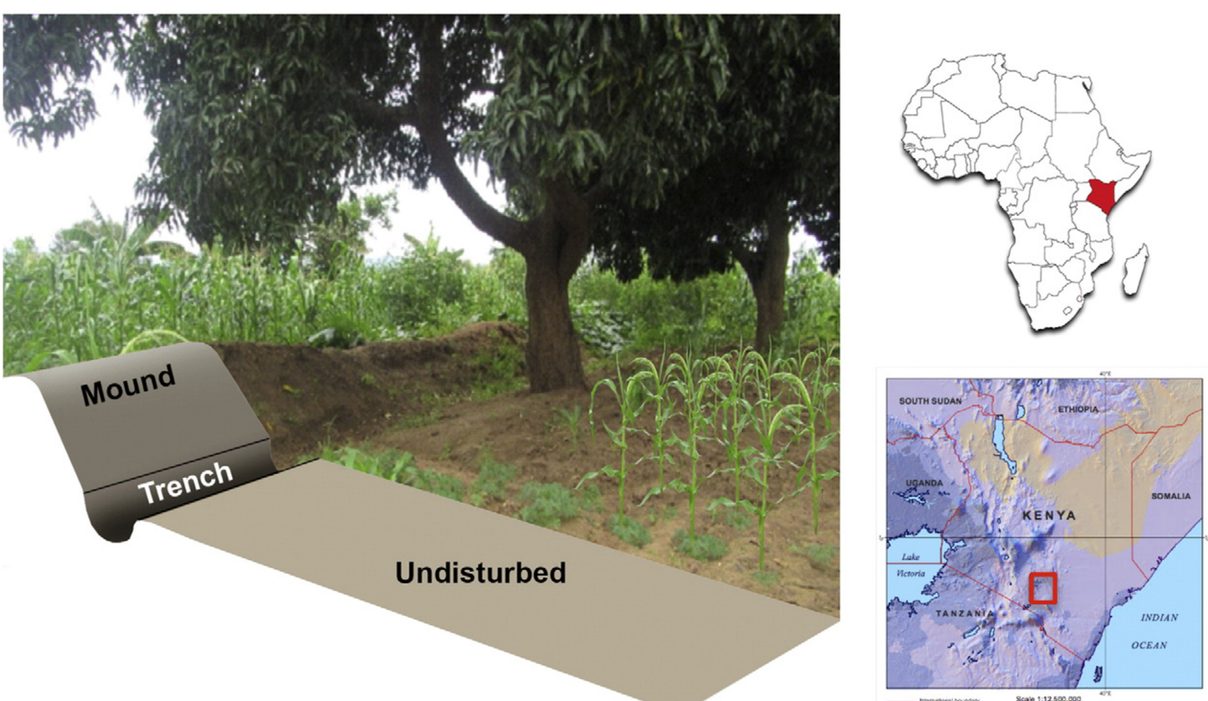

Fig. 1. Schematic representation of the SWC structures depicting the three contrasting ground features (trench, mound and undisturbed ground), and location maps for the Makueni/Wote CCAFS site in Kenya.