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Establishing an index and identification of limiting parameters for characterizing soil quality in Mediterranean ecosystems

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ABSTRACT

The aim of this work was to develop a suitable index for characterizing the quality of soils in semiarid Mediterranean ecosystems. The preliminary estimate of the attributes involved in soil quality was made taking into account the opinion of experts and our own experience in such ecosystems. These attributes were based on different physical (granulometry, aggregate stability, water holding capacity at 33 and 1500 Kpa, available water, bulk density, particle density and plant cover) and biochemical (organic carbon, nitrogen, pH in water and potassium chloride, electrical conductivity, cation exchange capacity, available ions such as sodium, potassium, magnesium, iron, copper, manganese and zinc, and dehydrogenase activity) properties of the soil related with its sustainability. Principal components analysis (PCA) was used to discriminate between the initial variables considered, in order to select those that may be included in an index that reflects the quality of soils in semiarid Mediterranean agricultural areas. The index obtained includes variables related with the physical properties of the soil, chemical fertilization and biological activity. The index potentially reflects the variations that occur in agricultural land and may be considered a suitable tool for the early detection of changes in the soil and for monitoring the effects that human actions may have on it.

1. Introduction

Soil quality suffers a significant decline in the world and particularly in Mediterranean ecosystems, due, among other factors, to climate and human pressure. In this sense, almost 16 million hectares are affected by processes of moderate or severe salinization in the Mediterranean basin and within them 1 million hectares belong to the Iberian Peninsula. A report by UNCED (1992) states that, in arid and semi-arid areas, 30% of agricultural land under irrigation is rapidly degraded by salinization and the destruction of its physicochemical and biological properties.

Land use type and agricultural management practices may cause alterations in soil physical and chemical properties and in soil biotic community (Caravaca et al., 2002). In this sense, there is a need of to develop new management systems that minimize soil degradation and ecosystem contamination concerning it, based in a quality index adapted to those ecosystems in order to identify their status and to define critical limits for different soil indicators. The type and intensity of actions and measures should be established considering these indexes to preserve soil functions in general, with special attention to those with special relevance to each specific ecosystem.

A basic function of soil is to act as a C sink. Carbon stored in soils represents the largest terrestrial carbon pool. Arable soils usually have low values of soil organic carbon, whereas values are higher under permanent plant cover. Conversion of natural to agricultural land resulted in the loss of 50–100 Pg of soil organic carbon worldwide over the past 200 years (Jarecki and Lal, 2003). Carbon stocks of these soils can be restored with improved management practices, at least temporarily, thus removing CO_2 from the atmosphere. However, current estimates of the actual soil C sink capacity are only 50–66% of the cumulative historic C loss (Lal, 2004).

Soil quality, defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994a), has been used by several authors as a method for evaluating the suitability of management practices carried out in a soil, and indices have been developed to grade and compare soil conditions over time or between different locations (Nortcliff, 2002; Sparling and Schipper, 2004), low pluviometric gradient (Ruiz Sinoga and Romero Díaz, 2010; Ruiz Sinoga et al., 2012) or in similar soils under different uses (Marzaioli et al., 2010).

Soil quality indices are obtained by integrating different indicators that represent the set of soil properties providing information about the soil status. The accurate, consistent assessment of soil quality requires a systematic method for measuring and interpreting the soil properties that serve as suitable soil quality indicators (Granatstein and Bezdicek, 1992). Although such methods exist for monitoring and evaluating air and water quality, no single method has been widely

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accepted for assessing soil quality due to the great complexity and variability of soil systems. Indeed, much remains to be known concerning the complex relationships between specific soil property measurements and overall soil quality. To further understand these relationships, a methodology for assessing and monitoring soil quality is required.

The most recent works on soil quality use statistical functions to group indicators, so that the initial number of parameters is reduced by choosing those that best represent the quality of soil (Brejda et al., 2000; Anderson, 2003; Sparling and Schipper, 2004). Factor analysis has been widely used to select soil parameters, with principal components analysis (PCA) being one of the most common procedures for reducing the number of dimensions (Wander and Bollero, 1999; Shukla et al., 2005). These properties are grouped into a Minimum Data Set (MDS), i.e. a collection of selected indicators able to measure soil state and function from plot to regional scale. Many papers and reports have been published in the last 20 years relating to the MDS (Arshad and Coen, 1992; Doran and Parkin, 1994a; Gregorich et al., 1994; Larson and Pierce, 1994; Karlen et al., 1997; Martin et al., 1998), but the effort has been limited to determine threshold values or critical limits for the proposed soil indicators. Selection of critical limits for soil quality indicators poses several difficult problems. The ability to supply moisture, nutrients and physical rooting support in the absence of toxic substances can be affected by many physical, chemical and biological parameters. A detrimental change in any of these can reduce the quality of the soil, but the quantitative values beyond which a further reduction in these properties is limiting depend strongly on the crop. However, natural soils have an inherent soil quality, which is based upon the parent material.

In light of the above, the assumption is that some soil functions may be influenced by the activities that take place on it, especially those related to agriculture. Therefore, preservation or not of these functions (production, storage, C sink, hydrologic, etc.) must be quantified by establishing a quality index that integrates soil properties that have been previously selected as indicators (Andrews et al, 2004; Cambardella et al, 2004).

The work presented aims to cover the gaps in the study of soil quality indices in Mediterranean areas as well as other studies in the same area (Bastida et al, 2008; Imaz et al, 2010; Fernández-Ugalde et al., 2009; Ruiz Navarro et al, 2012). and thus the purposes of this study were: (i) to quantify and to select useful indicators to assess soil quality under semiarid Mediterranean conditions; (ii) to obtain a quality index using an existing systematic method for evaluating soil quality under semiarid Mediterranean conditions; (iii) to establish a relationship between the obtained quality index and soil types, uses and geological material from which soil is formed and (iv) to identify the limiting parameters of the soil in these ecosystems.

This study was conducted in the SW of the province of Murcia (Spain), due to the coexistence of remaining areas with poorly degraded natural vegetation with others devoted to intensive agriculture, urban uses or mining activities. This change in land use has led to changes in their physical, chemical and biological properties and contamination by inorganic and organic chemicals (Oyarzun et al., 2011; Sánchez-Navarro et al., 2012a, 2012b).

2. Material and methods

2.1. Description of the study zone

The study zone refers to National Topographic Map sheet 976 (Mazarrón) E 1:50,000 (368 km^2), in the province of Murcia (Spain) (Fig. 1). Coordinates of the sampled locations ranged from 37°30′04″ 6N to 37°40′04″6N and 1°31′10″9W to 1°11′10″9W (UTM zone 30S 4,150,000 to 4,170,000 north and 630,000 to 660,000 east), and the average elevation in the study area was 213 m, reaching a maximum height of 886 m.

In this area, four of the thirty-two main groups of soils described by the USDA (2010) classification are found, with a percentage of occurrence in the samples as follows: Calcids (49%), Xerolls (29%), Fluvents (15%) and Orthents (7%). According to USDA (2010), soils in the area have an aridic moisture regime and a thermic temperature regime, with rainfall and annual average temperature of 223.5 mm and 18.4 °C, respectively and evapotranspiration of 912 mm.

These soils have been formed over the different materials of the area (I.G.M.E., 1974), which, in order of abundance, are quaternary sediments (41%), metamorphic and/or volcanic rocks (24%), limestones, dolomites and sandstones (20%) and alluvial deposits (15%). As regards soil uses, soils devoted to agriculture, both intensive farming and extensive farming, as well as urban soils and those supporting industrial or mining activities (or being devoted to such activities in the recent past) have been considered under "anthropic use", while soils where the natural vegetation cover has been preserved are classified under "natural use".

2.2. Soil sampling

For the general characterization of the study zone, samples were taken by hand from the arable layer of the soil (0–30 cm) in 41 sites in 2008, after establishing a 3 × 3 km grid size (Fig. 1), where different soil uses and types are represented, as well as the diversity of parent materials from which those soils have developed. Sample density was designed following the recommendations given by Boulaine (1980) and those gathered by SECS (2002). Samples were taken in the autumn season. Each sample comprised subsamples taken from three different points. The samples were air-dried and sieved to 2 mm for subsequent analysis in the laboratory. The soil samples were analyzed in triplicate to ascertain the reproducibility of the analytical results.

2.3. Soil analyses

The indicators were selected on the basis of the "key soil indicators for quality assessment" (Arshad and Coen, 1992; Doran and Parkin, 1994b; Gregorich et al., 1994; Larson and Pierce, 1994; Carter et al., 1997; Karlen et al., 1997; Martin et al., 1998) and considering our own knowledge and experience in the study area.

2.3.1. Chemical parameters

The chemical parameters were determined as follows: organic carbon (OC) content according to Anne (1945) and modified by Duchaufour (1970); Total Nitrogen (TN) by Kjeldahl's method, as described by Duchaufour (1970); pH in a 1:1 suspension of soil in water (pHw); pH in a 1:1 suspension of soil in 1 M KCl solution (Anderson and Ingram, 1993); Electrical Conductivity (EC) in a soil–water ratio of 1:5 (Andrades, 1996); total carbonates ($CaCO_3$) by volumetric analysis using a Bernard calcimeter (USDA, 1996); cation exchange capacity (CEC) by means of the method described by USDA (1996); sodium, potassium and magnesium cations by atomic absorption (USDA, 1996); and phosphorus by Watanabe and Olsen's method (USDA, 1996). The elements, iron, copper, manganese and zinc, were determined by atomic absorption after extraction with a solution of 0.05 M DTPA, 0.01 M $CaCl_2$ and 0.1 M triethanolamine at pH 7.3 (USDA, 1996). The dehydrogenase activity (DH) was determined by the method of Trevors et al. (1982) and modified by García et al. (1993).

2.3.2. Physical parameters

The particle size distribution (clay, silt and sand) of the soil samples was determined by Robinson's pipette method, as described by USDA (1996).

Aggregate stability (AS) <2 mm was determined using the method described by Lax et al. (1994), and the water retained at 1/3 atm ($pF_{1/3}$) and 15 atm (pF_{15}) was determined by Richard's membrane method