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Microbiological degradation index of soils in a semiarid climate

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Abstract

Soil degradation and desertification affect many areas of the planet. One such area is the Mediterranean region of SE Spain, where the climatological and lithological conditions, together with the relief of the landscape and anthropological activity, including agricultural abandonment, are responsible for increasing desertification. It is therefore considered to be of extreme importance to be able to measure soil degradation quantitatively. The aim of this study was to make a microbiological and biochemical characterisation of different soil catenas in SE Spain, including in a wide range of plant cover densities in an attempt to assess the suitability of the parameters measured to reflect the state of soil degradation and the possibility of using the parameters to elaborate a microbiological degradation index (MDI) valid for use in semiarid climates. For this, several indices related with the organic matter content (total organic carbon, TOC, water-soluble carbon, WSC, and water-soluble carbohydrates, WSCh), with the size of microbial populations (microbial biomass carbon, MBC) and related activity (respiration and enzymatic activities) were determined in the soils of three different catenas in different seasons of the year. The values of these parameters were seen to be closely related with the degree of vegetal cover, forest soils with a high cover value showing the highest indices. There was a highly significant positive correlation ($p < 0.01$) between the TOC and WSC content, and other parameters such as MBC, ATP, dehydrogenase activity and the activity of different hydrolases (urease, protease, phosphatase and β-glucosidase). The results show that the parameters analysed are a good reflection of a soil's microbiological quality since the soils with the worst characteristics (saline and with low organic matter and nutrient content) showed the lowest values. The study provides a soil degradation index based on its microbiological properties: MDI. This index is a function of the following five parameters, which showed the greatest weight in the factorial analysis made with all the parameters analysed: dehydrogenase activity, WSCh, urease activity, WSC and respiration.

Keywords: Soil degradation index; Soil respiration; Water-soluble C; Water-soluble carbohydrates; Enzymatic activities; Semiarid soils

1. Introduction

Desertification is the degradation of soils in arid, semiarid and dry subhumid areas, resulting from several factors, including climatic change and human activity (Article 1, UN Convention of the fight against desertification). It is of global importance since it affects about 40% of continental areas. In Spain the risk of desertification is considered high in 31.49% of its surface area, almost all in the Mediterranean region (website of Spanish Ministry for the Environment). Soil degradation is a serious problem because the soil fulfils several vital functions: (i) it is the growth medium of plants, acting as physical support and reservoir of water and essential nutrients; (ii) it regulates the flow of water in the environment and (iii) it has a certain capacity to attenuate the harmful effects of contaminants by means of physical, chemical and biological processes. In natural conditions, the soil tends to maintain an equilibrium between pedogenetic properties (Parr and Papendick, 1997). However, this equilibrium is easily upset by human activity (for example, agricultural abandonment) and this effect is aggravated in semiarid regions, such as SE Spain, by climatic conditions, which include an annual rainfall of 300 mm, most in torrential form and of great erosive potential, and a mean temperature of 18 °C (López Bermúdez and Albaladejo, 1990). In such conditions, the scarcity of water

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limits vegetation and, consequently, the entry of organic matter into the soil (García et al., 1997), triggering in many cases degradation.

Soil quality and its degradation depend on a large number of physical, chemical, biological, microbiological and biochemical properties, the last two being the most sensitive since they respond rapidly to changes (Dick and Tabatabai, 1993; Trasar-Cepeda et al., 1998; Ros et al., 2003). The microbiological activity of a soil directly influences ecosystem stability and fertility (Smith and Papendick, 1993) and it is widely accepted that a good level of microbiological activity is essential for maintaining soil quality. However, it should be remembered that a soil's microbiological activity is a mosaic of metabolic processes that cannot be assessed from one parameter alone, but only from a variety of parameters (Nannipieri et al., 1990).

Some fractions of the organic matter, for example WSC, are easily degraded by microorganisms since they act as energy source (Cook and Allan, 1992) and so it is useful to study them when analysing the soil's microbial activity (Biederbeck et al., 1994; García et al., 2000; Pascual et al., 2000). Microbial biomass carbon (MBC) is useful for evaluating microbial population size and this parameter has been considered in the evaluation of natural and degraded systems (Ross et al., 1982), although such activity can also be evaluated by parameters like ATP (Nannipieri et al., 1990) and respiration. Enzymatic activities are biological catalysts of essential processes in the life of microorganisms, and the simultaneous measurement of several of these activities may be useful when studying the level of bioactivity in a soil (Nannipieri et al., 1990). Among these activities are those related with the N (urease and BAA-protease), P (phosphatase) and C (β-glucosidase) cycles (Harris and Birch, 1989; García et al., 1994, 2002). Other enzymatic activities provide a more general knowledge of microbiological activity. For example, García et al. (1994) showed that dehydrogenase activity is a clear indicator of the microbiological status of soils in semiarid zones subject to processes of degradation and desertification.

Soil is an environmental and economic resource and preserving it from degradation and desertification is, in purely financial terms, more cost effective than attempting to remediate the environmental, social and economic consequences of not doing so. However, the question arises as to when action should be taken and to answer this we need objective tools that will tell us the exact state of a soil and whether any treatment is necessary: in other words, we need a soil degradation index. The literature describes several indices for soil quality and fertility (Stefanic et al., 1984; Beck, 1984; Karlen et al., 1998; Trasar-Cepeda et al., 1998; Andrews et al., 2002), but none identifies levels of degradation that could be used to know when a soil, for whatever reason (whether of anthropic or natural origin), has reached a state of degradation that affects it functionality.

The objective of this work was to microbiologically and biochemically characterise a wide range of soils of different characteristics and densities of vegetal cover in an attempt to establish the suitability of the parameters measured for reflecting the degree of soil degradation and the possibility of establishing a microbiological degradation index (MDI) for use in semiarid climates.

For this, several indices related with the organic matter content (total organic carbon, TOC, water-soluble carbon, WSC, and water-soluble carbohydrates, WSCh), and with the size of microbial populations MBC and their activity (ATP, respiration and enzymatic activities) were established in three catenas of SE Spain in three seasons of the year.

2. Materials and methods

2.1. Studied areas and soil sampling

Three soil catenas were chosen (Santomera, Abanilla and Los Cuadros), all situated in the province of Murcia (SE Spain), which offered a wide range of plant cover density, from practically bare soils to forest soils with a high percentage of plant cover. All the sites suffered agricultural abandonment many years ago, in some cases more than 40 years. Some sites were reforested with *Pinus halepensis* Millar. Three sampling zones were established in Santomera: a zone with a high plant cover density, where forests of *P. halepensis* Millar predominated (SF); a zone with a much less dense cover, where shrubs were predominant (SS) and, lastly a zone of degraded vegetation with almost bare soils (SB). In Abanilla, the catena possessed soils of high electrical conductivity (Table 1) and plant species that differed from those of the Santomera catena (Table 2). We selected a zone with a high density of cover (AHc) dominated by *Gramineae*, a zone of medium density (AMc), a third zone (AE) with quite a dense cover of *Gramineae* and esparto grass, and a fourth, almost bare zone (AB). In Los Cuadros, two of the zones chosen had a dense cover, having undergone reforestation with *P. halepensis* 20 (LCYF) and 40 (LCOF) years previously, one had quite a high density of shrub cover (LCSH) and the last one was an almost bare soil that had been left fallow for many years (LCB).

Sampling sites were divided in three plots with an approximate area of 1000 m^2 each. The sample from each plot was composed of 12 homogeneously mixed subsamples in an attempt to minimise the spatial variability of soil. Samples were taken from the top 15 cm in spring, summer and autumn. The results in this paper correspond to the mean of three plots of each sampling site. The vegetal remains were removed to prevent them from influencing the measurements made and the samples were sieved (2 mm) and kept at 3 °C. ATP was measured immediately after sieving.