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Analysis of organic fractions as indicators of soil quality under natural and cultivated systems

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ABSTRACT

Soil organic matter (SOM) or carbon (SOC) is the most important component of the soil and it is composed of fractions with different lability. Particulate organic carbon (POC) and carbohydrates (CH), among others, are the most sensitive to changes in crops and soil management practices. The purpose of this study was to analyze different soil parameters aimed for the evaluation of management practices effects under widely different soil and climatic conditions. Soils were located along a West–East transect in the most productive region of the Argentinean pampas: [West] Bengolea and Monte Buey (Córdoba), Pergamino (Buenos Aires) and Viale (Entre Rios) [East]. Three treatments were defined according to land use: "Good agricultural practices" (GAP): sustainable agricultural management under no-till; "Poor agricultural practices" (PAP): non-sustainable agricultural management under no-till; "Natural environment" (NE): rangelands long as reference situation. Samples were taken at 0–10 and 10–20 cm depths. SOC was determined in different particle size fractions: 105–2000 μm (coarse particulate organic carbon, POC_c), 53–105 μm (fine particulate organic carbon, POC_f), and 53 μm (mineral-associated organic carbon, MOC). Total (CH_t) and soluble (CH_s) carbohydrate contents were also determined. The SOC level in NE was decreasing from the East (27.3 g kg^{-1} in Viale) to the West (13.3 g kg^{-1} in Bengolea), following the rainfall and texture gradient among sites. The POC_c/SOC and $POC_c + POC_f$/SOC ratios in the NE showed differences among sites, suggesting different dynamic depending on the environmental characteristics at the different locations. The SOC levels in the upper layer of agricultural soils were 16–44% lower than natural ones. Carbon stocks were estimated for an equivalent mass of soil (950 and 2350 Mg ha^{-1}) in order to consider differences in bulk densities among different treatments. Mean values were significantly different ($p < 0.001$) for the different management practices: NE (26.6 Mg ha^{-1}) > GAP (20.1 Mg ha^{-1}) > PAP (16.3 Mg ha^{-1}). In general, labile organic fractions showed differential sensitivity. Fractions with an intermediate dynamic, as POC_f (53–100 μm) and CH_t, seem to be better indicators to detect the short- and medium-term management effects than more dynamic fractions.

1. Introduction

Soil quality has gained attention in recent years due to environmental problems related to land degradation and sustainable production considerations of the different cropping systems. Main concern has been focused on soil quality definition and on development of techniques for evaluation of this quality. With regard to the definition of soil quality, in recent years the soil has been recognized as key factor in crop production and also in water and atmospheric purification. According to Nortcliff (2002), the definition of quantitative indexes for soil quality is an important challenge for science. Especially, when many changes take place over the long-term and the soil quality changes can only be perceived when all the effects are combined over a period of time.

There is currently no general consensus regarding the soils that should be considered of maximum quality. The different approaches to the latter point can be summarized in two options. The first considers that a maximum quality soil is the soil in equilibrium with all the components of the environment, i.e. a

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climax soil developed under climax vegetation. The second option considers that the maximum quality reference soils are soils capable of maintaining high productivity and of causing the minimum of environmental distortion.

The use of climax soils as the highest quality soils is not new; it was suggested by Fedoroff (1987) for the evaluation of soil degradation, and is based on the fact that freely developed soils reach an equilibrium amongst their properties that leads to long-term stability in natural ecosystems. Rassmussen et al. (1989) used them for comparing different soil management systems, Cook and Hendershot (1996) did it in the establishment of admissible levels of lead pollution, Leirós et al. (1999) did it to evaluate the level of soil degradation from different practices, and Sanchez-Marañon et al. (2002) to study the effects of change in soil use on the quality of Mediterranean mountainous ecosystems.

The influence of agriculture on soil quality may be inferred through the measurement of soil attributes or parameters that are indicators of quality which may allow comparisons with non-agricultural soils or between different soil management (Bredja et al., 2000).

During the last 25 years there has been a big expansion of no-till management in Argentina modifying agricultural and cattle practices driven by lower production costs, higher yields and incorporation of the less productive areas for crop production (Derpsch et al., 2010).

In addition, and because of favorable market conditions, a substantial portion of that area is presently dedicated to soybean monoculture, often combined with minimal nutrient restoration. Soybean (*Glicine max*) cultivation in Argentina currently account for over 60% of the total cultivated area (MAGyP, 2011), while the area devoted to winter crops has declined to meet only 20–25% of the cultivated area. The negative impact on the content of soil organic matter (SOM) or carbon (SOC), which occurs when soybean is the main crop of the rotation compared to crops such as wheat (*Triticum aestivum*), corn (*Zea mays*) or sorghum (*Sorghum bicolor*) has been described by several authors in different regions of the world (Havlin et al., 1990; Studdert and Echeverria, 2002). Nevertheless, it is not well known the effects of monoculture on the chemical, physical and biological characteristics of soil. The new challenge in Argentina is to maintain soil fertility and sustainability while the monoculture prevails over the crop rotation (Cook, 2006).

The reduction in the intensity of soil tillage under no-till (NT) practices systems and the use of crops to maximize the amount of residue left on the surface are commonly used management practices to maintain or increase SOC (Martino, 1997; Six et al., 1999; Bayer et al., 2000; Galantini et al., 2008; Ferrari et al., 2010). Reviews of long-term experiments have shown that NT systems had, in general, higher SOC than tillage systems (Franzluebbers, 2002). Galantini and Iglesias (2007) found 17% higher SOC content in NT than in conventional tillage as mean results of 40 independent experiments developed in Argentina. However, rates of SOC accumulation found under NT have been highly variable, since its dynamics not only depend on soil management, but also on its mineralogy, climatic conditions, amount of residues and nitrogen (N) inputs. Baker et al. (2006) and Blanco-Canqui and Lal (2008) found no differences in the accumulation of carbon (C) between till and no-till systems.

Crop rotation changes the amount, timing and quality of organic debris introduced into the soil (Campbell et al., 1999), which has an effect on the size, rate of recycling and the vertical distribution of C and N compartments (Franzluebbers, 2002). Different authors agree that crop rotation improves the carbon balance in the soil (Gregory and Drury, 1996; Miglierina et al., 2000; Thomas, 2003; Andriulo et al., 2008; Galantini et al., 2008), although in some studies it was found no effects of rotation on the monoculture in the stocks of C and N in the soil (Lattanzi et al., 2005). This little or no variation reported between two contrasting management practices may be due because the authors were comparing masses of C and N from different soil masses (Ellert et al., 2001; Lee et al., 2009). This comparison does not take into account the effect of changes in bulk density with depth due to different managements. Thus, it has been recommended that comparisons should be made on the basis of the same mass of soil (Lal et al., 1998).

Most studies agree that SOC is the main indicator and certainly the one that has a significant influence on soil quality and productivity (Quiroga et al., 2005). The total SOC content and its fractions are important attributes of soil quality (Gregorich et al., 1994).

The SOC and its different fractions are soil parameters highly influenced by management practices (Haynes, 2005). Mainly the young or labile SOC fraction is key to interpret changes in quality (Kapkiyai et al., 1999), being a more sensitive indicator than the SOC and total nitrogen (N_t) (Biederbeck et al., 1998).

However, the physical conditions of soil and climate must be considered as factors that have a strong influence on the labile C fractions (Galantini and Rosell, 2006). Another variable that would detect changes in the carbon contribution in the short-term are soluble carbohydrates (CH_s). These are caused by soil microorganisms and crop residues, which among others are actively involved in soil aggregation (Liu et al., 2005).

Currently, in conventional tilled agriculture soils, the SOC levels are low to the limit of supporting physically fit and optimum nutrient supply. This decline has been linked to processes of degradation and has caused serious problems in much of Argentinean farmland (Michelena et al., 1989). Nowadays, no-till, crop rotation, the efficient use of agrochemicals and biotechnology are used as tools to achieve new levels of production. SOC by itself it is a poor indicator of soil quality, mainly to show short-term changes. The only way to optimize the use of these tools is through a more comprehensive understanding of the functioning of the productive system. SOC fractions and dynamics can be an adequate indicator to evaluate the effects of different agronomic practices and better tools when defining the most appropriate agronomic practices. The aim of this work was to analyze different SOC fractions as potential sensitive indicators to evaluate different agricultural management practices along a gradient of sites with different soil textures and climate conditions.

2. Materials and methods

2.1. Study site

This research is part of BIOSPAS project (Biology of Soil and Sustainable Agricultural Production, www.biospas.org).

The management and sites for this study were selected after thoughtful discussion between scientists and farmer participants of the Project. In turn, they were defined taking into account a series of working definitions of soil management in accordance with a set of descriptions of Agriculture Certified by Aapresid (www.aapresid.org.ar).

We selected four study sites with documented history of no-till management located across a West-East transect in the most productive region in the Argentinean pampas that correspond to different climate and soil conditions. The study sites were located at Bengolea (Cordoba; latitude 33° 01′ 32.9″ S, longitude 63° 37′ 36.4″ W), Monte Buey (Cordoba; latitude 32° 58′ 17.0″ S, longitude 62° 27′ 02.4″ W), Pergamino (Buenos Aires; latitude 33° 56′ 42.6″ S, longitude 60° 33′ 35.6″ W) and Viale (Entre Rios; latitude 31° 52′ 42.2″ S longitude 59° 41′ 16.2″ W).

Table 1
Data averages of temperature and precipitation sites.

Climate	Bengolea	Monte Buey	Pergamino	Viale
Annual rainfall (mm)	880	930	1000	1165
T (°C)	16.9	17.2	16.7	18.4
T_{max} (°C)	23.0	23.6	22.8	23.9
T_{min} (°C)	10.8	10.8	10.6	12.7

Mean annual temperature (T), maximum (T_{max}) and minimum (T_{min}).

The most relevant climatic conditions of each site are shown in Table 1.

Pergamino soils are Typic Argiudoll with silt loam in the surface horizons and silty clay loam in the deeper layers. Monte Buey soils are represented by Typic Argiudoll silt loam. The soils of Bengolea are Entic Haplustolls with sandy loam texture in the surface horizons and loamy subsurface, being limited by climate and low water holding capacity due to coarse texture. Viale soils are Vertic Argiudoll whose surface texture is silty clay loam and clay loam in subsurface soils, being characterized by poor drainage.

As treatments, different situations were studied at each sampling location:

"Good Agricultural Practices" (GAP): sustainable agricultural management under No Till, subject to intensive crop rotation, nutrient replacement and minimal use of agrochemicals (herbicides, insecticides and fungicides).

"Poor Agricultural Practices" (PAP): Non-sustainable agricultural management under No Till, minimal rotation or monoculture, low nutrient replenishment and high use of agrochemicals (insecticides, herbicides and fungicides).

"Natural Environment" (NE): soil without cultivation as reference situation near to cultivated plots.

2.2. Soil sampling

Samples were taken in February 2010 (summer). At each site-treatment situation, 3 subsampling points were localized using GPS for subsequent sampling. At each point, a homogenized sample was prepared by mixing between 16 and 20 soil cylinders randomly collected, at depths of 0–10 cm and 10–20 cm. Undisturbed soil samples were also taken from 0 to 5, 5 to 10, 10 to 15 and 15 to 20 cm depths by cylinders 5 cm in height and 4.7 cm in diameter to calculate the bulk density (BD). Two replicates were taken for each sampling point.

2.3. Soil chemical and physical analyses

The soil samples were air-dried and then passed through a 2 mm sieve. The following chemical determinations were made: total soil organic carbon, SOC by dry combustion (LECO Carbon analyzer) and total and soluble carbohydrates (Puget et al., 1999).

The contents of SOC and its fractions were transformed into values of stocks using the following equation (Ussiri et al., 2006; Andriulo et al., 2008):

$$C(\text{Mg}\quad \text{ha}^{-1}) = \left(\frac{X}{100}\right) \cdot \text{BD} \cdot d \cdot 10^4 \quad \text{m}^2 \quad \text{ha}^{-1}$$

where X is the content of SOC or its fractions (%), BD is bulk density (Mg m^{-3}) and d is the soil thickness (m).

Ellert and Bettany (1995) have described the advantages of evaluating the management-induced changes in SOC referring to equivalent soil masses. Andriulo et al. (2008) used 2500 Mg ha^{-1} of soil to make comparisons on equivalent masses of soil to compare the C and N stocks under different tillage systems and crop sequences. In this study, carbon stocks were also calculated for an equivalent soil mass (950 and 2350 Mg of soil ha^{-1}) according to Ellert and Bettany (1995) and Andriulo et al. (2008).

The samples collected for soil BD were dried at 105 °C until constant weight. Soil BD was then calculated by dividing the dry weight by the soil core volume (Blake and Hartge, 1986).

Silt + clay content was estimated by the difference between the fine fraction content (0–0.053 mm) minus its organic matter, assuming a 58% of carbon content (MOC/0.58).

2.4. Physical fractionation

For the size fractionation of SOC, we used the wet sieving of soil (Cambardella and Elliott, 1992; Galantini, 2005). Briefly, 50 g of soil previously air-dried and sieved (2 mm) were dispersed in glass containers of 120 mL, and mixed with 100 mL of distilled water. Ten glass beads (5 mm diameter) were added to increase aggregate destruction and reduce potential problems created by different content of sand (Cambardella and Elliott, 1992). The samples were subjected to mechanical dispersion through a rotary shaker for approximately 16 h (over night at 40 rpm) to disintegrate the aggregates. The sieving was done with a pair of sieves of 53 μm and 105 μm of diameter mesh, making moves back and forth until the water coming out through the sieve was clear to the naked eye. Three fractions were obtained:

- The coarse fraction (105–2000 μm) containing coarse particulate organic carbon (POC_c) and fine to coarse sands.
- The medium fraction (53–105 μm) which included fine particulate organic carbon (POC_f) and very fine sand.
- The fine fraction (<53 μm) containing mineral associated organic carbon (MOC) as well as silt and clay minerals.

The material retained in each sieve was transferred by means of water-jets to aluminum pots, and oven-dried at 105 °C for 24 h for later weighing. Carbon content of POC_c and POC_f was determined in the same way as the SOC. The difference between SOC and ($POC_c + POC_f$) was used to calculate the organic carbon content of the <53 μm (MOC).

2.5. Determination of total and soluble carbohydrates

Extraction of carbohydrates was performed employing two different samples. Total carbohydrates (CH_t) extraction was performed by an acid hydrolysis as follow: 1 g of soil sample was treated with 10 ml 0.5 M H_2SO_4, heated at 80 °C for 24 h.

In the other sample, soluble carbohydrates (CHs) extraction was carried out as follow: 1 g of soil sample was suspended in 10 ml of distilled water and heated at 80 °C for 24 h. After the extraction with hot water, H_2SO_4 was added to obtain a 0.5 M concentration as in the dilute acid hydrolysis procedure, and immediately processed.

After extraction by each way, each suspension was centrifuged at 4000 rpm during 15 min (Angers and Mehuys, 1989; Puget et al., 1999). Carbohydrate contents of the extract were determined by spectrometry using the antrona spectrometric method with glucose as the standard (Brink et al., 1960).

2.6. Statistical analysis

All data in tables and figures are presented as means. Differences of results as affected by treatments were tested by analysis of variance using Fisher's LSD_{05} mean separation test at $p < 0.05$. Correlation analysis was performed between the variables studied. Statistical analysis was performed with INFOSTAT software (Di Rienzo et al., 2008).

3. Results and discussion

3.1. Natural environments

The SOC level in NE was higher in the East (27.3 g kg^{-1} Viale) than in the West (13.3 g kg^{-1} in Bengolea), following the rainfall and texture gradient among sites (Table 2). The silt + clay content varied between different sites in the same way, from Viale (860 g kg^{-1}) to Monte Buey and Pergamino (724 g kg^{-1}) and to Bengolea (314 g kg^{-1}).

Several studies showed the influence of texture on the SOC contents and quality (Buschiazzo et al., 1991; Galantini et al., 2004). As fine material increases, greater protection of SOC is offered (Van Veen and Kuikman, 1990) due to the association between inorganic particles and the most transformed organic molecules (Wander, 2004).

In these natural environments, as in other studies conducted in the semiarid Pampean region, the SOC was significantly correlated with clay + silt content (Buschiazzo et al., 1991). Clay + silt contents showed correlation with all soil organic fractions, however, the correlation was stronger with the most recalcitrant organic fraction (MOC) than with labile ones (COP$_c$ and COP$_f$). As fine particle content increases (0–53 μm) organic materials attracted to mineral particles becomes greater, i.e. stable organo-mineral complexes were more abundant due to physical and biological protection (Galantini et al., 2004; Quiroga et al., 2005).

The distribution of organic fractions was also variable in the different studied sites. Considering the average values for all the samples of the same location, independently of the different treatments, the variation was greater in the POC$_c$ (Monte Buey $\geq$ Bengolea $\geq$ Viale $\geq$ Pergamino) than in the POC$_f$ (Bengolea $\geq$ Monte Buey $\geq$ Viale $\geq$ Pergamino), probably because the POC$_c$ fraction was less transformed and more variable and more dependent on dry matter input from plant debris than POC$_f$.

The organic fraction relationships showed statistically different changes among sites (Table 3). The POC$_c$ + POC$_f$/SOC relationship was higher in sandy soils than fine textured soils. When sand content increased, SOC decreased, as was previously discussed and particulate organic materials became more abundant than in fine textured soils. In Bengolea sandy soil, under low precipitation and low net primary productivity, there were differences in the dynamics of available nutrients and soil water. Because of this, the rate of transformation of organic materials incorporated into the soil could be lower than in the others sites. On the other hand, greater rainfall and silt + clay content likely increased the contributions of C from plant debris, which was reflected in a higher content of SOC, and increases the transformation of the organic materials, which would be reflected in the lower ratio POC/SOC.

Pergamino and Monte Buey had similar climatic and soil characteristics. However, Pergamino soil series (silty loamy, 227 g kg^{-1} and 648 g kg^{-1} of clay and silt, respectively) presented a high content of phytoliths in silt fraction (around 50% in A horizon), which could have had a significant impact on organic materials transformation and stabilization (Pecorari et al., 1990) compared to Monte Buey.

Table 3
Relationship of organic fractions and the silt + clay content of the natural soil at 0–20 cm depth.

Site	POC$_c$/SOC	POC$_{c+f}$/SOC	SOC/s + c	MOC/s + c
Bengolea	0.22 b	0.51 c	4.24 a	2.07 a
Monte Buey	0.16 b	0.33 b	3.36 a	2.28 a
Pergamino	0.06 a	0.17 a	2.99 a	2.49 a
Viale	0.07 a	0.19 a	3.18 a	2.57 a

For each relationship analyzed different letters indicate statistically significant differences between sites ($p < 0.05$), DMS test.

3.2. Effect of management practices on organic fractions

No significant interaction occurred between sites and treatments for total SOC and POC$_f$ in the 0–10 cm layer. For the rest of the analyses and depths, significant interaction was detected, probably due to the contribution and/or duration of the practices in each site.

Treatment differences in the 0–10 cm depth of all sites were similar for SOC (NE>GAP = PAP) and POC$_f$ (NE = GAP > PAP) (Table 4). Agriculture activity produced a significant drop of SOC levels. The management practices effect on SOC was not detected, however, differences were found in the particulate fractions.

The POC is a very labile fraction depending on dry matter input and the factors influencing their decomposition (climate, material quality and plant origin, and nutrient availability). The higher proportion of grass crops in the GAP rotation (approximately 60%), which provides more residues with highest C:N ratio into the system, led to improved POC$_f$ levels, while levels were lower in PAP due to the higher proportion of soybeans in the rotation (more than 70% in most cases), with less input of residues at soil and higher rate of decomposition (Table 4, averaged data).

The magnitude of the SOC decrease in the upper 20 cm as a result of the productive use varied among sites. The largest losses occurred in Monte Buey and Pergamino with approximate values of 40%, sites where the differences between GAP and PAP were lower than 6% (Table 4). Similar results were obtained by Andriulo and Cordone (1998), who indicated that the new balance of SOC in fine textured Argiudols of the Pampas was reached at 40–60% of the original level. According to Lal (2006), soil C losses are fast and sharp, whereas gains are slow and unsteady.

In Bengolea and Viale, SOC losses were lower and significant only in PAP (Table 4). In the first case, the most dynamic and labile fractions (POC$_c$ and POC$_f$) were found in greater proportion, therefore good management rapidly increased soil carbon levels (12.1 g kg^{-1} in GAP) and in turn inadequate management practices reduced it (9.9 g kg^{-1} in PAP). In the second case, the high content of fine material, especially clay, promoted the accumulation of organic matter due to different mechanisms of protection. The main mechanisms would be the adsorption of organic matter on the mineral particles (Oades, 1988), their encapsulation between clays (Tisdall and Oades, 1982) or its location within small pores inaccessible to microorganisms (Van Veen and Kuikman, 1990).

When analyzing the POC$_c$ in 0–20 cm depth (Table 4), although the trend was similar at all sites, the NE only differed ($p < 0.05$) from those cultivated in Bengolea (approximately 2.5 times less)

Table 2
Total organic carbon and fractions in natural soils at 0–20 cm depth.

Sites	SOC (g kg^{-1})	POC$_c$ (g kg^{-1})	POC$_f$ (g kg^{-1})	POC$_{c+f}$ (g kg^{-1})	Silt + clay (g kg^{-1})
Bengolea	13.3 a	3.24 bc	3.57 b	6.81 bc	314 a
Monte Buey	24.2 b	4.64 c	3.22 ab	7.86 c	720 b
Pergamino	21.8 ab	1.50 a	2.21 a	3.70 a	728 b
Viale	27.3 b	2.40 ab	2.81 ab	5.21 ab	860 c

For each parameter analyzed different letters indicate statistically significant differences between sites ($p < 0.05$), DMS test.
SOC, soil organic carbon; POC$_c$ and POC$_f$ particulate organic carbon in 105–2000 and 53–105 μm particle sizes, respectively.

Table 4
Total and labile carbon concentrations in 0–10, 10–20 and 0–20 cm.

	0–10 cm			10–20 cm			0–20 cm		
	NE (g kg^{-1})	GAP (g kg^{-1})	PAP (g kg^{-1})	NE (g kg^{-1})	GAP (g kg^{-1})	PAP (g kg^{-1})	NE (g kg^{-1})	GAP (g kg^{-1})	PAP (g kg^{-1})
Bengolea									
SOC	16.9 b	14.4 ab	11.9 a	9.8 b	9.9 b	7.8 a	13.3 b	12.1 ab	9.9 a
POC$_c$	5.13 b	2.50 a	1.69 a	1.35 b	0.46 a	0.46 a	3.24 b	1.48 a	1.07 a
POC$_f$	4.11 ab	4.49 b	2.83 a	3.02 b	2.63 b	1.74 a	3.57 b	3.56 b	2.28 a
Monte Buey									
SOC	30.6 b	18.3 a	15.5 a	17.9 b	12.5 a	12.4 a	24.2 b	15.4 a	14.0 a
POC$_c$	8.13 b	3.34 a	1.72 a	1.15 b	0.29 a	0.24 a	4.64 b	1.82 a	0.98 a
POC$_f$	4.51 b	2.60 a	2.07 a	1.93 b	1.27 ab	0.98 a	3.22 b	1.93 a	1.52 a
Pergamino									
SOC	32.1 b	17.5 ab	15.7 a	11.6 a	10.2 a	10.6 a	21.8 b	13.9 ab	13.1 a
POC$_c$	2.58 a	1.97 a	2.07 a	0.41 b	0.21 ab	0.17 a	1.50 a	1.09 a	1.12 a
POC$_f$	3.23 a	2.43 a	2.11 a	1.18 a	1.10 a	1.02 a	2.21 a	1.77 a	1.57 a
Viale									
SOC	35.2 a	34.1 a	24.8 a	19.4 ab	24.0 b	15.3 a	27.3 b	29.0 b	20.0 a
POC$_c$	4.24 b	1.83 a	2.23 ab	0.56 a	0.73 a	0.18 a	2.40 a	1.28 a	1.20 a
POC$_f$	4.33 a	4.03 a	2.17 a	1.29 b	1.32 b	0.83 a	2.81 b	2.68 ab	1.50 a
Average									
SOC	28.7 b	21.1 a	17.0 a						
POC$_f$	4.05 b	3.39 b	2.30 a						

For each depth and at each site different letters for each parameter analyzed indicate statistically significant differences between treatments ($p < 0.05$), DMS test. POC$_f$, fine particulate organic carbon; POC$_c$, coarse particulate organic carbon; SOC, total organic carbon; NE, natural environment; GAP, good agricultural practices; and PAP, poor agricultural practices.

and Monte Buey (approximately 3.5 times less). No differences were found between GAP and PAP. Many authors suggest that labile fractions of SOC, which are more dynamic and sensitive to management practices, can be used as early indicators of the production system effects (Campbell et al., 1999; Kapkiyai et al., 1999; Amado et al., 2006). It should be noted that the POC$_c$ represents less transformed organic material and the balance between aboveground residues and root inputs on one side and on the other, the rate of decomposition, depending on the material quality, location, temperature and humidity. Therefore, the inherent variability of this fraction, together with the variable effect because of soil depth and vegetation growth cycle, require a more precise definition for sampling (time and depth) to use this parameter as an indicator of soil quality.

The natural stratification of POC$_c$ causes a change according to depth. For example, the amount of POC$_c$ in NE (0.513%) is approximately twice that present in GAP (0.250%), while in 10–20 the values were much lower (0.135% and 0.046% respectively) and the relative difference was greatest (2.7 times) (Table 4).

The general trend in 0–20 cm for POC$_f$ was NE > GAP > PAP at all locations, although differences were variables (Table 4). This fraction represents a transition material, so it was not as variable as POC$_c$, but not as stable as MOC. The trend found in 0–20 cm was similar in the two depths analyzed, already discussed in 0–10 cm, and 10–20 cm where the interaction site × treatments was positive, possibly due to minor differences found in Pergamino and Monte Buey.

3.3. Bulk density

The bulk density in the four sites varied among treatments and soil depths (Table 5). There was no significant interaction sites × treatments at 0–5 and 10–15 cm depth, while for the other depths the interaction was significant ($p < 0.05$). Thus, the effect of shallow SOC on BD, either by natural accumulation (NE) or surface accumulation of crop residues (under GAP and PAP), produced a similar effect on the various sites.

The presence of organic residues would have a protective effect against soil compaction. This is the reason, there were lowest values of BD in the first centimeters of soil. Within the SOC, the coarse fraction becomes more important due to porosity increases by changing the overall soil behavior and to avoiding its compaction (Pecorari et al., 1990). On the surface, NE presented the lowest values compared with GAP and PAP, as these are treatments which are not subject to any heavy traffic. Furthermore, the large amount of roots produced in these environments allows biological soil decompaction.

Similar results were found in the 10–15 cm layer (Table 5), with significant differences between treatments. These results are consistent with the work of Thomas et al. (1996), where they found below the layer rich in SOC a zone more impoverished where compaction increased. In deeper layers, BD values were different among sites and management effects were variable.

Table 5
Soil bulk density (BD) of the different sites and treatments.

Sites	Depth	BD (Mg m^{-3})		
		NE	GAP	PAP
Bengolea	0–5	0.93 a	1.04 ab	1.14 b
	5–10	1.18 a	1.23 a	1.26 a
	10–15	1.19 a	1.30 b	1.25 ab
	15–20	1.50 b	1.38 ab	1.31 a
Monte Buey	0–5	1.00 a	1.29 b	1.19 b
	5–10	1.32 a	1.52 b	1.45 ab
	10–15	1.37 a	1.56 c	1.48 b
	15–20	1.36 a	1.51 b	1.44 ab
Pergamino	0–5	0.96 a	1.12 a	1.17 a
	5–10	1.27 a	1.40 ab	1.50 b
	10–15	1.43 a	1.49 ab	1.62 b
	15–20	1.48 ab	1.42 a	1.58 b
Viale	0–5	1.00 a	0.98 a	1.01 a
	5–10	1.20 a	1.18 a	1.40 b
	10–15	1.13 a	1.17 a	1.32 a
	15–20	1.25 a	1.20 a	1.21 a
Average	0–5	0.97 a	1.11 b	1.13 b
	5–10	1.24 a	1.34 b	1.40 c
	10–15	1.28 a	1.38 b	1.42 b
	15–20	1.40 a	1.38 a	1.39 a
	0–20	1.24	1.31	1.34

For each depth and site, different letters indicate significant differences ($p < 0.05$). NE, natural environment; GAP, good agricultural practices; and PAP, poor agricultural practices.

Table 6
Statistical analysis of soil organic carbon stocks (SOC, Mg ha^{-1}) at fixed depth (0–10 and 0–20 cm) and equivalent soil mass (950 and 2350 Mg ha^{-1}).

	SOC Mg ha^{-1}			
	0–10	950 Mg soil	0–20	2350 Mg soil
Bengolea	16.14 a	12.37 a	28.29 a	27.14 a
Monte Buey	27.24 b	22.30 b	47.81 b	42.24 b
Pergamino	26.31 b	19.54 b	42.54 b	37.97 b
Viale	35.19 c	29.80 c	58.84 c	59.14 c
NE	32.01 b	26.64 c	51.43 c	49.73 c
GAP	25.22 a	20.07 b	44.16 b	41.26 b
PAP	21.43 a	16.30 a	37.53 a	33.88 a
Site	***	***	***	***
Treatment	***	***	***	***
Site × treatment	ns	ns	ns	ns

For each depth and equivalent soil mass different letters indicate statistically significant differences between sites and treatment ($p < 0.05$), DMS test.
NE, natural environment; GAP, good agricultural practices; and PAP, poor agricultural practices.

3.4. Changes in carbon stock

Carbon content was calculated for each depth (0–10 and 10–20 cm) and for an equivalent soil mass. This last option was applied to avoid errors in the comparisons due to different original depth measurement (Ellert and Bettany, 1995; Alvarez and Steinbach, 2006; Lee et al., 2009) and 950 and 2350 Mg soil ha^{-1} were used as the equivalent soil masses.

Comparison of the carbon stock calculated in 0–10 cm, 950 Mg ha^{-1}; 0–20 cm and 2350 Mg ha^{-1} showed differences between sites ($p < 0.05$) between treatments ($p < 0.05$), but no significant interaction (Table 6).

The highest and lowest SOC contents, both 0–10 and 0–20 cm, were found in Bengolea and Viale soils, respectively. These differences were associated with textural differences that clearly separate the two soils.

Carbon stock comparison in 0–20 cm showed the greatest differences between treatments in Monte Buey, with significant differences between the three treatments ($p < 0.05$). In the other cases, no significant difference was found, although the trend was similar (NE > GAP > PAP).

As was mentioned, the carbon stock increased from East to West (Fig. 1a and b) and these increases were less marked in the case of GAP and PAP. The largest losses occurred in Monte Buey and Pergamino due to management practices with respect to the natural environment (Fig. 1a). Such losses were around 30%, both for GAP and PAP, and lower in Bengolea, with losses of 10 and 30% for GAP and PAP, respectively. These values are consistent with Burke et al. (1989) results under grasslands of the U.S. and Brown and Lugo (1990) under tropical forest areas.

In Viale there was no difference between NE and GAP (Fig. 1a). Probably, these Vertisols, with expandable clay minerals, had greater protection capacity of the organic material and the NE vegetation was different (trees and shrubs). Overall, despite the extractions made by the crops, carbon inputs were greater in cultivated soils, indicating that the most important factor in the balance may be the rate of transformation of the SOC (Hevia et al., 2003).

The results in the 0–10 cm layer (Fig. 1a) were similar to data in 0–20 cm (Fig. 1b), except Bengolea where the differences between treatments disappeared. In agricultural agro-ecosystems under rotations, the soil carbon content is related to the carbon contribution of vegetation. Studdert and Echeverria (2002) observed that increasing the number of crops per year or crops with higher biomass production, the level of carbon in the soil after several years was greater. This may account for the clear differences found in Monte Buey, where GAP with respect to PAP have higher rotation index, lower fallow period, linked to the practice of cover crops and higher proportion of corn compared to soybeans. In the other sites the contrast between GAP and PAP was not so marked (Fig. 1a and b).

The comparison of C stocks on the basis of equivalent soil mass (2350 Mg ha^{-1}) showed similar differences to calculated carbon stocks at a fixed depth (0–20 cm). However, these differences were greater for equivalent soil mass based data, whose values were 8.5 Mg to GAP and 15.9 Mg to PAP with respect to NE (Table 6).

The stock of POC_c to equivalent soil mass (2350 Mg) in Bengolea, Monte Buey and Viale decreased about 60% in average in GAP and PAP treatments with respect to NE, this shows the sensitivity of this parameter related to management practices (Table 7). This organic fraction is very sensitive to degradation when systems are disturbed and thus increases turnover more than the physically or chemically protected fractions (Galantini et al., 2004).

In general, the same results were obtained for 950 Mg ha^{-1}, in the case of Monte Buey. A in the SOC, differences were found among the three treatments ($p < 0.05$).

3.5. Carbohydrate content

Soil CH showed similar trends as SOC. For 2350 Mg ha^{-1}, significant differences ($p < 0.05$) was only observed in NE with respect to GAP and PAP. Differences were higher in CH_s than in CH_t (Table 7).

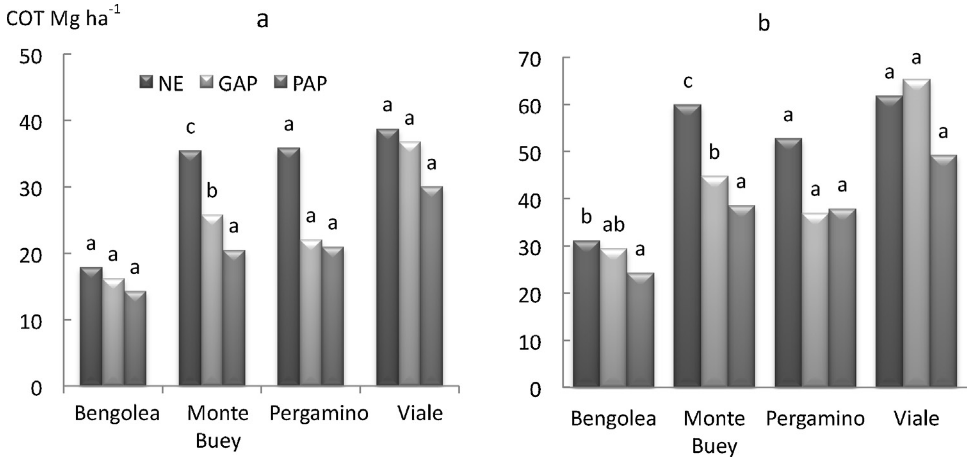

Fig. 1. Soil organic carbon (SOC) content (Mg ha^{-1}) at fixed depths (0–10 and 0–20 cm).

Table 7
Organic fractions to two equivalent soil masses.

Site	Carbon fraction	950 Mg soil			2350 Mg soil		
		NE (Mg ha^{-1})	GAP (Mg ha^{-1})	PAP (Mg ha^{-1})	NE (Mg ha^{-1})	GAP (Mg ha^{-1})	PAP (Mg ha^{-1})
Bengolea	SOC	14.8 b	12.6 b	9.7 a	30.3 b	27.9 ab	23.2 a
	MOC	7.3 a	7.0 a	7.0 a	15.1 a	16.6 a	15.4 a
	POC$_c$	4.87 b	2.37 a	1.61 a	7.17 b	3.39 a	2.56 a
	POC$_f$	3.90 ab	4.26 b	2.69 a	8.25 b	8.29 b	5.39 a
	CH$_t$	4.20 a	4.07 a	3.63 a	9.70 a	9.19 a	8.07 a
	CH$_s$	0.26 a	0.27 a	0.22 a	0.58 a	0.83 b	0.54 a
Monte Buey	SOC	30.7 c	19.8 b	16.4 a	55.6 b	37.6 a	33.6 a
	MOC	17.1 b	11.7 a	11.2 a	38.4 b	27.7 a	27.0 a
	POC$_c$	7.72 b	3.18 a	1.63 a	10.80 b	4.98 a	2.52 a
	POC$_f$	4.29 b	2.47 a	1.96 a	7.53 b	4.85 a	3.74 a
	CH$_t$	6.27 b	4.95 ab	3.55 a	12.97 b	9.98 ab	7.74 a
	CH$_s$	0.40 b	0.18 a	0.11 a	0.82 b	0.36 a	0.27 a
Pergamino	SOC	27.7 b	15.5 a	15.5 a	50.2 a	32.4 a	31.3 a
	MOC	24.9 b	12.4 ab	10.9 a	41.6 a	26.2 a	24.8 a
	POC$_c$	2.45 a	1.88 a	1.96 a	3.38 a	2.72 a	2.93 a
	POC$_f$	3.07 a	2.31 a	2.01 a	5.06 a	4.27 a	3.86 a
	CH$_t$	7.53 c	4.26 b	2.02 a	15.69 c	9.59 b	4.19 a
	CH$_s$	0.88 b	0.25 a	0.26 a	1.40 b	0.50 a	0.53 a
Viale	SOC	33.5 b	32.4 b	23.6 a	62.9 ab	67.2 b	47.4 a
	MOC	25.3 ab	26.8 b	19.4 a	51.3 ab	58.4 b	40.9 a
	POC$_c$	4.03 b	1.74 a	2.12 ab	5.37 a	2.90 a	2.88 a
	POC$_f$	4.12 a	3.83 a	2.07 a	6.38 b	6.03 ab	3.57 a
	CH$_t$	3.86 b	3.28 a	3.23 a	8.89 b	7.41 ab	6.36 a
	CH$_s$	0.33 b	0.27 ab	0.17 a	0.68 b	0.50 a	0.37 a

For each equivalent soil mass different letters for each parameter analyzed indicate statistically significant differences between treatments ($p < 0.05$), DMS test.
POC$_f$, fine particulate organic carbon; POC$_c$, coarse particulate organic carbon; SOC, total organic carbon; MOC, mineral-associated organic carbon; CH$_t$ and CH$_s$, total and soluble carbohidrates; NE, natural environment; GAP, good agricultural practices; and PAP, poor agricultural practices.

The CH$_t$ represented 9, 11, 15 and 20% of SOC for Viale, Bengolea, Pergamino and Monte Buey, respectively (Table 7). Others authors found similar values, between 5 and 25% of SOC, and reported that it was sensitive to changes in land use (Guggenberger et al., 1995).

When CH$_t$ content of NE was used as reference, a decrease was observed only at Monte Buey and Pergamino. Bongiovanni and Lobartini (2006) comparing natural and cropped systems with similar soils, found that CH$_t$ decreased by 47% due to over 50 years of cultivation. However, the decrease in CH$_t$ was not so big in this study. The highest loss was about 40% in Monte Buey and Pergamino sites. Probably, GAP and PAP systems were not as aggressive as the Bongiovanni and Lobartini (2006) management practices.

The CH$_s$ contents were the most affected by management practices, and the losses were higher than 50% in Monte Buey and Pergamino, and 20% in Viale. However, management effect on CH$_s$ contents was only detected in Bengolea site. The CH$_s$ are mainly polysaccharides of plant exudates or microbial origin (Angers and Mehuys, 1989). Root exudates and its dead tissues may comprise up to 30–40% or more of the total input of organic matter of soils (Fogel, 1985). Therefore, a change in the sequence of crops, both in frequency and in the type of crops can modify the CH content. A fallow period in a sequence of crops can significantly reduce the carbohydrate content (Cheshire, 1979). Even though CH$_s$ content was suggested as a soil quality indicator (Haynes and Beare, 1996), this work showed low sensibility to the changes of crop sequences under no-tillage.

4. Conclusions

The analysis of SOC fractions allows the differentiation between different agricultural practices under No-Till. Calculating the carbon stocks for an equivalent soil mass of soil allowed better detection of differences among management practices only when bulk density was different between different treatments.

The SOC content in the NE was strongly influenced by the clay + silt content, where the most abundant fraction was closely related to clay content. The POC$_c$/SOC and POC$_{c+f}$/SOC relationship showed differences among natural sites, suggesting different dynamics depending on the climatic and soil characteristics.

The SOC levels in the upper layer of agricultural soils were 16–44% lower than natural ones.

The POC$_c$ and CHs had lower sensibility to management practices than POC$_f$ and CH$_t$ fractions.

Fractions with intermediate dynamics, as POC$_f$ (53–105 μm) and CH$_t$, seem to be better indicators to detect the short- and medium-term management effects than highly dynamics fractions.

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References

Alvarez, R., Steinbach, H.S., 2006. Efecto del sistema de labranza sobre la materia orgánica. In: Pascale, A.J. (Ed.), Materia orgánica: Valor agronómico y dinámica en suelos pampeanos. Facultad de Agronomía, Universidad de Buenos Aires, pp. 69–78.

Amado, T.J.C., Bayer, C., Conceição, P.C., Spagnollo, E., Costa de Campos, B., da Veiga, M., 2006. Potential of carbon accumulation in not till with intensive use and cover crops in southern Brazil. Journal of Environmental Quality 35, 1599–1607.

Andriulo, A., Cordone, G., 1998. Impacto de labranzas y rotaciones sobre la materia organica del suelo en la Region Pampeana Humeda. In: Panigatti, J.L., Marelli, H., Buschiazzo, D., Gil, R. (Eds.), Siembra directa. Hemisfeio Sur, Bs. As., Arg., pp. 65–96.

Andriulo, A., Sasal, M.C., Irizar, A., Restovich, S., Rimatori, F., 2008. Efectos de diferentes sistemas de labranza, secuencia de cultivos y de la fertilización nitrogenada sobre los stocks de C y N edáfico. In: Galantini, J. (Ed.), Estudio de las fracciones orgánicas en suelos de la Argentina. EdiUNS, Bahia Blanca, Argentina, pp. 117–129.

Angers, D.A., Mehuys, G.R., 1989. Effects of cropping on carbohydrate content and water-stable aggregation of a clay soil. Canadian Journal of Soil Science 69, 373–380.

Baker, J.M., Ochsner, T.E., Venterea, R.T., Griffis, T.J., 2006. Tillage and soil carbon sequestration–what do we really know? Agriculture, Ecosystems and Environment 118, 1–5.

Bayer, C., Mielniczuk, J., Amado, T.J.C., Martin-Neto, L., Fernández, S.V., 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. Soil and Tillage Research 54, 101–109.

Biederbeck, V.O., Campbell, C.A., Rasiah, V., Zentner, R.P., Wen, G., 1998. Soil quality attributes as influenced by annual legumes used as green manure. Soil Biology and Biochemistry 30, 1177–1185.

Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1, Agron. Monogr. 9. 2nd ed. ASA and SSSA, Madison, WI, pp. 363–375.

Blanco-Canqui, H., Lal, R., 2008. No-tillage and soil-profile carbon sequestration: an on-farm assessment. Soil Science Society of America Journal 72, 693–701.

Bongiovanni, M.D., Lobartini, J.C., 2006. Particulate organic matter, carbohydrate, humic acid contents in soil macro- and microaggregates as affected by cultivation. Geoderma 136, 660–665.

Bredja, J.J., Moorman, T.B., Karlen, D.L., Dao, T.H., 2000. Indentification of regional soil quality factors and indicators, I Central and Southern High Plains. Soil Science Society of America Journal 64, 2115–2124.

Brink, R.H., Dubach Jr., P., Lynch, D.L., 1960. Measurement of carbohydrates in soil hydrolyzates with anthrone. Soil Science 89, 157–166.

Brown, S., Lugo, A., 1990. Effects of forest clearing and succession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. Plant and Soil 124, 53–64.

Burke, I.C., Yonker, C.M., Parton, W.J., Cole, C.V., Flach, K., Schimel, D.S., 1989. Texture, climate and cultivation effects on soil organic matter content in US Grassland soils. Soil Science Society of America Journal 53, 800–805.

Buschiazzo, D., Quiroga, A., Stahr, K., 1991. Patterns of organic matter distribution in soils of the Semiarid Argentinean Pampas. Z. Pflanzenernähr. Bodenk. 154, 437–441.

Cambardella, C.A., Elliott, E.T., 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal 56, 777–783.

Campbell, C., Biederbeck, V., McConkey, B., Curtin, D., Zentner, R., 1999. Soil quality–effect of tillage and fallow frequency. Soil Biology and Biochemistry 31, 1–7.

Cheshire, M.V., 1979. Nature and Origin of Carbohydrates in Soils. Academic Press, London.

Cook, R.J., 2006. Toward cropping systems that enhance productivity and sustainability. Proceedings of the National Academy of Sciences USA 103, 18389–21839.

Cook, N., Hendershot, W.H., 1996. The problem of establishing ecologically-based soil quality criteria: the case of lead. Canadian Journal of Soil Science 76, 335–342.

Derpsch, R., Friedrich, T., Kassam, A., Li, H., 2010. Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering 3, 1.

Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L., Tablada, M., Robledo, C.W., 2008. InfoStat. Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina.

Ellert, B.H., Bettany, J.R., 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Canadian Journal of Soil Science 75, 529–538.

Ellert, B.H., Janzen, H.H., McConkey, B.G., 2001. Measuring and comparing soil carbon storage. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Assessment Methods for Soil Carbon. Lewis Publishers, Boca Raton, FL, pp. 131–144.

Fedoroff, N., 1987. The production potential of soils. Part 1. Sensitivity of principal soil types to the intensive agriculture of north-western Europe. In: Barth, E., L'Hermite, P. (Eds.), Scientific Basis for Soil Protection in the European Community. Elsevier, London, pp. 65–86.

Ferrari, A.E., Gabbarini, L.A., Reyna, D.L., González Baro, M., Wall, L.G., 2010. Indicadores de calidad de suelos agrícolas con distintos manejos. Actas CD Taller SUCS-ISTRO, Colonia (Uruguay).

Fogel, R., 1985. Roots as primary producers in belowground ecosystems. In: Fitter, A.H., Atkinson, D., Read, D.J., Usher, M.B. (Eds.), Ecological Interactions in Soil: Plants, Microbes and Animals. Blackwell Scientific Publications, Oxford, pp. 23–36.

Franzluebbers, A.J., 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil and Tillage Research 66, 95–106.

Galantini, J., 2005. Separación y análisis de las fracciones orgánicas. In: Marban, L., Ratto, S. (Eds.), Manual "Información y Tecnología en los Laboratorios de Suelos para el Desarrollo Agropecuario Sostenible". de la AACS. Capitulo IV parte 2, pp. 95–106.

Galantini, J., Iglesias, J., 2007. Capacidad de secuestro de carbono y efecto de las prácticas agronómicas en suelos de la Región Pampeana de Argentina. In: Gallardo, J. (Ed.), Captura de Carbono en Ecosistemas Terrestres de Iberoamérica. pp. 169–182.

Galantini, J., Iglesias, J., Landriscini, M.R., Suñer, L., Minoldo, G., 2008. Calidad y dinámica de las fracciones orgánicas en sistemas naturales y cultivados. In: Galantini, J. (Ed.), Estudios de las Fracciones Orgánicas en Suelos de la Argentina. EdiUNS. Bahía Blanca, Argentina, pp. 71–95.

Galantini, J.A., Rosell, R.A., 2006. Long-term fertilization effects on soil organic matter quality and dynamics under different production systems in semiarid Pampean soils. Soil and Tillage Research 87, 72–79.

Galantini, J.A., Senesi, N., Brunetti, G., Rosell, R., 2004. Influence of texture on the nitrogen and sulphur status and organic matter quality and distribution in semiarid Pampean grassland soils. Geoderma 123, 143–152.

Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., Ellert, B.H., 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soil. Canadian Journal of Soil Science 74, 367–385.

Gregory, E., Drury, C., 1996. Fertilizer increases corn yield and soil organic matter. Better Crops 80 (4), 3–5, Potash and Phosphate Institute. Norcross, Georgia, EE.UU.

Guggenberger, G., Zech, W., Thomas, R.J., 1995. Lignin and carbohydrate alteration in particle-size separates of an oxisol under tropical pasture following native Savanna. Soil Biology and Biochemistry 27, 1629–1638.

Havlin, J.L., Kissel, D., Maddux, L., Claassen, M., Long, J., 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Science Society of America Journal 54, 448–452.

Haynes, R., 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. Advance in Agronomy 85, 221–268.

Haynes, R.J., Beare, M.H., 1996. Aggregation and organic matter storage in mesothermal, humid soils. In: Carter, M.R., Stowart, B.A. (Eds.), Structure and Organic Matter Storage in Agricultural Soils. CRC Press, Boca Raton, FL, pp. 213–262.

Hevia, G.G., Buschiazzo, D.E., Hepper, E.N., Urioste, A.M., Antón, E.L., 2003. Organic matter in size fractions of soils of the semiarid Argentina. Effects of climate soil texture and management. Geoderma 116, 265–277.

Kapkiyai, J., Karanja, N., Qureshi, J., Smithson, P., Woomer, P., 1999. Soil organic matter and nutrient dynamics in a Kenian nitisol under long-term fertilizer and organic input management. Soil Biology and Biochemistry 31, 1773–1782.

Lal, R., 2006. Soil carbon sequestration in Latin America. In: Lal, R., Cerri, C.C., Bernoux, M., Etcheves, J., Cerri, E. (Eds.), Carbon sequestration in soils of Latin America. Food Products Press, New York, pp. 49–64.

Lal, R., Follet, R.F., Kimble, J.M., Cole, C.V., 1998. The Potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publisher, Boca Raton, FL pp. 128.

Lattanzi, A., Arce, J., Marelli, H., Lorenzon, C., Baigorria, T., 2005. Efecto de largo plazo de la siembra directa y de las rotaciones de cultivos sobre los rendimientos, el carbono y le nitrógeno orgánico en un Argiudol Típico de Marcos Juarez. In: XIII Congreso AAPRESID, Rosario. , pp. 61–67.

Lee, J., Hopmans, J.W., Rolston, D.E., Baer, S.G., Six, J., 2009. Determining soil carbon stock changes: simple bulk density corrections fail. Agriculture. Ecosystems and Environment 134, 251–256.

Leirós, M.C., Trasar-Cepeda, C., García-Fernández, F., Gil-Sotres, F., 1999. Defining the validity of a biochemical index of soil quality. Biology and Fertility of Soils 30, 140–146.

Liu, A., Ma, B.L., Bomke, A.A., 2005. Effects of cover crops on soil aggregate stability, total organic carbon, and polysaccharides. Soil Science Society of America Journal 69, 2041–2048.

MAGyP, 2011. Ministerio de Agricultura, Ganaderia y Pesca. Base de datos sistema integrado de información agropecuaria. Disponible en: http://www.minagri.gob.ar.

Martino, D., 1997. Siembra directa en los sistemas agrícola-ganaderos del litoral. INIA La Estanzuela. Serie Tecnica 82, 28.

Michelena, R., Irurtia, C., Vavruska, F., Mon, R., Pittaluga, A., 1989. Degradación de suelos en el norte de la Región Pampeana. INTA, Publ. No. 6. Centro Regional Buenos Aires Norte, Pergamino, Provincia de Buenos Aires pp. 120.

Miglierina, A.M., Iglesias, J.O., Landriscini, M.R., Galantini, J.A., Rosell, R.A., 2000. The effects of crop rotations and fertilization on wheat productivity in the Pampean semiarid region of Argentina. 1. Soil physical and chemical properties. Soil and Tillage Research 53, 129–135.

Nortcliff, S., 2002. Standardisation of soil quality attributes. Agriculture, Ecosystems and Environment 88, 161–168.

Oades, J.M., 1988. The retention of organic matter in soils. Biogeochemistry 5, 35–70.

Pecorari, C., Guerif, J., Stengel, P., 1990. Fitolitos en suelos pampeanos. Influencia sobre las propiedades físicas determinantes de la evolución de la estructura. Ciencia del Suelo 8 (2), 135–141.

Puget, P., Angers, D.A., Chenu, C., 1999. Nature of carbohydrates associated with water-stable aggregates of two cultivated soils. Soil Biology and Biochemistry 31, 55–63.

Quiroga, A., Furano, D., Noellemeyer, E., Peinemann, N., 2005. Barley yield response to soil organic matter and texture in the Pampas of Argentina. Soil and Tillage Research 90, 63–68.

Rassmussen, P.E., Collins, H.P., Smiley, R.E., 1989. Long-term Management Effects on Soil Productivity and Crop Yields in Semi-arid Regions of Eastern Oregon. Station Bulletin 75. USDA-ARS and Oregon State University, Pendleton.

Sanchez-Marañon, M., Soriano, M., Delgado, G., Delgado, R., 2002. Soil quality in Mediterranean mountain environments: effects of land use change. Soil Science Society of America Journal 66, 948–958.

Six, J., Elliott, E.T., Paustian, K., 1999. Aggregate and soil organic matter dynamics under conventional and no-till systems. Soil Science Society of America Journal 63, 1350–1358.

Studdert, G., Echeverria, H., 2002. Crop rotations and nitrogen fertilization to manage soil organic carbon dynamics. Soil Science Society of America Journal 64, 1496–1503.

Thomas, E.A., 2003. Evolución del carbono orgánico edáfico en las series Hansen y general Baldissera bajo agricultura contínua. Aplicación de un modelo de simulación. Tesis de Especialización, Facultad de Ciencias Agrarias-Universidad Nacional de Mar del Plata Estación Experimental Agropecuaria de Balcarce-INTA, 43 págs.

Thomas, G.W., Haszler, G.R., Blevins, R.L., 1996. The effects of organic matter and tillage on maximum compactability of soils using the Proctor test. Soil Science, Baltimore 161, 502–508.

Tisdall, J.M., Oades, J.M., 1982. Organic matter and water-stable aggregates. Journal of Soil Science 33, 141–163.

Ussiri, D.A.N., Lal, R., Jacinthe, P.A., 2006. Soil properties and carbon sequestration of afforested pasture in reclaimed Minesoils of Ohio. Soil Science Society of America Journal 70 (5), 1797–1806.

Van Veen, J.A., Kuikman, P.J., 1990. Soil structural aspects of decomposition of organic matter by micro-organisms. Biogeochemistry 11, 213–233.

Wander, M., 2004. Soil organic matter fractions and their relevance to soil function. In: Magdoff, K., Weil, R.R. (Eds.), Soil Organic Matter in Sustainable Agriculture. CRC Press, Boca Raton, Florida, EE.UU, pp. 67–102.