



## Short Communication

## Is soil carbon storage underestimated?

José Luis Díaz-Hernández\*

IFAPA Camino de Purchil, Consejería de Agricultura y Pesca, Junta de Andalucía, Aptdo. 2027, 18080 Granada, Spain

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## ABSTRACT

An accurate evaluation of the carbon stored in soils is essential to fully understand the role of soils as source or sink of atmospheric CO<sub>2</sub>, as well as the feedback processes involved in soil–atmosphere CO<sub>2</sub> exchange. Depth and strategies of sampling have been, and still are, sources of uncertainties, because most current estimates of carbon storage in soils are based on conventional soil surveys and data sets compiled primarily for agricultural purposes. In a study of the Guadix-Baza basin, a semiarid area of southern Spain, sizeable amounts of carbon have been found stored in the subsoil. Total carbon estimated within 2-m was 141.3 kg C m<sup>-2</sup> compared to 36.1 kg C m<sup>-2</sup> if estimates were based solely on conventional soil depths (e.g. 40-cm in Regosols and 100-cm in Fluvisols). Thus, the insufficient sampling depth could lead to considerable underestimation of global soil carbon. In order to correctly evaluate the carbon content in world soils, more specific studies must be planned and carried out, especially in those soils where caliche and other carbonated cemented horizons are present.

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## 1. Introduction

Soils are a significant pool in the global geochemical carbon cycle. It has been estimated that plants and soils store almost three times as much carbon as that found in the atmosphere (Schlesinger, 1999; Janzen, 2004; Lal, 2004). One third of the terrestrial carbon is stored in biomass, whereas the other two thirds are stored in soils (Post et al., 1982; Trumbore, 1997), in both humic matter and inorganic forms (carbonates). The carbon stored in soils plays an important role in global climate change processes, because soils can function as either a sink or a source of atmospheric CO<sub>2</sub>, depending on the circumstances. A change of climate would result in a redistribution of vegetation belts, which, in time, would bring about a change in the carbon content of the underlying soils (Post et al., 1982; Adams et al., 1990; Prentice and Fung, 1990; Trumbore, 1997; Lal, 2004). This would lead to either sequestration or release of atmospheric CO<sub>2</sub>, with the consequent feedback on climate (Adams et al., 1990; Prentice and Fung, 1990; Schlesinger et al., 1990; Vloedveld and Leemans, 1993; Kirschbaum, 2000). Thus, an accurate quantification of carbon stored in soils under different ecosystems is indispensable to the understanding and modeling of the feedback processes.

The role of inorganic carbon in these processes is perhaps less important than that of organic forms, because the former are more stable and their release to the atmosphere is more difficult (Serna-Pérez et al., 2006). However, the stability of the pedogenic carbon-

ate means that its determination is essential to evaluate the role of soils as a sink for carbon dioxide (Kern and Schlesinger, 1992; Adams, 1993).

The evaluation of soil carbon stocks in different ecosystems is at present based on data obtained from general purpose surveys (Bohn, 1976, 1982; Post et al., 1982; Schlesinger, 1982; Eswaran et al., 1993; Sombroek et al., 1993; Batjes, 1996; Jones et al., 2005), such as basic soil maps and agricultural reports. Thus, the sampling depth is usually determined by the soil studied in these surveys and consequently limited to scarcely more than 1 m. As Bohn (1976, 1982) suggested, these data must be looked upon with some caution, because in soil surveys, soils are frequently sampled at points judged to be 'typical' within a given landscape. This judgment sampling can introduce a significant bias in the final results (Webster, 1977; Yates, 1981).

In the evaluation of organic soil carbon, limitation of depth does not cause any serious problems *a priori*, as humus accumulates for the most part on surficial horizons and usually decreases rapidly with depth (Parsons and Tinsley, 1975; Bohn, 1976; Jobágy and Jackson, 2000; Smith et al., 2000). However, in the case of carbon stored as pedogenic carbonate, evaluation is more difficult because in arid and semiarid regions it accumulates at depth, frequently as indurated layers (petrocalcic horizons or caliches). Caliches are hard to excavate and so the description and study of such horizons ceases just where it begins to become interesting. This is normally justified because soil features at these depths are relatively unimportant for soil taxonomy or for judging the soil as a support for plants. However, these data are essential when soils are viewed as a sink for atmospheric carbon and few have followed this direction (Jobágy and Jackson, 2000).

\* Tel.: +34 958 895310; fax: +34 958 895200.

E-mail address: [josel.diaz@juntadeandalucia.es](mailto:josel.diaz@juntadeandalucia.es)

The aim of this study is to compare the carbon contents determined using conventional survey criteria (adjusted to soils taxonomy), with the carbon contents estimated for deep profiles. To determine the quantities of both organic and inorganic carbon in a representative semiarid Mediterranean zone, a study was carried out in an area of approximately 3500 km<sup>2</sup> located in the Guadix-Baza basin, in the northern part of the province of Granada (Spain) (Díaz-Hernández, 1998). This area is especially appropriate for a case study because it displays clearly expressed geomorphological features, and most of the soils have well developed calcic or petrocalcic horizons. It is also relevant because arid and semiarid ecosystems are significant in a global evaluation of soil carbon, as they occupy roughly a third of the continental surface area (Schlesinger, 1982; Le Houérou, 1996).

**2. Materials and methods**

Because existing data were not satisfactory to evaluate carbon stored in soils with caliche, soil profiles were studied at 81 points where the depth and features of the caliche could be accurately determined. The pits (natural or artificial) reached an average depth of about 2 m (in several cases down to 4 m) and the sampling points were distributed as evenly as possible, to simulate a probabilistic sampling in 10 × 10 km cells with one or two sites selected per cell.

Samples were taken at 20 cm depth intervals after cleaning the exposures to reveal fresh material. Organic and inorganic carbon were analysed in sieved samples (<2 mm) using standard techniques (USDA-NRCS, 1996): organic carbon was determined by the Walkley and Black method, the CaCO<sub>3</sub> equivalent was obtained by a manometric method, and calcite and dolomite contents were deduced from the CaCO<sub>3</sub> equivalent and the peak height ratios found in the XRD powder diagrams. Bulk densities were determined by coating clods and caliche fragments from each horizon with saran resin. The fine earth fraction (Cm coefficient) was calculated by the weight of gravel separated by sieving, in non-cemen-

ted samples, and by the volume of gravels embedded in cemented horizons, which was determined by image analysis of polished cross-sections. Finally mass fractions of SOC and SIC determined in the fine earth of individual samples were converted into total amounts contained in a soil column of unit area by taking into account layer thickness, bulk densities of cemented caliches and fine earth, and correction to allow for the presence of coarse fragments (Cm).

**3. Results and discussion**

Fig. 1 shows the average distribution by depth of both organic and inorganic (calcite and dolomite) carbon for the studied area. The average organic carbon decreases rapidly with depth, tending to near-zero values below 1.2 m (n = 81 profiles), and continues to decrease slightly down to a depth of 2.20 m depth (n = 27 profiles). Although the analyses carried out in this paper are confined to the first 2 m depth in order to establish comparisons, it must be emphasized that below 2.20 m there is a tendency for organic matter content to increase from 0.11% (at 2.20 m) to 0.22% (at 3.40 m). Two reasons can explain this fact: the number of observations is increasingly smaller and therefore the average is more susceptible to oscillations; the other reason is that the lowest horizons may present impedance since the pores are smaller, which implies a concentration of organic matter translocated to this soil depth. The latter cause was observed in individual deep profiles and both reasons can coexist.

The distribution with depth of average inorganic carbon (calcite) shows relative decarbonation near the surface, and an increasing carbon content at about 40 cm (43% in the bulge); below this depth the carbon content decreases progressively until 2 m depth. A second bulge at a depth of 2.20–2.40 m is apparent and could be the result of at least three polycyclic profiles showing maxima of carbonate accumulation within this depth range.

Although the origin of dolomite remains a long-standing enigma in geology, well-ordered stoichiometric dolomite has been doc-

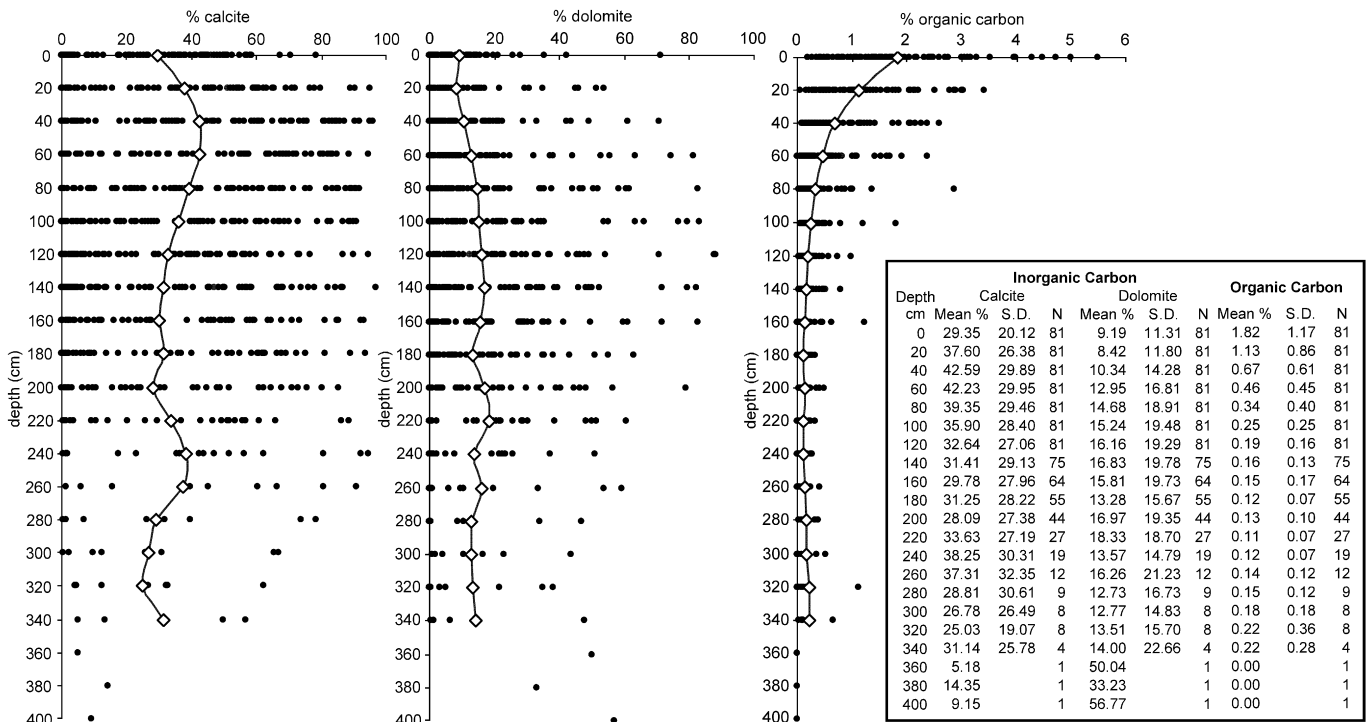


Fig. 1. Depth-wise (y-axes) variation of the average soil organic and inorganic carbon in the studied profiles of Guadix-Baza basin.

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