

Organic carbon stocks and soil erodibility in Canary Islands Andosols

A. Rodríguez Rodríguez*, C.D. Arbelo, J.A. Guerra, J.L. Mora, J.S. Notario, C.M. Armas

Department of Soil Science and Geology, Faculty of Biology, University of La Laguna, Avda. Astrofísico Francisco Sánchez s/n, 38204 La Laguna, Tenerife, Canary Islands, Spain

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Abstract

Soil organic carbon (SOC) plays a key role in the structural stability of soils and in their resistance against erosion. However, and as far as andic soils are concerned, these mechanisms and processes, as well as the influence of the different types of SOC on aggregate stability, are not fully understood. The targets of this paper are: (i) to determine the content and forms of SOC in Andosols under evergreen forest vegetation [laurel (*Laurus*) and heather (*Erica*) forest] and (ii) to find out the role of soil organic matter (SOM) in the aggregate stability and in the resistance of Andosols to water erosion. Soil samples have been collected in 80 sites in a 40 km² area under udic soil moisture regime. In them, fulvic and humic acids, Walkley–Black SOC, pyrophosphate-extractable SOC, Fe and Al, potassium sulphate extractable SOC, dissolved SOC, acid oxalate-extractable Fe, Al and Si, USLE K-factor and aggregate stability have been determined. The Andosols over volcanic ash are Aluandic Andosols (non-allophanic Andosols), whereas over basaltic lava flows are Silandic Andosols (allophanic Andosols). The surface (0–30 cm) samples analyzed contain 9.5–30 kg C m⁻² being significantly higher in allophanic Andosols ($p < 0.5$). Organic carbon adsorbed onto the mineral fraction (extractable pyrophosphate, C_p) accounts for 35–55% of the total SOC. All samples show a high stability to slaking and raindrop impact, being the first one highly correlated ($r = 0.6$) with pyrophosphate extractable C (C_p), Fe (Fe_p), and Al (Al_p) in allophanic Andosols, unlike non-allophanic ones. The stability to raindrop impact correlates with pyrophosphate extractable C (C_p) and Fe (Fe_p) in both types of soils ($r = 0.3–0.6$, $p < 0.05$). These findings suggest that the high stability to both slaking and water-drop impact is due to the occurrence of allophane–Fe–OC complexes, rather than to the total OC, and the active Fe and Al forms, generated by the weathering of volcanic materials, constitute an essential constituent responsible for C sequestration and resistance to degradation in these soils.

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1. Introduction

Soil organic carbon (SOC) is recognized as a main soil constituent and a key parameter to measure soil quality, provided the fair correlation between the SOC content and many soil properties and functions such as soil porosity, water holding capacity, nutrient availability, soil biodiversity, soil structural stability, etc. (Karlen and Andrews, 2000; Singer and Ewing, 2000). Therefore, an increase in SOC levels in terrestrial ecosystems is desirable, because of its favourable effects on soil dynamics, and its contribution to mitigate the greenhouse effect.

SOC contents usually are the net result of diverse processes, some of which tend to accumulate carbon in surface horizons, whereas others behave oppositely. Among the latter ones, interrill erosion, that is, the detachment and transport of soil material by raindrops and very shallow flows (Lafren and Roose, 1997), is one of the most important.

Eswaran et al. (1995) distinguished the following forms of SOC: dissolved, labile, slowly oxidizable and passive or recalcitrant. The stability of various SOC pools relates directly to their mobility, the chemical complexity of the organic molecules (biochemical recalcitrance), their location in soil aggregates (physical protection), and their association with metals and secondary soil minerals (chemical stabilization) (Golchin et al., 1998; Jastrow and Miller, 1998).

* Corresponding author. Tel.: +34 922 318 371; fax: +34 922 318 311.
E-mail address: antororo@ull.es (A. Rodríguez Rodríguez).

The interrelationship between SOC and the stability of topsoil aggregates has been well established. Several mechanisms are involved in soil susceptibility to particle detachment, and they are mainly related with soil erodibility. It is difficult to measure soil erodibility, given the complex interactions between soil properties and time-related conditions that make soil erodibility a dynamic (rather than a constant) property (Roose, 2003).

Andosols (Soil Survey Staff, 1999) are characterized by a high organic carbon content (80 to 300 g kg⁻¹), because of the stabilization of organic matter by short-range ordered minerals or Al-humus complexes (Dahlgren et al., 1993; Parfitt et al., 1997). Hence, Andosols typically show a structure made up of highly stable, crumbly and granular microaggregates where SOC, as organomineral and organometallic complexes, is physically protected from microbial mineralization (Warkentin and Maeda, 1980), and have a large potential to sequester organic carbon, although the SOC dynamics in these soils and the mechanisms that rule the stabilization of organic compounds are far from being well known (Lal et al., 1998).

The resistance to water erosion and the low erodibility of Andosols rely largely on their unique physical and mechanical properties (Khamisouk et al., 2002; Rodríguez Rodríguez et al., 2002a), derived from their organic matter content and forms and their particular mineralogical composition (Warkentin and Maeda, 1980). Field studies have shown, however, that high losses may occur when these soils are subjected to changes in use and management (Poulenard et al., 2001; Rodríguez Rodríguez et al., 2002a).

Many attempts have been made to devise a simple erodibility index and several authors have pointed out that aggregate stability is a critical factor in this sense (Barthès and Roose, 2002). The determination of soil aggregation and structural stability affords an indirect measurement of erodibility that can be used to help establish the mechanisms of particle detachment in andic soils (Imeson and Vis, 1984; Le Bissonnais and Arrouays, 1997).

Our objectives were: (i) to determine the SOC content and forms of Andosols under evergreen forest vegetation (laurel and heather forest), and (ii) to determine the role of different forms of SOC in aggregate stability and resistance of Andosols to water erosion.

2. Materials and methods

2.1. Study area and environmental conditions

The study was conducted in a 40 km² area in the Garajonay National Park (La Gomera, Canary Islands), characterized by a thermomediterranean mesophytic subhumid bioclimate (Rivas-Martínez et al., 1993). The annual rainfall, average temperatures and potential evapotranspiration are 650–900 mm, 14.2 °C and of 750–800 mm year⁻¹,

respectively. These conditions give rise to an udic soil moisture and a mesic soil temperature regimes. The natural vegetation consists of laurel and heather forest (Lauro–Perseetum indicae and Myrico–Ericetum arboreae).

Andosols (Melanudands, Fulvudands and Hapludands) have developed over a complex geologic material constituted by Miocene–Pliocene basaltic lava flows and successive deposits of volcanic ash of diverse grain size, generally from the eruptive stage of the same eruptions, that predominate in these areas.

The weathering of this parent materials under a humid climate is relatively fast, and yields allophane-like noncrystalline minerals that, together with plant residues supplied by the existing vegetation, originates thick, dark, humus-rich epipedons and Al/Fe humus complexes.

Illuviation of clay-sized materials is hindered in these soils, as noncrystalline materials cannot be readily dispersed in field conditions (Shoji et al., 1993). The presence of a clayey horizon at depth is therefore interpreted as an in situ weathering of the underlying rock that yields halloysite and smectite-type clay minerals.

2.2. Soil sampling

The sampling strategy described below had been undertaken for a global study of soils at the Garajonay National Park, but it should be noted that only those analytical data corresponding to andic soils are used in this paper. In spite of this, a detailed description of sampling tasks has been considered as convenient. Initially, a detailed study of 31 soil profiles was carried out, to find out the soil distribution pattern in the area. Later on, 88 soil samples (0–30 cm) were collected at three randomly distributed sampling points in each location, following a 500 m × 1000 m sampling grid covering the entire study area. The sampling was intensified in those areas with the highest evidence of degradation for both vegetation and soils, where 75 samples were collected on a 250 m × 250 m grid, up to give 163 sampling points. Soil samples were mixed and air-dried at room temperature. One part of each soil sample was passed through a 2-mm mesh and analysed, and another part was stored to determine the aggregate stability. Three separate sample cores were collected for bulk density using tin cylinders. As stated above, 83 samples were found to correspond to non-andic soils (mainly in degraded areas), so that only the remainder 80 samples have been used here.

2.3. Laboratory analysis

The soil properties determined is listed as follows:

- a) *Walkley–Black soil organic carbon (SOC)*: Determined by wet oxidation with 1 N potassium dichromate Walkley–Black procedure, according to Nelson and Sommers (1982).

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