Catena 126 (2015) 60–67

Contents lists available at ScienceDirect

Catena

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

Impact of sheet erosion mechanisms on organic carbon losses from crusted soils in the Sahel

S.B. Maïga-Yaleu [a,b,c,*], P. Chivenge [d], H. Yacouba [c], I. Guiguemde [a], H. Karambiri [c], O. Ribolzi [e], A. Bary [a], V. Chaplot [d,f]

[a] Laboratory of Analytical Chemistry, Radiochemistry and Electrochemistry (LACARE), University of Ouagadougou, 03 BP 7118, Burkina Faso
[b] Laboratory of Hydrology and Water Resources, International Institute of Water and Environmental Engineering (Institute 2iE), 01 BP 594, Burkina Faso
[c] Department of Training and Research, Regional Center AGRHYMET, BP 11011, Niamey, Niger
[d] School of Agricultural, Earth & Environmental Sciences, Rabie Saunders Building, University of KwaZulu-Natal, Scottsville 3209, South Africa
[e] Géosciences Environnement Toulouse (GET), UMR 5563, IRD-Université de Toulouse, UPS (OMP), CNRS, 14 Av Edouard Belin, F-31400, Toulouse, France
[f] Laboratoire d'Océanographie et du Climat, Expérimentations et approches numériques, UMR 7159, 4, place Jussieu, 75252, Paris, France

ARTICLE INFO

Article history:
Received 7 April 2014
Received in revised form 23 October 2014
Accepted 1 November 2014
Available online 20 November 2014

Keywords:
Erosion mechanism
Soil surface feature
Land degradation
Soil organic carbon
Nutrients
Africa

ABSTRACT

Soil surface crusting influences water infiltration and runoff but its impact on soil organic carbon (SOC) losses by sheet erosion is largely unknown. Because there are different mechanisms of sheet erosion, from raindrop detachment and transport by raindrops interacting with flow (RIFT), to detachment and transport by flow, that require a certain slope length to be operative, this study examined the impact of slope length on SOC and nutrient losses. Field experiments were conducted on crusted soils in the Sahel region of Africa. Three replicates of micro-plots (1 m × 1 m), plots (10 m long × 5 m width) and long plots (25 m × 6 m) were installed for each crust type in the area (structural, STRU; desiccation, DES; gravel, GRAV; and erosion, ERO) and followed for each rainfall event in the 2012 rainy season. Sediment, SOC content in sediments and selected nutrients (NO_3^-; PO_4^{3-}) in the runoff were analyzed to evaluate the annual losses by sheet erosion. SOC losses decreased significantly with increasing slope length from 0.24 g C m^{-1} on micro-plots to 0.04 g C m^{-1} on plots and to 0.01 g C m^{-1} on long plots and similar trends were observed for NO_3^- and PO_4^{3-} losses. This suggested a strong scale dependency of sheet erosion with the efficiency of transport by saltation and rolling by RIFT decreasing significantly with increasing slope length, by 6 folds in average between 1 and 10 m, with values between 1.8 on DES crusts and 19 on STRU crusts. These results on the relationship between soil crusting and sheet erosion should be further used to mitigate against the loss of SOC through the implementation of improved soil conservation techniques, as well as to improve soil erosion and/or SOC models.

1. Introduction

In the sahelian region of West Africa, the combination of poor soil fertility with low and erratic rainfall, high soil and air temperature, surface crusting, low water-holding capacities and recurrent droughts are the main constraints to food productivity (Bationo and Buerkert, 2001). These factors influence water erosion process, the main process by which soil and soil nutrients are lost from the soil matrix. The soil water erosion significantly impacts the soil organic carbon (SOC) pool (Berhe et al., 2007; Lal, 2003; Van-Oost et al., 2007) with huge consequences on soil ecosystem functions such as those associated with food productivity, water availability and its quality, biodiversity and regulation of greenhouse gas emissions, among others (Bationo et al., 2007; Hien et al., 1996; Jacinthe et al., 2004; Lal, 2004; Martínez-Mena et al., 2012).

The process of water erosion is complex, and can affect SOC through the combined action of detachment and transport mechanisms (Kinnell, 2005). These mechanisms are associated with raindrop impact and overland flow, either as Hortonian flow or saturation excess surface runoff (Hewlett and Hibbert, 1967). Once detachment has taken place, three types of transport mechanisms can be operative: (1) splash transport (ST); (2) raindrop-induced flow transport (RIFT); and transport by flow without stimulation by drop impact (FT) (Kinnell, 2005; Parlak and Özaslan Parlak, 2010).

While all of these erosion mechanisms are likely to operate within hillslopes during rainstorms, their effiiency is intimately linked to slope length (e.g., Chaplot and Le Bissonnais, 2003; Kinnell, 2005).

ST moves the detached soil particles radially away from their initial location and is thus a relatively inefficient transport mechanism. In contrast, RIFT, which stimulates particles to roll and saltate, is much more efficient in transporting particles than ST. While ST is a point process which efficiency mainly depends on raindrop energy, the ability of RIFT to move the detached soil material downslope tends to increase

* Corresponding author at: P.O. Box: 7118 Ouagadougou, Burkina Faso. Tel.: +226 76 73 36 60.
E-mail address: yalstephanie@gmail.com (S.B. Maïga-Yaleu).

http://dx.doi.org/10.1016/j.catena.2014.11.001
0341-8162/

with increasing flow velocity and to some degree, flow depth, before thick layers of overland flow protect the soil surface from the impact of raindrops.

In-situ experimental designs involving runoff plots with different slope lengths thus, become important tools for the investigation of erosion mechanisms. Not only are water erosion mechanisms affected by slope length but also by factors such as raindrop energy, land cover and soil properties (e.g. texture, soil organic matter content, soil aggregation among others). Soil crusting is another important factor of control of water erosion, especially in the fragile Sahel region of Africa. However, while the impacts of environmental factors of control of sheet erosion such as land use and land management, slope gradient, soil structure, soil texture, clay mineralogy, and SOC content on the efficiency of soil erosion mechanisms at hillslope level have been widely investigated (Chaplot et al., 2007; Dlamini et al., 2011; Sharma, 1996; Terrence et al., 2002), little is known on the potential effects of soil crusting.

Soil surface crusts form as the result of soil disaggregation by the action of mainly raindrops. They are thin and compacted layers of low porosity and water infiltration, potentiating runoff and soil erosion (Bajracharya et al., 2000; Mills and Fey, 2003; Moore and Singer, 1990). Crusts are common features in the silty and loamy soils of the northern hemisphere (Le Bissonnais et al., 1998) and the sandy soils of the dry regions of the world. Several studies have been conducted in the Sahel region of Africa to determine the influence of soil crusting on soil water infiltration. These studies show that reduced infiltration is associated with accelerated soil erosion (de Rouw and Rajot, 2004; Graef and Stahr, 2000; Karambiri et al., 2003; Malam-Issa et al., 2011). More recently, Maïga-Yaleu et al. (2013) reported SOC losses on micro-plots between 0.15 and 0.37 g C m^{-2} y^{-1}. In that study, SOC losses tended to be greater under erosion crusts (ERO), which consist of a thin, clayey micro-horizon and desiccation crusts (DES), which are characterized by the presence of a single sandy micro-horizon out cropping on the soil surface. Inversely, the SOC losses tended to be lower on structural crusts (STRU) composed of a sandy layer overlying a thin film of soil plasma, and gravel crusts (GRAV) with an additional gravel micro-horizon on the soil surface. Such results were however obtained on micro-plots, where, as previously pointed by for instance Chaplot and Poesen (2012) and Oakes et al. (2012), RIFT is assumed to be less efficient than on longer slope lengths.

Accordingly, while crust type may affect SOC detachment by raindrops, their impact on sheet erosion mechanisms remain uncertain. The main objective of this study was to evaluate the impact of slope length and the associated sheet erosion mechanisms on SOC and nutrient losses from crusted soils for a range of precipitation events. This study was conducted in the Sahel region, which is characterized by sandy soils and a semi-arid climate with a cumulative annual rainfall amount of 500 mm y^{-1}.

2. Materials and methods

2.1. Characteristics of study site

The study was conducted in a semi-arid climate in Tougou catchment, Burkina Faso (Lat. 13°11′ N; Long. 2°64′ E) (Fig. 1). The mean annual temperature is 28 °C and the mean annual precipitation is 500 mm. During the study period from July to September 2012, the annual rainfall was 638 mm and was distributed in thirty-six rainfall events. Forty percent of the storms produced runoff and erosion, most of which occurred in August. During the rainy season, the minimum rainfall amount was 1 mm and the maximum was 98 mm. The soils of Tougou catchment are Ferric Lixisols (WRB, 2007) on which different types of soil crusting occur. The catchment is characterized by three types of surface conditions; cultivated soil, degraded soil and soil

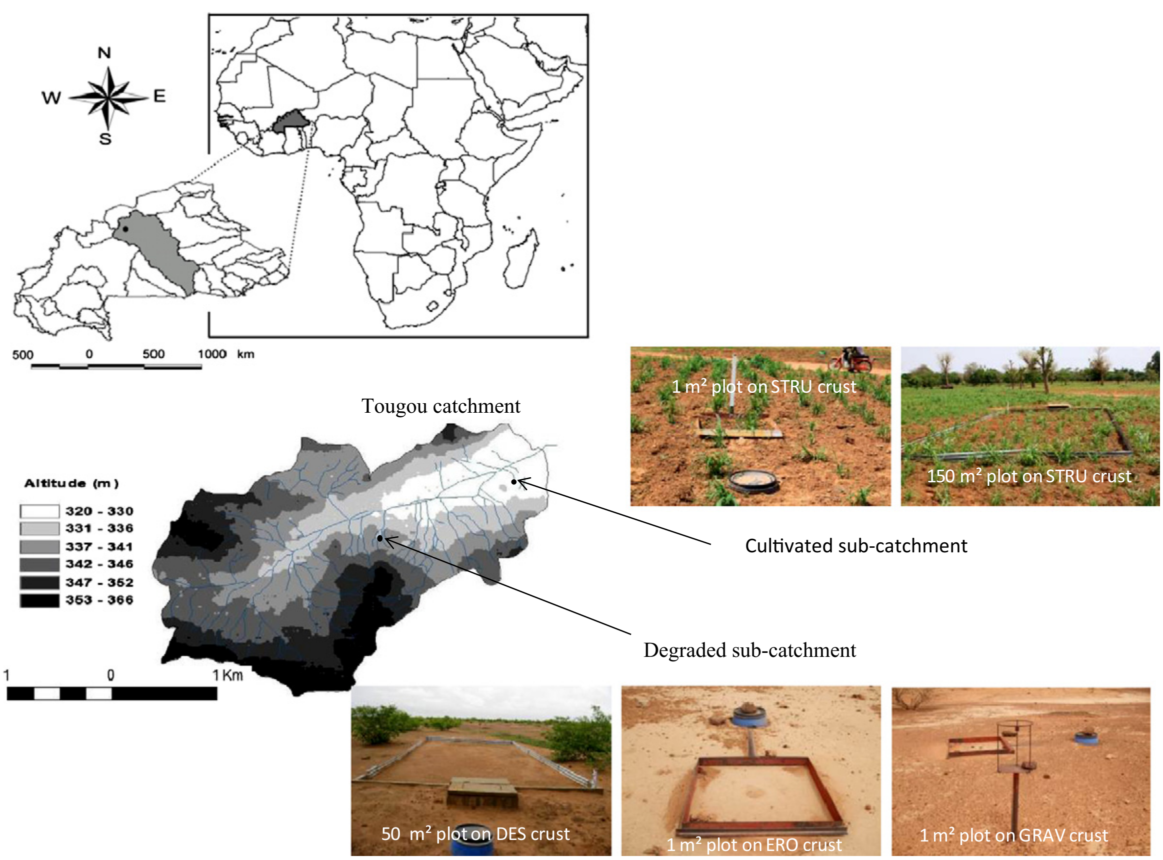

Fig. 1. Location of the study site and photographs of the experimental plots.