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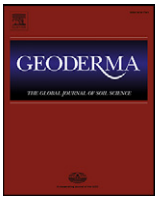

Soil aggregate stability to predict organic carbon outputs from soils

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ABSTRACT

Soil structure (e.g. aggregation) has been recognized as a key element in the stabilization of soil organic matter. While aggregate breakdown is assumed to expose the enclosed soil organic carbon (SOC) to preferential erosion and to accelerated decomposition, the link between the stability of soil aggregates and SOC exports from soils, has either been overlooked or unaccounted for, especially when developing carbon cycle models. This study compared SOC losses in particulate (POC), dissolved (DOC) and gaseous (GOC) forms to an indicator of the soil aggregate stability, the mean weight diameter of aggregates (MWD). SOC outputs were considered at 24 locations of a typical hillslope of the South African Highveld showing clayey to sandy soils. Both POC and DOC were evaluated in-situ under natural rains using 1×1 m^2 runoff plots while soil CO_2 emissions were assessed in the laboratory from undisturbed 0–0.05 m soil samples. MWD was finally compared to selected soil and terrain attributes for predictive purpose and as a means to further the understanding of SOC outputs from soils. MWD ranged between 1.4 mm for unstable aggregates and 3.4 mm for stable aggregates. The increase in aggregate stability resulted in a significant increase in POC and DOC concentrations in the eroded sediments ($r = 0.76$) and in GOC losses from soils ($r = 0.91$ when expressed as g C-CO_2 per gram of soil; $r = 0.95$ when as g C-CO_2 per gram of soil carbon). In contrast, high aggregate stability induced low total DOC and POC losses ($r = -0.81$ and -0.77, respectively). The lower POC and DOC losses in the most stable soil aggregates were explained by increased soil infiltration by water and reduced transport by runoff, while the greater CO_2 emissions correlated with high SOC concentration. Furthermore, there was a tendency for clayey soils which were fully covered by grass to present stable aggregates and thus to yield greater CO_2 emissions but lower POC and DOC outputs than degraded sandy soils of low aggregate stability. Such a quantitative assessment of the role of soil aggregation on SOC outputs might enhance knowledge on organic matter persistence in soils, a prerequisite for developing more accurate global carbon cycle models. Finally further research is required to investigate the downslope to downstream fate of the eroded SOC and to develop land management strategies that aim at lessening carbon losses from soils while enhancing adaptation to climate change.

1. Introduction

The soil organic carbon (SOC) pool, the biggest of terrestrial ecosystems shows important exchanges with the atmosphere through photosynthesis and decomposition of organic matter. This pool has been highly reduced by past human activities (Lal, 2003) such as changes in land use and land management. It is thus thought that the current rise in greenhouse gases (GHGs) in the atmosphere can be mitigated by sequestration of organic carbon (C) in soils (Batjes, 1996; Lal, 2003). In this context, understanding the balance between SOC inputs and outputs and their mechanisms and factors of control is key to improve sequestration of organic C in soils while supporting important ecosystem functions such as food and biomass production and biodiversity.

Soil aggregation has the potential to enhance organic matter (OM) stabilization in soils, which can be defined as the ability to increase the residence time of organic C in the soil compared with a reference situation or benchmark (e.g. Berhe and Kleber, 2013; Novara et al., 2012).

While the molecular structure of OM has long been thought to determine the persistence of organic compounds in soils, Schmidt et al. (2011) recently argued that environmental and biological controls have to be considered to explain OM protection in soil against microbial decomposition for centuries to millennia of, for instance, potentially labile compounds such as sugars.

Water erosion is a natural process which significantly affects the net flux of C between the soil and atmosphere. By removing OM from soils and transporting it to depositional sites and/or to the atmosphere it induces key mechanisms such as (1) the replacement of OM at eroding

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sites; (2) deep burial of OM at sedimentation sites; and (3) enhanced decomposition of OM as a result of soil aggregate breakdown during either detachment or transport (Van Oost et al. 2007). In particular, the break-down of soil aggregates by raindrops and overland flow, in the process of water erosion, has been shown to induce preferential detachment and transport of soil OM due to low density of most organic compounds compared to the other soil constituents (Rumpel et al., 2009; Maïga-Yaleu et al., 2013). Moreover, aggregate breakdown enhances the liberation of protected OM and its exposure to oxidizing conditions (Schmidt et al., 2011), which in turn increases CO_2 emissions. In this context, the susceptibility of soil aggregates to break-down may constitute an important soil characteristic governing OM persistence in soils.

Yet, little is known on the impact of the soil aggregate stability (i.e. natural resistance to disaggregation by mechanical breakdown, slaking or dispersion; Le Bissonnais, 1996) on organic C outputs from soils. This issue is crucial not only to enhance our understanding of the controls of OM dynamics but also to improve the prediction of OM persistence in soils through the use of soil proxies, which are easy to access and relatively cheap to implement. Understanding the link between soil aggregation and C outputs from soils is also important for designing agricultural practices aiming at increasing OM stabilization. It is finally key for improving current soil C models, which are empirical in nature and mostly lacking to integrate the environmental controls of OM outputs from soils (von Lützow et al., 2008; Schmidt et al., 2011; Segoli et al., 2013).

This study was conducted to test the hypothesis that aggregate stability plays an important role in controlling SOC outputs, though decomposition, which results in losses in gaseous form, and water erosion, which leads to SOC losses in dissolved and particulate forms. Aggregate stability tests following Le Bissonnais (1996) were performed from topsoil (0–0.05 m) bulk material at 24 locations of a typical hillslope of the South African Highveld showing clayey to sandy substrate and different levels of grass basal cover. The results were compared to SOC losses in particulate (POC), dissolved (DOC) or gaseous (GOC) forms, with POC and DOC evaluated in-situ using 1 × 1 m^2 runoff plots under natural rains and soil CO_2 emissions assessed in the laboratory from undisturbed 0–0.05 m soil samples. Moreover, a comparison between SOC outputs and the main soil, topography and vegetation control parameters (e.g. soil texture, SOC concentration, cation exchange capacity: CEC, soil bulk density but also grass basal cover, mean slope gradient, drainage area and compound topographic index) was performed to elucidate the underlying processes much more extensively.

2. Materials and methods

2.1. Characteristics of the study area

The study area is located in Potshini community of the Drakensberg region, Kwazulu-Natal province, South Africa (Fig. 1). It is marked by a temperate climate with a summer rainfall pattern with a mean annual precipitation of 684 mm per annum, a potential evaporation of 1600 mm per annum and a mean annual temperature of 13 °C (Schulze, 1997). The area is under natural rangeland with no fertilization and regular winter grass burns to prevent the rangeland from becoming woody. Features of land degradation such as a decrease of grass basal cover and the presence of patches of bare soils are common in the area.

At Potshini, altitude ranges from 1381 to 1492 m.a.s.l., the relief being relatively gentle with a mean slope gradient of 16%, but with a maximum value of 70% found on the midslope, whereas bottomland and plateau are flat (slope gradient between 2 and 4%).

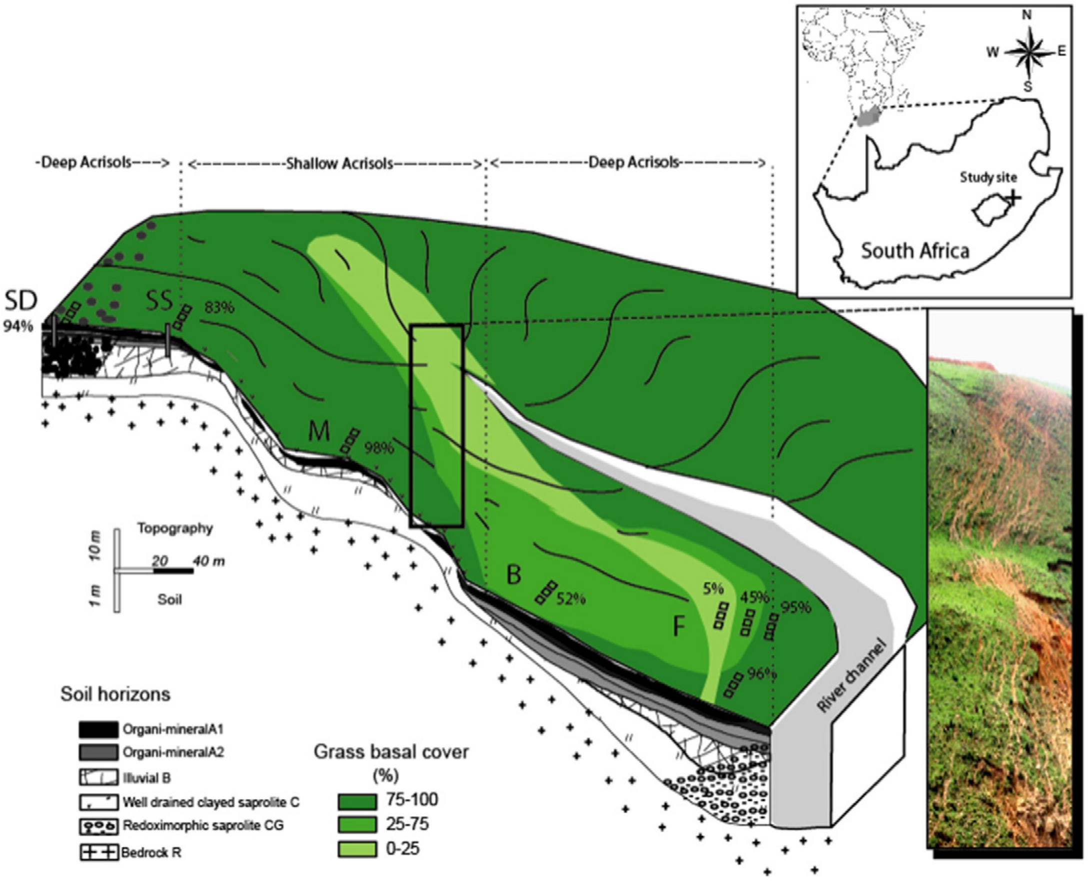

Fig. 1. Location of the study site in South Africa. Variations of soils and grass basal cover and position of the 1 m × 1 m microplots at the study slope positions.