Geoderma 245–246 (2015) 21–30

Contents lists available at ScienceDirect

Geoderma

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

Detachment of soil organic carbon by rainfall splash: Experimental assessment on three agricultural soils of Spain

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ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 8 January 2015
Accepted 10 January 2015
Available online 20 January 2015

Keywords:
Splash erosion
Soil organic carbon
Rainfall erosivity
Particle fractions
Cambisol
Solonchak
Gypsisol

ABSTRACT

An experiment was undertaken to measure the concentration of soil organic carbon (SOC) in particles mobilized by rainfall splash under natural precipitation and to assess its relationship with soil and precipitation properties. Splash cups were deployed on three agricultural soils typical of the central Ebro Valley in Spain (a Cambisol, a Gypsisol, and a Solonchak), and the rainfall characteristics (intensity, kinetic energy) were measured by means of a disdrometer (optical spectro-pluviometer). Evidences of SOC enrichment, i.e. a significantly higher concentration in the splashed material with respect to the parent material, were found in the three soils under study. Differences were found, too, between two particle size fractions (less than 0.05 mm and between 0.05 and 0.5 mm), with higher SOC enrichment in the coarsest fraction. While the amount of splash was clearly related to the erosivity of each rainfall event, no significant effect was found with respect to the SOC concentration. Between the three soils, the Gypsisol exhibited the highest rates of SOC enrichment, and also the largest difference between size fractions. Splash plays an important role on mobilizing fresh carbon fractions, and under certain conditions it may interrupt the soil carbon cycling by favoring the removal of SOC by other erosive processes such as runoff wash, thus preventing its incorporation into the soil carbon pool.

1. Introduction

The soil organic carbon (SOC) is a heterogeneous mixture of organic components such as plant, animal and microbial residues in different stages of decomposition (Post and Kwon, 2000), being the major component of organic matter in the soils. The SOC improves the aggregation, permeability and water-holding capacity of the soils, having a large influence on soil quality and fertility. As such, the content of SOC in soils is normally used as an indicator of soil quality (Sinoga et al., 2012). SOC also has a great capacity for storage and exchange with atmospheric CO_2 through plant photosynthesis, thus having an important role on the global carbon cycle. Therefore, to preserve the quality of the soils it is necessary to maintain a neutral or positive balance between the input of SOC by the addition of litter and dead animal material, and SOC loss by mineralization or by physical removal (erosion) (Lal et al., 2004).

At the field scale, large spatial differences in SOC content can exist due to soil erosion and redistribution processes. Recent studies examined the relationships between the patterns of SOC and soil redistribution processes using fallout ^{137}Cs, demonstrating a very good relationship between SOC loss/gain ratios and soil erosion rates (Ritchie et al., 2007; Navas et al., 2012). In many natural and agricultural landscapes water erosion is the main agent redistributing SOC (Jacinthe et al., 2004), and apart from mineralization, the depletion of SOC in agricultural soils has been related to the degree of soil erosion (Lal, 2005; Li et al., 2006). The loss of organic carbon compounds as a result of water erosion reduces soil aggregation and stability, further intensifying the efficacy of erosive processes in a positive feedback that may ultimately lead to the loss of soil fertility and to desertification.

Water erosion is a complex process involving several other processes. Splash, that is the detachment of soil particles and their transportation caused by raindrop impacts, can be considered a first stage in the process of soil particle detachment and transport (Quansah, 1981). Raindrop impacts occur everywhere, and may come from natural precipitation as well as from overhead irrigation. The energy of raindrops impacting the soil surface during a rain or irrigation event is able to detach soil particles and even to break some soil aggregates. The displacement of splashed particles occurs in all directions, but if the soil is not totally flat it results in a preferential movement of soil particles in the direction of the slope. Perhaps most importantly, the splashed particles are more vulnerable to experience further erosion by rain wash. Depending on the topographical conditions the displacement of soil particles can be more influenced by splash than by runoff (Rose, 1960; Hairsine and Rose, 1991). Meyer and Wischmeier (1969) indicated that the capacity of rainfall to transport soil by splash depends on factors such as the slope gradient, the amount and intensity of rainfall, the soil

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http://dx.doi.org/10.1016/j.geoderma.2015.01.010
0016-7061/

properties and other factors such as the micro-topography and the wind velocity during the rainfall event. Mati (1994) and Ghahramani et al. (2011) found that soil splashed varied very much as a function of the land use, with the highest splash erosion rates occurring over bare soil, and amounts depending on crop type and cover percentage. Agricultural soils are especially prone to splash, since they remain bare during several months every year. Moghadam et al. (2015) found that land use and soil management practices significantly influenced splash erosion rates on farming lands in Iran. Although the total amount of sediment mobilized by interrill processes (rain splash and rain wash) is small compared to rill and tillage erosion, they affect all arable soil surfaces resulting in a significant mobilization of sediment right at the soil–atmosphere interface, and thus may have a relevant role in the global carbon cycle (Kuhn et al., 2009).

SOC is mobilized in association with soil particles by rain splash and rain wash (Gregorich et al., 1998). Therefore splash may play a relevant role in the dynamics of SOC, especially under bare conditions such as those of agricultural soils during part of the year. However, there is very little information concerning the magnitudes of SOC mobilized by splash from different soil types and conditions. It is known that splash does not have the same effect on all soil particles, and for example differences in the magnitude of splash exist as a function of the size, density and aggregation of the soil particles. In particular, splash tends to be stronger in lighter particles, such as those with a high SOC content. For example, SOC enrichment ratios between 1 and 2.5 times have been recorded in splashed material with respect to the original material at the soil surface (Mermut et al., 1997; Martínez-Mena et al., 2002; Jin et al., 2008; Kuhn, 2007). Small, poorly decomposed plant fragments have an important role on this enrichment of SOC in splashed material, since these light and poorly decomposed vegetal particles are more easily transported than heavier, mineral, particles (Ghadiri and Rose, 1991). The fate of SOC-rich particles splashed from the soil surface is especially important. They may be removed from the site as suspended sediment if trapped by runoff wash on rills and gullies, or else they may accumulate in depositional crusts where SOC is largely unconnected from the soil structure and is exposed to the atmosphere (Le Bissonnais et al., 2005; Kuhn et al., 2009). Either way, it reduces the input of SOC into the soil and has potential for affecting the carbon exchange balance between the soils and the atmosphere. Therefore, a characterization of SOC in the soil particles detached by splash is highly needed.

We undertook an experimental study in order to determine the amount of SOC and enrichment ratios in splashed soil on three soil types, under natural rainfall. To date most studies that examined the contents of SOC on splashed soil particles were carried out in the laboratory or in the field under simulated rainfall (Polyakov and Lal, 2004a; Jin et al., 2008). Very few studies were done under natural rainfall, but they did not look specifically at splash (Martínez-Mena et al., 2008). Our study focused on splash erosion by collecting in splash cups the amount of splash generated after each rainfall event. Precipitation and raindrop characteristics were monitored by means of an optical disdrometer.

The objectives of our study were determining:

1. The differences in SOC concentration and in total SOC mobilized by splash between soil types and size fractions.
2. The differences in SOC concentration between splashed particles and the original soil surface (SOC enrichment) between soil types and size fractions.
3. The effect of rainfall properties (mainly rainfall erosivity) on SOC concentration and total SOC mobilized by splash.

2. Materials and methods

2.1. Experimental site

The experiment was located in the Aula Dei Experimental Station (41°43′30″N, 0°48′39″O, 230 m. a.s.l), and the monitoring period was between March 2010 and October 2011, spanning a period of 20 months (Fig. 1).

Three soils typical of the semi-arid central Ebro River depression agricultural and natural lands were considered: a Cambisol, a Gypsisol and a Solonchak (FAO and ISRIC, 1988). These soils are subject to accelerated erosion because they are either occupied by agricultural lands that remain bare during several months every year (Machín and Navas, 1998) or else they sustain low-coverage plant communities due to their restrictive conditions for vegetation and to the semi-arid climatic conditions prevailing in the region (Guerrero-Campo et al., 1999; Pueyo and Alados, 2007). Soil from the upper 40 cm was collected from nearby cropping fields and placed in plots of 14 × 1 × 0.8 m in the experimental site. After 20 years, the conditions of these experimental soils are very close to those found in the field, in terms of bulk density and other fundamental properties (Table 1). Details about how these properties were determined are given in the Appendix.

Cambisols are developed over glacis and terraces from fluvial deposits and marls. Its texture is silty with 25% pebbles, alkaline pH and low salinity. They show good drainage, low organic matter content and low gypsum content. Gypsisols are located in colluvial–alluvial valley areas developed over deposits from nearby gypsiferous hills. They have a sandy-loam texture, alkaline pH and higher salinity than Cambisols. They have a low organic matter and carbonate content and high gypsum content. Solonchaks are found in depressions or level areas. Their texture is clay-loam, and they have poor drainage.

2.2. Measurement of splash erosion

The experimental setup is shown in Fig. 2.

The three soils were arranged side to side in three plots of 14 × 1 m at the experimental station, so they were subject to the same precipitation events with equal characteristics of rainfall intensity, duration and kinetic energy. The plots were completely level to avoid slope gradient effects, and the soils were kept bare by mechanical removing of any new seedlings. Apart from that, the soils were kept undisturbed and as close to their natural condition as possible. Although this setup may not be representative of the natural conditions under which these soils appear (with different slope gradients, vegetation cover and soil treatments), it eliminates several factors of variability and eases comparison between the three soils.

Splash erosion was monitored using Morgan-type splash cups (Morgan, 1981). This device consists in a closed circular plate with a smaller circular hole inside that is placed in direct contact with the soil. The inner circle has a sampling area of 0.0085 m^2. Soil particles detached by raindrop impacting the bare soil in the inner circle need to jump over a rim of 2.5 cm, and then they are trapped within the outer circle inside the splash cup. The outer rim of the cups is 25 cm high to avoid contamination of splashed material from outside. To avoid sediment loss by overflowing during very intense storms, some drainage is allowed through small holes at the edges of the cups. A porous membrane was used to let the water slowly drain from the cups while preventing the sediment from escaping.

Five clean splash cups were deployed in each of the three plots and collected after each rainfall event. If sediment was present in the cups it was collected and the cups were deployed in the field again. In order to maintain randomness and to avoid sediment exhaustion effects, the cups were placed each time at a different location within the plots.

The splash samples were air-dried, weighted and sieved in fractions of silt and clay (<50) and fine sand (50 to 500 μm) to account for the SOC associated with the mineral part of these fractions. SOC was analyzed by the dry combustion method using a LECO RC-612 multiphase carbon analyzer designed to differentiate forms of carbon by oxidation temperature (Nelson and Sommers, 1996). A sub-sample of the <2 mm fraction is inserted into a quartz tube, heated to 550 °C and the SOC is oxidized to CO_2, which is selectively detected by an infrared