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Sensitivity of different soil quality indicators to assess sustainable land management: Influence of site features and seasonality

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ABSTRACT

The turnover rate of labile organic fractions varies continuously due to different soil uses and managements, weather conditions and sampling time. The aim of this study was to quantify the effect of different agricultural management, season and soil type on soil organic carbon (SOC) and its different fractions. The study was conducted on four sites located in the Argentinean Pampas. In each site, three treatments were defined: Good Agricultural Practices (GAP), Poor Agricultural Practices (PAP) and Natural Environment (NE). During two consecutive years (2010 and 2011) and at two different times (February and September) undisturbed soil samples were taken at 0–20 cm depth. Variables assessed included: SOC and its organic fractions: coarse (POC_c) and fine (POC_f) particulate organic carbon, SOC associated with a mineral fraction (MOC), total (CHt) and soluble (CHs) carbohydrates, bulk density (BD), and large pores ($P_{>30}$). Also, indices associated with soil and management variables were determined. SOC reductions caused by agricultural practices were mainly from POC_c. This fraction represented 34–52% and 50–74% for PAP and GAP, respectively, of the observed in NE. The carbon pool index (CPI) shows that agricultural treatments induced greater variations in all the labile organic fractions compared with SOC and MOC. In turn, the magnitude of variability was different among fractions, where temporal fluctuations increased according to the following order $MOC < SOC < POC_f \leq CHt < CHs \leq POC_c$. Independently of the soil type, the CPI was a sensitive indicator of soil quality in these systems under no-tillage. The multivariate analysis has proven to be an efficient analytical methodology for the identification of soil indicators that respond to agricultural practices, in which chemical properties (POC_f and CHt), physical (BD and $P_{>30}$), and indices (SOC: clay, structural index and intensification sequence index) were the variables that best explained the total variance of information of the four sites. Therefore, these indicators/indices should be included in any minimum data set for evaluating the agricultural soil quality under no-tillage in the studied area.

1. Introduction

Land use for agricultural purposes causes soil degradation, therefore there is great concern regarding the quantification of loss of soil quality generated by agricultural management (Lal et al., 1998). Among the different practices, conservation agriculture aims to preserve the soil structure, productivity and biodiversity throughout three fundamental principles: reduced tillage or no-tillage, cover crops and crop rotation (ECAF, 1999).

The intensification of land use is growing worldwide because of the need of food, increasing the magnitude and intensity of the deterioration becoming in unsustainable agroecosystems. In the Pampean Region of Argentina, this effect is accentuated by a decrease in the surface covered by crop-pasture rotation systems and growth of the areas dedicated to annual agricultural cropping systems where soybean (*Glycine max* [L.] Merr.) monoculture predominates (Caviglia et al., 2011), negatively affecting soil quality. These land-use changes are frequently associated with a reduction in the levels of soil organic carbon (SOC), due to two

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facts: the former is that an important part of the biomass produced is exported with the harvest (reduced carbon input) and the latter is the occurrence of an enhanced decomposition after physical disturbance (Poeplau et al., 2011) or by fallow periods (Sasal et al., 2010). These changes significantly alter the SOC dynamics (Raiesi, 2006) that trigger negative effects on the physical, chemical and biological properties of the soil (Li et al., 2009). In the Pampean Region, approximately one third of the SOC content was lost due to the unsuitable agricultural practices (Álvarez, 2005). In turn, different management practices including restoration of permanent vegetation, maximization of residue carbon input, a reduction of area under fallow management and improvement of water administration may increase SOC contents of cultivated soils (Lal, 2004).

Due to the necessity of reverting the deterioration processes, and to get knowledge about it a joint effort with BIOSPAS project (Wall, 2011) was conducted to study physical, chemical and biological quality of soils with different managements assessed in farmers' fields, adjusted or not to the criteria defined by the Program of Certification of Good Agricultural Practices (http://www.aapresid.org.ar/ac/buenas-practicas-agricolas). For this purpose, different agricultural soils from fields with Good Agricultural Practices were compared to neighbor fields with non-sustainable managements and, in addition, non-agricultural soils were used as reference. This block of three treatments was replicated at four different locations, in the most productive central area of agriculture in the Argentinean Pampas, in a 400 km east-west transect. The same physical soil sample was used for a set of different analyses (Wall, 2011). This experimental design was useful to describe differences with regard to microbial diversity, and biochemical characteristics of soils because for the different soil use and management (Figuerola et al., 2012, 2015; Agaras et al., 2014; Ferrari et al., 2015). In this context, we focused in this work on the assessment and analyses of SOC under different forms.

The SOC comprises several fractions with different physical and chemical properties and consequently different stabilization degrees by specific mechanisms with particular turnover rates. To determine the effect of management practices or soil uses on SOC, it is essential to quantify and understand the sensitivity of the different organic fractions toward this disturbance (Martin et al., 1990). These organic fractions are mainly defined by their turnover times ranging from years to millenniums (Bol et al., 2009). The organic fractions associated with particle sizes >50 μm are easily available for microorganisms and thus rapidly degradable (Zimmermann et al., 2007). In the short-term, the organic fractions associated with the sand fraction show alterations that are the result of changes in the management practices (von Lützow et al., 2007). There are labile organic fractions such as the particulate organic carbon (POC, between 53 and 105 μm) and the total carbohydrates (CHt) that respond more rapidly than the SOC to the changes produced by different soil managements (Duval et al., 2013). However, the exchange rate of these fractions varies continually (Graham et al., 2002). Therefore, apart from the effects caused by the different soil uses and managements, there are factors such as climatic conditions and sampling times (season of the year) that may also affect the most labile organic fractions (Puget and Lal, 2005).

Possible options for increasing efficiency and productivity of current agricultural systems include agricultural intensification by greater use of resources (Caviglia and Andrade, 2010), involving annual double cropping and crop rotation with pastures and/or cover crops (Caviglia et al., 2004). To characterize systems with different soil use intensities, there exist several indices that include the number of months with growing crops or the frequency of a specific crop in the cropping sequence (Caviglia and Andrade, 2010; Novelli et al., 2011). Hence, natural grasslands may be characterized by high intensification indices in soil use compared with the sequences consisting of long periods of fallow based on annual crops (Sasal et al., 2010). Also, several indices and relationships related to SOC have been proposed for soil quality evaluation (Blair et al., 1995). These indices are early and efficient indicators of changes in soil quality caused by the production system (Bayer et al., 2009), even before the change in SOC contents is observed. The indices include the carbon pool index (CPI) that relates the SOC content of the soil under agricultural practice to a reference soil, which is generally under its natural vegetation (Blair et al., 1995). This is an efficient indicator of soil quality both in tropical (Vieira et al., 2007; Bayer et al., 2009) and temperate climates (Blair et al., 1995). Other authors suggest the relationships between SOC and POC, and the fine fraction of the soil (silt + clay) as indicators of the effect of agricultural practices (Galantini et al., 2004; Noellemeyer et al., 2006). These indices may provide a useful parameter to assess soil quality in different production systems or under different management practices (Blair et al., 2006; Verma and Sharma, 2007).

In general, long-term effects of soil management practices on the evolution of soil quality have been closely related to SOC contents (Franzluebbers et al., 1995; Roldán et al., 2005), while for

Table 1
Soils characteristics (0–20 cm) for each of the different sites and treatments at baseline sampling.

	Bengolea			Monte Buey			Pergamino			Viale		
	NE	GAP	PAP	NE	GAP	PAP	NE	GAP	PAP	NE	GAP	PAP
Climate	Temperate subhumid			Temperate subhumid			Temperate humid			Temperate humid		
MAT[a] (°C)	17			17			16			18		
MAR[b] (mm year^{-1})	870			910			1000			1160		
Soil Taxonomy[c]	Entic Haplustoll			Typic Argiudoll			Typic Argiudoll			Argic Pelludert		
	0–20 cm											
Sand (g kg^{-1})	594	555	577	169	208	196	179	185	178	26	22	32
Silt (g kg^{-1})	284	306	293	570	578	578	622	587	605	609	519	588
Clay (g kg^{-1})	122	139	130	261	214	226	200	228	217	365	459	380
Texture	Sandy loam			Silty loam			Silty loam			Silty clay loam		
SOC (g kg^{-1})	13.5	12.6	9.2	27.1	16.3	15.1	20.5	14.8	16.7	38.7	29.7	20.1
Nt (g kg^{-1})	1.24	1.24	1.02	2.47	1.49	1.18	1.82	1.30	1.24	3.06	2.18	1.54
pH	6.5	6.3	6.2	5.8	5.8	6.2	6.5	6.2	5.7	6.7	7.1	6.6

NE: Natural Environment; GAP: Good Agricultural Practices; PAP: Poor Agricultural Practices; SOC: soil organic carbon; Nt: soil total nitrogen.
[a] MAT: mean annual temperature.
[b] MAR: mean annual rainfall.
[c] (Soil Survey and Staff, 2010).