



Research paper

Carbon losses from prolonged arable cropping of Plinthosols in Southwest Burkina Faso



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ABSTRACT

The ongoing conversion of natural ecosystems of the tropics into agricultural land usually results in a loss of soil organic carbon (SOC), the extent of which being largely affected by climate and soil order. We assumed that i) SOC losses are not restricted to the surface soil but extend into the subsoil, but that ii) the rate of SOC losses is controlled by interactions of SOC with Fe oxides. Hence, we sampled Plinthosols down to one meter (if feasible) that had been converted from native savannah into cropland 0 to 29 years ago in the Dano district (Southwest Burkina-Faso). Beside the assessment of SOC stocks, we also determined the proportion of surface (0–10 cm) SOC remaining after Fe oxide removal as well as its distribution among the following particle-size fractions: 2000–250 μm (coarse sand-sized SOC; POM1), 250 μm –53 μm (fine-sand-sized SOC; POM2), 53 μm –20 μm (very fine sand-sized SOC; POM3), and < 20 μm (nonPOM). We found that the soils lost 24 t C ha⁻¹ from the upper 10 cm and 49 t C ha⁻¹ from the upper 30 cm, respectively, after 29 years. SOC losses extended also into the subsoil, and, on the average, 0.7–19.5 t C ha⁻¹ was lost from the 30–100 cm depth interval. The loss rates of SOC were similar to those reported for other soil types. Rapid losses of SOC occurred from all POM fractions as well as from the Fe-oxide pool, which, on average, contained about 16% of total SOC stock. We conclude that even if Fe oxides as well as other silt- and clay-sized organomineral complexes delay losses of SOC relative to POM, they failed to efficiently protect SOC from decomposition in these Plinthosols.

1. Introduction

The increase of carbon dioxide in the atmosphere is causing concerns worldwide; hence, recent focus is set on soil carbon sequestration for its mitigation. In fact, it is estimated that soils contain about 2500 gigatons (Gt) of carbon, of which 1550 Gt are SOC (Batjes, 1996; Jobbágy and Jackson, 2000). Tropical soils contain about 26% of this global SOC inventory and are thus considered as important sources and sinks for carbon dioxide and methane (Batjes, 2004, 1996). However, only very few studies acknowledged that particularly in the West African savannah the influx of SOC is larger than its efflux (Ciais et al., 2011). The savannah ecosystems cover about 60% of tropical Africa (Callo-Concha et al., 2012). They are characterized by structurally degraded and nutrient depleted soils with poor natural fertility and low fertilizer input (Doraiswamy et al., 2007). Maintaining SOC stocks in these ecosystems is thus mandatory for sustaining essential soil functions such as nutrient and water storage, soil biological activity, and structural stability.

For the African savannah ecosystem, especially in West Africa, several studies revealed a decline in SOC stocks by 20–50% when sites under natural vegetation were converted into cropland (McDonagh et al., 2001; Murty et al., 2002). Most of such SOC losses are reported to occur within the first 20 years (Birch-Thomsen et al., 2007). To understand the underlying mechanisms, however, the monitoring of changes in SOC should include pools of different SOC stability, since overall response rates may be slow and thus ignored when based on bulk SOC analyses only (Powlson et al., 1987; Skjemstad et al., 2004). A common approach for assessing such pools of different stability has been to fractionate soil into classes of different equivalent particle-size diameter (Christensen, 1992). When done, usually SOC decomposition rates are faster for the sand sized SOM fractions than for the remaining soil (e.g., Balesdent et al., 1988). Lützwow et al. (2008) reported about 50–75% of total organic carbon (TOC) to be associated with the clay fraction, 20–40% with the silt fraction and < 10% with the sand fraction. The SOC of the latter fraction is frequently named as particulate organic matter (POM), due to its chemical properties matching

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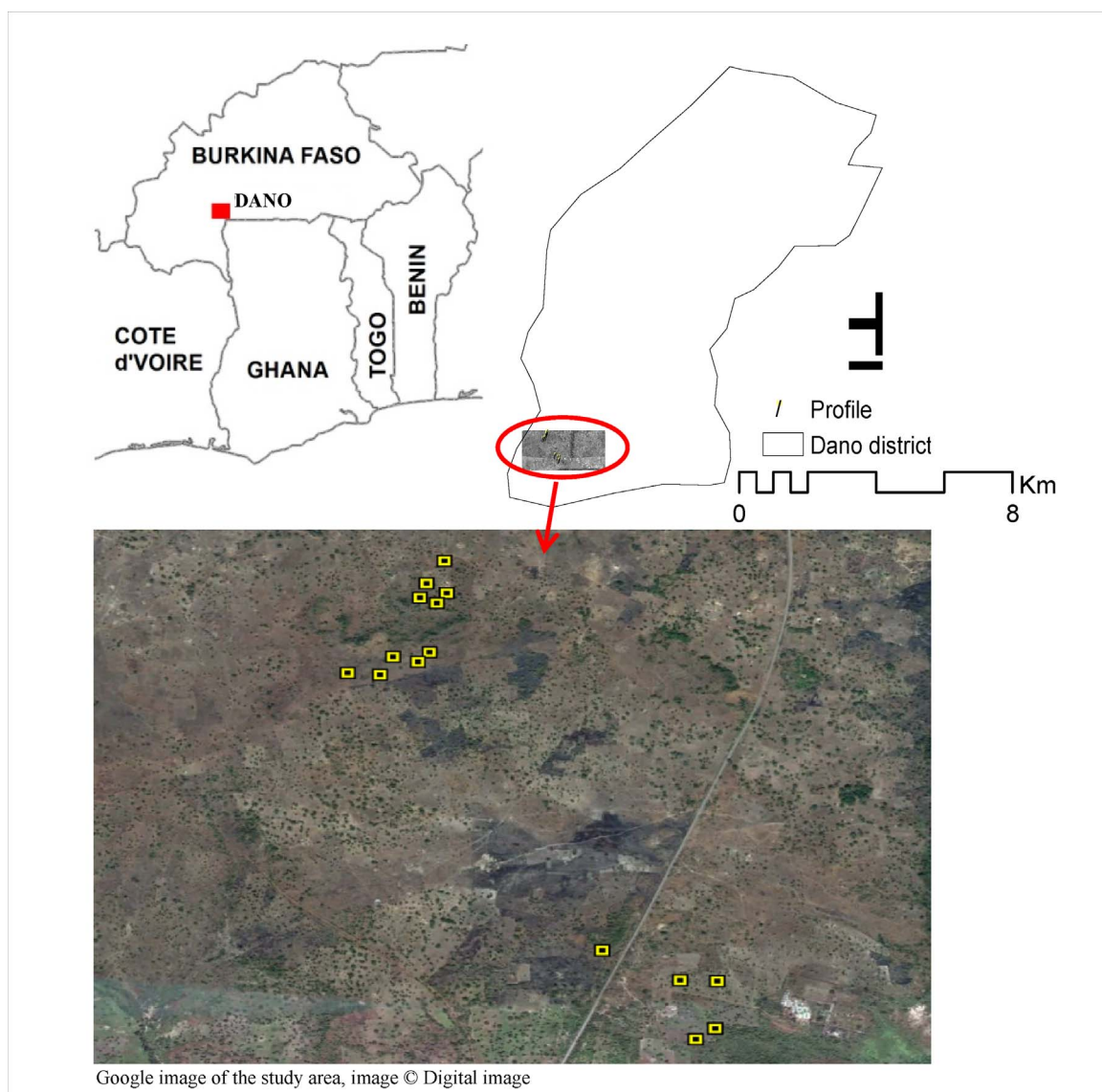


Fig. 1. Dano district and localities of profile sampling (yellow square). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

those of more or less recent plant residues, and because this pool usually responds fast to land-use change (Besnard et al., 1996; Chan, 2001). Besnard et al. (1996), for instance, found that initial POM-C contents declined rapidly by 50 to 92% of total SOC following a land use change from forest to cropland. Balesdent et al. (1998) reported a 82% POM-C loss after 35 years of cultivation with 76% lost in the silt fraction and 53% in the clay fraction. While most of these studies have been carried out in temperate areas, data on the SOC dynamics after this conversion into low-input agriculture in the West African savannah soil are still sparse (Bruun et al., 2013).

The stability of soil organic matter (SOM) is a major factor that characterizes its mineralization rates, being dependent on various physical, chemical and biological processes. The physicochemical interactions in tropical soils are largely affected by their significant portions in low activity clays (LACs; Barthès et al., 2008). In contrast to the high activity clay soils (HACs) in temperate climates, LACs have a smaller cation exchange capacity ($CEC < 24 \text{ cmol}^{(+)} \text{ kg}^{-1} \text{ clay}$) due to elevated portions of kaolinite, Fe and Al oxides, and hydrous oxides (Juo and Adams, 1984; Powers and Schlesinger, 2002). These oxidic mineral phases, however, may exhibit strong affinity to SOM. While Bationo et al. (2007) pointed to low correlations between the contents

of SOC and kaolinite, Feller and Beare (1997) reported that SOC content did not differ significantly between the LACs and HACs. In their study on different tropical soils of Ghana, Bruun et al. (2010) finally refuted the general concept of smectite (i.e., HACs) having higher SOC stabilizing power over kaolinite (i.e., LACs), whose sorption properties are similar to that of oxides (Denef and Six, 2005).

Influences of sesquioxides for stabilization of SOC via organo-mineral complexes have been discussed in detail by Lützwow et al. (2006) and Kögel-Knabner et al. (2008). Beside Al oxides, particularly Fe oxides exhibit a large sorption capacity for SOC compared to other metal oxides (Chorover and Amistadi, 2001; Kaiser and Guggenberger, 2007). And both, Al oxides (e.g., Miltner and Zech, 1998; Amelung et al., 2001) as well as the presence of Fe oxides might delay the decomposition rate of SOM (Baldock and Skjemstad, 2000; Kalbitz et al., 2005). Lalonde et al. (2012) and Wagai and Mayer (2007) extracted Fe oxides by a dithionite treatment and concluded that Fe-bound SOM may contribute up to 22% and 40% to total SOC content, respectively. Similar estimates for tropical soils are lacking. Such estimates, however, may be particularly needed for tropical semiarid climates, where beside Ferralsols particularly Plinthosols dominate the soil orders with Fe enrichment, especially on the African continent (Jones et al., 2013).

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