Soil & Tillage Research 159 (2016) 9–22

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

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

Matias E. Duval[a,b,*], Juan A. Galantini[b,c], Juan M. Martínez[a,b], Fernando M. López[a,b], Luis G. Wall[d]

[a] CONICET, Universidad Nacional del Sur, Argentina
[b] CERZOS (UNS-CONICET)—Departamento de Agronomía, Universidad Nacional del Sur, Argentina
[c] Comisión de Investigaciones Científicas, Provincia de Buenos Aires, Argentina
[d] Laboratorio de Bioquímica, Microbiología e Interacciones Biológicas en el Suelo, Departamento de Ciencia y Tecnología, Universidad Nacional de Quilmes, Argentina

ARTICLE INFO

Article history:
Received 4 August 2015
Received in revised form 12 January 2016
Accepted 13 January 2016
Available online xxx

Keywords:
Soil organic carbon
Organic fractions
Multivariate analysis

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

---

* Corresponding author at: San Andrés 800-Bahía Blanca, Buenos Aires, Argentina.
E-mail address: mduval@criba.edu.ar (M.E. Duval).

http://dx.doi.org/10.1016/j.still.2016.01.004
0167-1987/© 2016 Elsevier B.V. All rights reserved.

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).

the detection of short-term effects, labile fractions of SOC are more useful (Melero et al., 2009; Duval et al., 2013). In turn, short-term changes are more complex and also depend on soil conditions, such as soil texture, climate, cropping system and the type of residue as well as on the current management (Paustian et al., 1997). We hypothesized that although management practices with diverse carbon contributions affect the amount and quality of the different organic fractions, the time of sampling modifies the differences attributed to climatic conditions and to contributions of preceding crop residue and the current sampling time. The aim of this study was to quantify the effect of different agricultural management, season and soil type on SOC and its different fractions.

2. Materials and methods

2.1. Study site

Predominant soils were Mollisolls developed in aeolian sediments (loess), with a wide range of depth fluctuation, texture, soil organic carbon content and fertility (Álvarez and Lavado, 1998). The climate is subhumid/humid temperate with annual rainfall ranging from 850 to 1200 mm concentrated in summer and spring.

We selected four study sites with documented history of no-tillage management (more than 5 years) located in the most productive region of the Argentinean Pampas that correspond to different climate and soil conditions (Table 1). The study sites were located at Bengolea (Córdoba, 33°01′32.9″S; 63°37′36.4″W), Monte Buey (Córdoba, 32°58′17.0″S, 62°27′02.4″W), Pergamino (Buenos Aires, 33°56′42.6″S, 60°33′35.6″WO) and Viale (Entre Ríos, 31°52′42.2″S, 59°41′16.2″WO). The soils and environments analyzed ranged from the most sandy and less rainy in the west to the most humid and clayey in the east (Figs. 1 and 2).

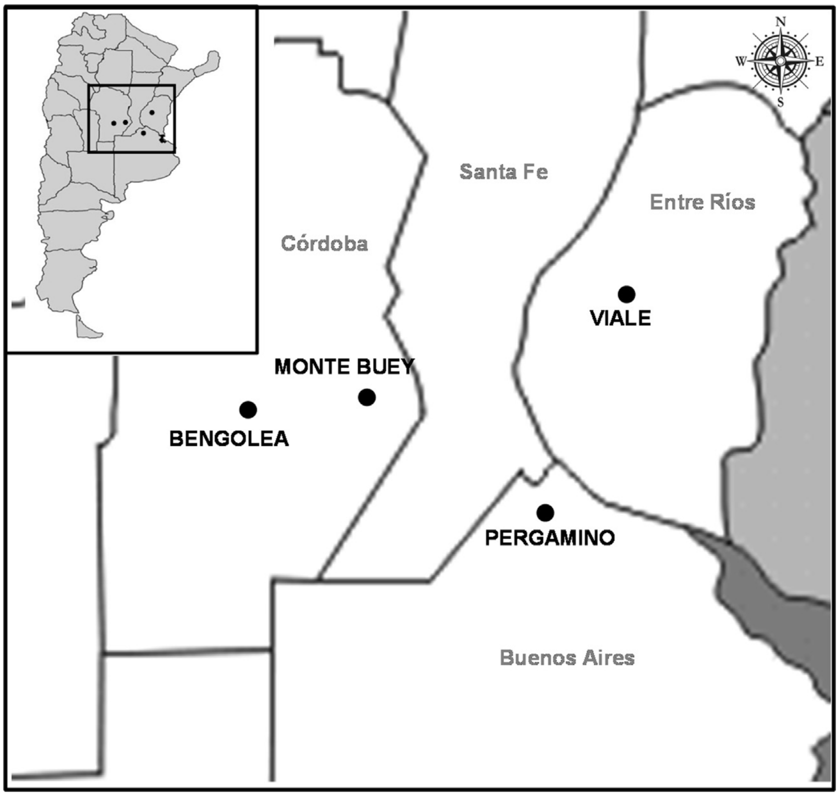

Fig. 1. Location of the study sites in the Pampa Region of Argentina.

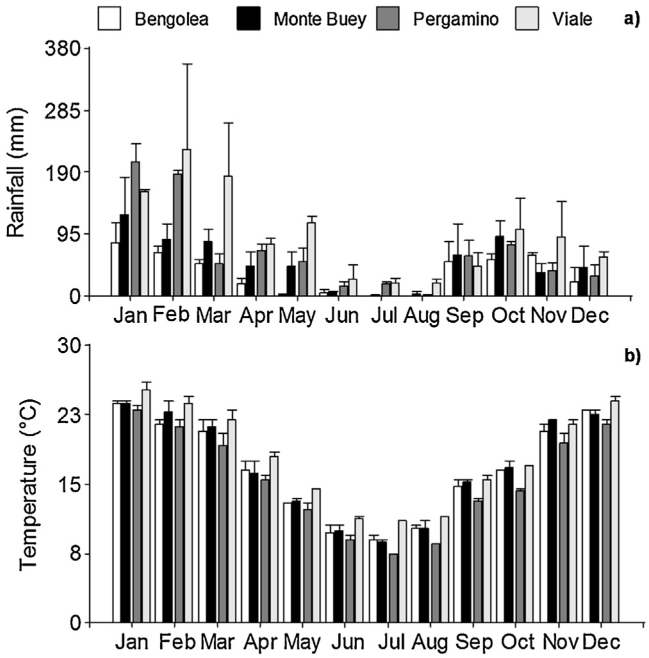

Fig. 2. Monthly rainfall (mm) (a) and mean air temperature (°C) (b), 2010–2011.

2.2. Treatments

Three treatments were defined at each sampling location:

1. "Good Agricultural Practices (GAP): Sustainable agriculture management under no-tillage, subject to intensive rotation with winter crops such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare*), and summer crops such as soybean (*Glycine*

Table 2
Agricultural treatments; management and crop yields.

	Bengolea		Monte Buey		Pergamino		Viale	
	GAP	PAP	GAP	PAP	GAP	PAP	GAP	PAP
History no-tillage (years)	13	5	28	10	6	5	13	9
Soybean/maize ratio[a]	1.5	4	0.67	4	1.5	5	1.5	4
% Wheat[b]	60	40	60	20	10	0	40	20
% Cover crops[c]	20	0	40	0	0	0	20	0
Fertilization N–P (kg ha^{-1} year^{-1})[d]	68-18	3-3	64-18	17-5	41-17	7-31	64-27	34-23
Soybean yield (kg ha^{-1})	3067	2775	3167	2675	2933	2885	3000	1805
Maize yield (kg ha^{-1})	10500	2700	12550	8000	9500	–	7030	3450
Carbon input (kg ha^{-1} year^{-1})[e]	5608	2765	6378	3548	4291	2486	4010	2845

[a] Number of soybean cycles to number of maize cycles over the last 5 years.
[b] Percentage of winters that wheat was planted.
[c] Percentage of winters that a cover crop (*Vicia* sp., *Melilotus alba* or *Lolium perenne*) was planted. Cover crops were chemically burned before summer crops were planted.
[d] Calculated as kilograms of N and P (element) applied per hectare per year.
[e] C input estimated (shoots + roots).

max [L.] Merr.), maize (*Zea mays* L.) or sorghum (*Sorghum bicolor* L. Moench) and occasionally, cover crops, such as vetch (*Vicia sativa* L.) and triticale (*Triticum aestivum* × *Secale cereale*). Nutrients were applied according to crop needs, with minimal use of agrochemicals (herbicides, insecticides and fungicides) (Table 2).

2. "Poor Agricultural Practices" (PAP): Non-sustainable agriculture management under no-tillage subject to minimal rotation or soybean monoculture (*Glycine max* [L.] Merr.), low nutrient application and high use of agrochemicals (herbicides, insecticides y fungicides) (Table 2).
3. "Natural Environment" (NE), soil without cultivation as reference situation, with native vegetation near to cultivated plots (less than 5 km), where equilibrium among the different organic fractions had been achieved. Predominant species in the NE varied according to the sites: in Bengolea the most abundant species was bermudagrass (*Cynodon dactylon* L.); in Monte Buey the predominant species included wild lettuce (*Lactuca virosa* L.), annual nettle (*Urtica urens* L.), bermudagrass (*C. dactylon* L.) and rescuegrass (*Bromus catharticus* Vahl.); in Pergamino species such as bermudagrass (*C. dactylon* L.), wild lettuce (*L. virosa* L.), needlegrass (*Amelichloa brachychaeta*), hairy vetch (*Vicia villosa* Roth.) and rescuegrass (*B. catharticus* Vahl.) were predominantly found, while in Viale predominant arboreous species included caranday palm (*Trithrinax campestris*), ñandubay (*Prosopis affinis*), chañar (*Geoffroea decorticans*), while some herbaceous species such as *Baccharis* spp. and gramineous of the genus *Panicum*,*Paspalum*, *Piptochaetium*, *Chloris* and *Eragrostis* were observed.

2.3. Soil sampling

At each site, soil samples at 0–20 cm (each 5 cm depth) were taken (three replicates) during two consecutive years (2010 and 2011) in February (summer) and September (spring) (Season factor) in the agricultural management (GAP and PAP) and in natural environments (NE) (Treatment factor). In each situation, the three sampling points (replicates), represented by three subsamples were localized using GPS for subsequent sampling. Undisturbed soil samples were taken at 0–20 cm using cylinders of 5 cm in height and 4.7 cm in diameter.

2.4. Soil organic carbon and nitrogen

The soil samples taken on the different sampling dates and management conditions were air-dried and passed through a 2 mm sieve. The following chemical determinations were made: soil organic carbon (SOC) by dry combustion (LECO Carbon analyzer) and soil total nitrogen (Nt) using Kjeldahl, (Bremner, 1996).

2.4.1. Determination of particulate organic carbon

For the size fractionation of SOC we used wet sieving of soil (Cambardella and Elliott, 1992; Duval et al., 2013). The sieving was done with a pair of sieves of 53 μm and 105 μm of diameter mesh. Three fractions with different characteristics 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; and the fine fraction (<53 μm), containing mineral associated organic carbon (MOC) as well as silt and clay. A detailed description of the methodology is illustrated in Duval et al. (2013).

Carbon contents in the coarse and medium fraction were determined using the same method as mentioned above for SOC. The carbon of the fine fraction was determined by difference between SOC and ($POC_c + POC_f$).

2.4.2. Determination of total and soluble carbohydrates

Extraction of carbohydrates was performed employing two different procedures (Puget et al., 1999): To determine total carbohydrates (CHt), extraction was performed by an acid hydrolysis as follow: 1 g of soil sample was treated with 10 mL de H_2SO_4 0.5 M, heated at 80 °C for 24 h. For the determination of 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, and hydrolysis was attained by adding H_2SO_4 to obtain a 0.5 M concentration as in the dilute acid hydrolysis procedure.

After extraction, each suspension was centrifuged at 4000 rpm for 15 min (Puget et al., 1999). Carbohydrate contents were determined using the phenol–sulphuric acid spectrophotometric method with glucose standard curve (Dubois et al., 1956).

In the present study, contents of SOC and its fractions in the different treatments were calculated according to equivalent soil mass (ESM, Ellert and Bettany, 1995), using a soil mass of 2350 Mg as reference treatment (Duval et al., 2013). The results were expressed in grams of SOC or its fractions per kilogram of ESM (g kg^{-1}).

2.5. Physical determinations

Soil physical properties were sequentially determined. First, the undisturbed soil samples were saturated by wetting from the bottom for 48 h using water. From the saturation state, before the beginning of measurements, water content was determined (θ_s)

following the methodology proposed by Klute (1986). The soil samples were subject to potential of 10 kPa, equivalent to −1 m of hydraulic head (h) using pressure plate extractor (Soil Moisture Equipment Co., Santa Barbara, California) and then oven-dried at 105 °C for 24 h, until constant weight. The mass/volume ratio was calculated to obtain the values corresponding to bulk density (BD) (Blake and Hartge, 1986). Total porosity (TP) was considered equal to water content at θ_s. The pore size corresponding to the pressure established was estimated using the capillary rise formula (Eq. (1)) (Hassink et al., 1993). Thus, the volume of large pores (>30 μm, $P_{>30}$) was determined (Kay and Vanden Bygaart, 2002). The effective pore diameter (d) was estimated in each undisturbed soil sample from the water retention curve as:

$$d = \frac{-30.0 \times 10^{-6}}{\mathrm{h}} \tag{1}$$

where h = pressure head (m).

Soil texture was also determined by the Gee and Bauder (1986) method.

2.6. Simple indices

Taking into account that the most sensitive soil quality indicators (physical and chemical) applied for detecting the changes caused by management may also be sensitive to meteorological, edaphic, topographic and seasonal variations, it is recommended to apply indices related to the system performance (functional indices) since they are considered of major importance in determining the degradation state or recovery of soil quality (Zornoza et al., 2008).

2.6.1. Carbon pool index

The carbon pool index (CPI) was calculated according to the equation proposed by Blair et al. (1995):

$$\mathrm{CPI} = \frac{\text{Organic carbon}_{\mathrm{T}}}{\text{Organic carbon}_{\mathrm{Ref}}} \tag{2}$$

where Organic $\text{carbon}_{\mathrm{T}}$ = soil organic carbon (total or fraction) in agricultural treatments (GAP and PAP), Organic $\text{carbon}_{\mathrm{Ref}}$ = soil organic carbon (total or fraction) of reference (NE). This index was calculated to compare the magnitude of the changes in the different sampling seasons on the different organic fractions.

2.6.2. Intensification index

The intensification sequence index (ISI), was calculated as the ratio of number of months occupied by crops and the total number of months of the year, for instance NE = 12/12 (Sasal et al., 2010). Data on crop sequences were obtained from the farmers' records during a period of 10 years, prior to soil sampling time.

2.7. Statistical analysis

The effects of soil use (NE, GAP and PAP), sites (Bengolea, Monte Buey, Pergamino and Viale) and sampling season (summer and spring) on the variables determined were assessed by ANOVA, using a randomized complete block design (replicates). Least significant difference was used to detect differences among means. If no interaction occurred among factors, the sampling sites were treated as replicates (random effect) and the different soil uses as treatments (fixed effects). Analysis of the principal components was conducted to summarize the chemical, physical characteristics and indices associated with the soils studied and to understand the associations among the edaphic variables. All the statistical analyses were done with a level of significance of $P < 0.05$ using INFOSTAT software (Di Rienzo et al., 2013).

3. Results and discussion

3.1. Variability of organic fractions

The analysis of the results on the three variation factors showed significant effects, mainly for the sites and treatments. Considering the source of temporal variation (Season), the CHt was the only organic fraction that showed significant effects for this variable. In all the organic fractions a significant interaction among the sites and treatments was observed, therefore, all the results were assessed individually in each site.

SOC and MOC did not show a differential effect of the treatment by sampling season (not significant interaction), therefore, these fractions were analyzed as a whole (average dates). In average, for the four sampling dates, in all sites SOC contents showed statistically significant differences between NE and PAP treatments, in which agricultural management reduced SOC content between 3.1 to 10.2 g kg^{-1} (Table 3). Significant differences were also revealed between NE and GAP only for Pergamino and Monte Buey with 5.9 and 8.0 g kg^{-1} higher in NE, respectively (Table 3). By comparing the agricultural treatments, SOC contents were lower in PAP ($P < 0.05$) compared with GAP, at three of the four sites (Table 3). Short-term temporal variability of SOC was low (CV 3–10%); in general, SOC contents remained almost constant between seasons (Fig. 3a).

The MOC showed differences between NE and PAP in Monte Buey and Pergamino, and no differences in Bengolea and Viale; in comparison with NE, GAP showed higher MOC content in Viale, lower content in Monte Buey and Pergamino and no significant differences in Bengolea. Significant difference between GAP and PAP was observed only in Viale (Table 3). The temporal variability of MOC was similar to that observed in SOC (CV 4–16%), thus MOC contents remained almost constant between seasons (Table 3 and Fig. 3b). The amount of mineralized carbon from the different fractions increased with increasing temperature (Benbi et al., 2014). This effect would explain the slight reductions observed between summer and spring, where the highest temperatures and rainfalls occur (Fig. 2a and b). In turn, the authors also observed that SOC and MOC showed the lowest mineralization compared with the other more labile fractions independently of the temperature, confirming the poor variability found in these fractions in the four sites. These results agree with those reported by other authors, who confirm the influence of the temperature

Table 3
Average values for total organic carbon (SOC) and organic carbon associated with mineral fraction (MOC) at each of the sites and treatments.

Organic fractions (g kg^{-1})	Treatment		
	NE	GAP	PAP
	Bengolea		
SOC	13.6b (4.3)	12.9b (9.7)	10.5a (5.4)
MOC	7.7a (12.4)	8.0a (16.0)	7.3a (7.8)
	Monte Buey		
SOC	25.9c (9.4)	17.9b (9.8)	15.7a (7.7)
MOC	19.8b (14.5)	13.9a (12.3)	12.9a (7.8)
	Pergamino		
SOC	21.3b (3.0)	15.4a (5.2)	14.6a (13.5)
MOC	15.9b (8.9)	12.4a (6.0)	11.9a (14.8)
	Viale		
SOC	26.8b (7.4)	30.0b (5.3)	21.5a (6.6)
MOC	21.6a (11.2)	25.7b (4.2)	18.6a (8.9)

At each site different letters for each parameter analyzed indicate statistically significant differences between treatments ($P < 0.05$). The numbers in brackets indicate the coefficient of variation (CV%) of each parameter over two years.

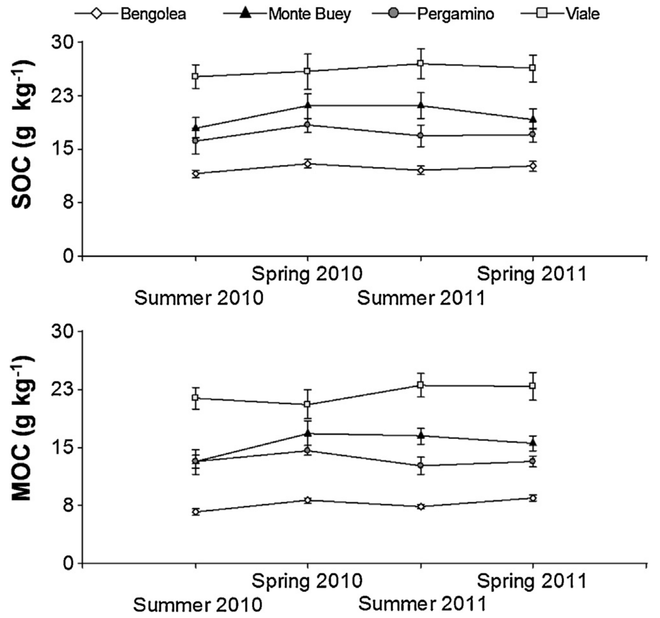

Fig. 3. Content of total organic carbon (SOC) (a) and organic carbon associated with the mineral fractions (MOC) (b) at different sampling dates.
The vertical bars represent ± one standard deviation.

and rainfall on SOC contents by analyzing a great variety of soils in the Pampean Region (Álvarez and Lavado, 1998; Hevia et al., 2003).

Comparison of the changes in soil use by the carbon pool index (CPI) revealed that SOC contents in the agricultural treatments were lower than NE in Bengolea, Monte Buey and Pergamino, but higher (CPI > 100) for GAP in Viale. PAP showed SOC contents ranging from 60 to 80% regarding NE for all the sites. In GAP, the SOC contents were 70% of the value determined in NE for Monte Buey and Pergamino, and similar and higher values to those of NE in Bengolea and Viale, respectively (Fig. 4a). CPI for MOC, as well as SOC, showed decreases in PAP, but less marked, and in GAP only lower contents than NE were observed in Monte Buey and Pergamino (Fig. 4b). SOC showed highly significant differences ($P < 0.001$) in the CPI between GAP and PAP in Bengolea, Monte Buey and Viale, and no significant differences in Pergamino (Fig. 4a). MOC showed significant differences between treatments in Viale (Fig. 4b). The vast agricultural history in the studied soils significantly affected SOC contents and to a lower extent MOC ones. The most noticeable effects of agricultural use were observed in Monte Buey and Pergamino, with contents between 60–70% and 70–80% of the value determined in NE for SOC and MOC, respectively, while in Bengolea and Viale the effects were less marked. The magnitude of the reductions of SOC falls within the range of reductions from 10 to 44%, which was previously observed in the Pampean Region (Álvarez et al., 2009) and between 20 and 50% observed in other parts of the world (Lal, 2004; Benbi et al., 2015). The perennial species in NE would make a greater and more continuous supply of shoot and root biomass (higher ISI), consuming more soil water, reducing the biological activity and causing a slower rate of mineralization as compared to the annual agricultural species (Bayer et al., 2006). In addition, NE is characterized by zero carbon exported compared with the grain harvest (Franzluebbers and Stuedemann, 2002). Therefore, SOC contents can be higher in NE than agricultural treatments. The CPI for SOC and MOC also showed a few temporal variations, which were revealed by low variation coefficients (less than 20% for both fractions). Throughout the period assessed (2 years), the results obtained agree with those observed at the beginning of the study (Table 1), revealing the stability of the fractions in the short-term.

The differences observed between agricultural treatments show that no-tillage with high predominance of monoculture (PAP) significantly reduced the SOC content. The permanent organic soil cover constitutes a previous requirement for the success of no-tillage systems (Derpsch et al., 2010). Soybean residues have a low C:N ratio and therefore they rapidly decompose, remaining on the soil surface for a short-time. On the other hand, incorporation of gramineous plants such as wheat or maize in the rotation (GAP), with high C:N ratios in their residues, results in a high soil protection. Several studies conducted worldwide reported that no-tillage and crop intensification are two efficient tools to increase the SOC (Sá et al., 2001; Johnson et al., 2005). The present study corroborates reports by those authors who argue that differences between GAP and PAP respond to different carbon inputs through the primary production (higher in GAP, with higher maize frequency and ISI) (Table 2), increase in carbon outputs by decomposition (higher in PAP, with lower ISI and therefore longer period of fallow) and combined changes in carbon inputs and outputs (Table 2).

3.2. Organic fractions (POC_c and POC_f)

Soil fractioning by particle size may indicate how the different organic fractions are modified by the changes in soil use and agricultural practices (Balesdent et al., 2000; von Lützow et al., 2007). Variable effects of the different factors were observed (Treatment and Season) in the organic fractions associated with the sand particle sizes (POC_c and POC_f) in each site.

In Bengolea, significant effects were observed in the treatments and sampling season on POC_c, while only the effect of the treatments was observed on POC_f. The POC_c presented significant differences both between the soil uses (NE vs agricultural practices) and between managements (GAP vs PAP) in summer, while in spring the differences between NE and GAP disappeared (Fig. 5a). In turn, GAP presented higher POC_c contents in spring

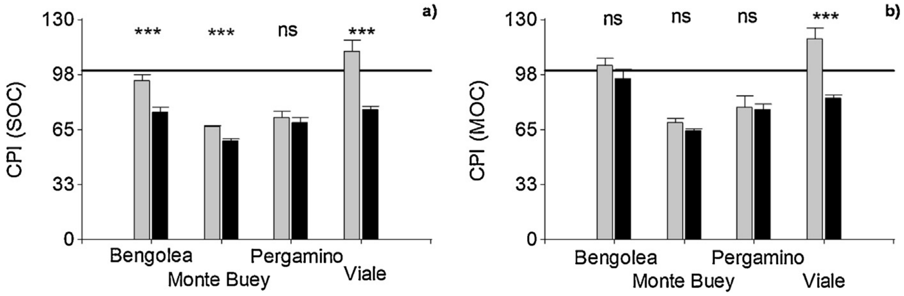

Fig. 4. Carbon pool index (CPI) for different agricultural practices. Natural environment was taken as reference (CPI = 100).
The bars represent standard errors. For each site, (***), (**), (*) and ns indicate significant differences at $P < 0.001$, $P < 0.01$, $P < 0.05$ and not significant, respectively, between treatments. Good agricultural practice (gray); poor agricultural practice (black).

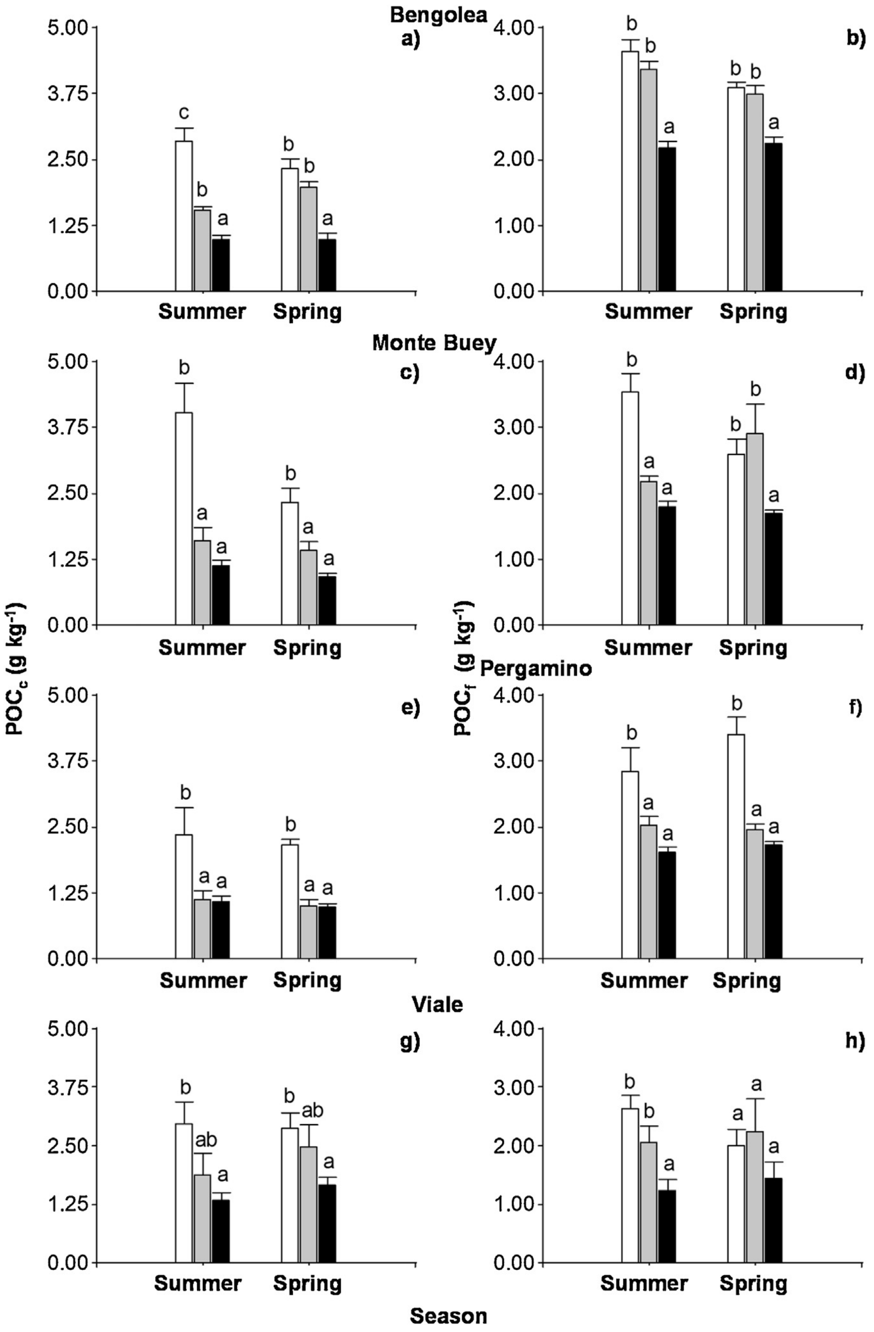

Fig. 5. Contents of coarse particulate organic carbon (POC$_c$) (a, c, e, g) and fine particulate organic carbon (POC$_f$) (b, d, f, h) to summer (2010 and 2011) and spring (2010 and 2011) at different sites.
The bars represent standard errors. Different letters each time between treatments indicate significant differences ($P < 0.05$). Natural Environment (white); good agricultural practice (gray); poor agricultural practice (black).

(1.97 g kg^{-1}) than in summer (1.54 g kg^{-1}), possibly due to the contribution of previous crop residues (summers 2010 and 2011 with crops) and lower contents in summer (spring 2010 under fallow), due to microbial activity and therefore, decomposition of residues favored by the soil type (sandy loam). It is widely accepted that decomposition occurs more rapidly in coarse texture soils (Strong et al., 1999). Variability of POC$_c$ throughout the two years of study in Bengolea was higher in the agricultural treatments (CV 26 and 20%, for PAP and GAP, respectively) than in NE (CV 16%) and higher than in SOC (Table 4). This higher variability in the agricultural treatments corresponded with different amounts and diversities of residues (different C:N ratio) that are incorporated in the soil. The POC$_f$ presented significant differences between agricultural managements with no differences between NE and GAP (Fig. 5b). Also, POC$_f$ showed similar behavior among treatments throughout the different sampling seasons, with no differences between sampling in summer and spring. The POC$_f$ exhibited lower temporal variation than the POC$_c$ throughout the two years of study, with CV of 13, 11 and 10% for NE, GAP and PAP, respectively (Table 4).

The carbon content of the >105 μm fraction was the one most affected by the agricultural practices compared with those of SOC and MOC, with values below 40% for PAP treatments both in summer and in spring and values ranging from 50 to 80% for GAP in summer and spring, respectively. Significant differences were found between GAP and PAP in both seasons (Fig. 6a). Reserves of

Table 4
Average values for the labile organic fractions at each of the sites and treatments.

Site	Treatment	POC_c (g kg^{-1})	POC_f (g kg^{-1})	CHt (g kg^{-1})	CHs (g kg^{-1})
Bengolea	NE	2.59 (16.1)	3.36 (13.2)	3.05 (24.3)	0.28 (11.8)
	GAP	1.75 (19.1)	3.18 (10.8)	2.60 (33.1)	0.29 (15.5)
	PAP	0.98 (26.4)	2.21 (10.1)	2.35 (30.6)	0.22 (16.2)
Monte Buey	NE	3.17 (44.4)	3.07 (25.0)	4.46 (25.6)	0.60 (45.1)
	GAP	1.50 (33.5)	2.54 (33.8)	3.53 (22.7)	0.34 (55.3)
	PAP	1.02 (21.6)	1.74 (10.5)	2.85 (19.4)	0.20 (49.6)
Pergamino	NE	2.25 (38.6)	3.12 (25.6)	4.28 (35.0)	0.53 (18.6)
	GAP	1.07 (31.2)	1.99 (12.9)	2.99 (23.6)	0.28 (29.0)
	PAP	1.03 (22.3)	1.67 (10.0)	2.02 (18.9)	0.21 (15.0)
Viale	NE	2.91 (25.7)	2.26 (31.9)	4.16 (32.0)	0.54 (40.2)
	GAP	2.17 (52.9)	2.14 (49.0)	4.26 (27.1)	0.41 (35.8)
	PAP	1.49 (29.2)	1.34 (41.7)	3.27 (29.0)	0.36 (36.0)

POC_c: coarse particulate organic carbon; POC_f: fine particulate organic carbon; CHt: total carbohydrates; CHs: soluble carbohydrates. The numbers in brackets indicate the coefficient of variation (CV%) of each parameter over two years.

POC_c also showed temporal variations with higher POC_c contents in spring than in summer, which were associated mainly with the rainfall peak and higher summer temperatures (Fig. 2a and b). Several authors report the importance of maize as a major contributor to carbon in agricultural systems (Diekow et al., 2005; Zanatta et al., 2007). In turn, some particular studies highlight the contribution of maize roots to increase soil organic matter (Balesdent and Balabane, 1996; Bolinder et al., 1999). In Bengolea, values of the soybean/maize relationship were much lower in GAP (1.5) compared with those in PAP (4) (Table 2); in other words, a higher participation of maize crop occurred in GAP, affecting POC_c due to the statements above. These results point out the importance of crop systems with high residue addition and reveal that no-tillage by itself is not sufficient to increase or maintain the organic contents in the soil. The management practices that favor the accumulation of SOC interact positively among themselves, so that the net balance of SOC will be higher when management practices are combined (Grant et al., 2001). The POC_f presented, in average, CPI values ranging from 95 to 66% for GAP and PAP treatments, respectively (Fig. 6b). Although, the same differences as in POC_c were observed between GAP and PAP, the POC_f levels in GAP tended to reach the same levels as NE in both sampling seasons.

In Monte Buey, significant effects of the treatments on both POC_c and POC_f, but no seasonal changes in either of the fractions were observed. The POC_c differed between NE and agricultural managements; however, no differences between GAP and PAP in both sampling seasons were found (Fig. 5c). In this site, POC_c also presented high temporal variability for all the treatments (CV 44, 34 and 22% for NE, GAP and PAP) (Table 4). The POC_f presented the same behavior as the POC_c in summer, while in spring this fraction allowed differentiation between agricultural practices (Fig. 5d). In this case, GAP (2.90 g kg^{-1}) presented 59% more of POC_f compared with PAP (1.69 g kg^{-1}). As in Bengolea, the POC_f allowed discriminating between agricultural treatments (GAP > PAP), in which GAP reaches the same contents as NE (GAP = NE). The temporal variability of this fraction was higher in GAP (CV 34%) than in NE (CV 25%) and PAP (CV 11%).

In Monte Buey, CPI values for POC_c were 50% and 34% in GAP and PAP treatments, respectively, with significant differences between GAP and PAP only in spring (Fig. 6c). In this case, the POC_c in the agricultural treatments represented approximately half (1.16 g kg^{-1}) of the mean levels in NE (2.32 g kg^{-1}). The CPI for POC_f exhibited significant differences between GAP and PAP both in summer and spring (Fig. 6d). However, while levels of POC_f in PAP did not exceed 70% of those observed in NE, in GAP higher levels than those in NE were observed; this effect can be attributed to the use of cover crops in GAP, which were established four months before the spring sampling.

In Pergamino, the POC_c and POC_f showed the same variations among treatments as those observed for SOC and MOC (NE>GAP = PAP), with no differences between sampling seasons. Only significant differences between NE and agricultural treatments in POC_c for both seasons were observed. The contents of POC_c in the agricultural treatments had a decrease of 1.20 g kg^{-1} compared with NE (Fig. 5e). The POC_f contents presented the same differences as the POC_c (NE>GAP = PAP) (Fig. 5f). However, when agricultural treatments were analyzed by CPI, significant difference was detected only in spring (Fig. 6f).

The temporal fluctuations for POC_c and POC_f, as in the other sites were higher than in SOC and MOC, with variations among treatments (Table 4). Therefore, an effect of the management practices on the dynamics of these labile fractions is observed. No significant differences were found in the CPI for the POC_c, in which the agricultural managements showed 50% less for POC_c independently of the treatment and sampling season (Fig. 6e). As previously mentioned, the CPI for the POC_f showed significant differences between agricultural practices in spring where GAP presented approximately 60% of the POC_f for NE, while PAP did not exceed 50% (Fig. 6f).

In Viale, POC_c content was significant higher in NE than in PAP, while no differences were observed between agricultural treatments and between NE and GAP for both seasons (Fig. 5g). As in Pergamino, no differences were detected between sampling seasons either for POC_c or POC_f. However, the latter fraction revealed differences between GAP and PAP in summer. The temporal variability at this site was higher for the GAP (CV 53–49%), PAP (CV 29–42%), than for NE (CV 26–32%) for POC_c and POC_f, respectively (Table 4). Differences in the CPI between agricultural treatments were only observed for POC_f, in which GAP, like in Bengolea, presented similar contents to NE (CPI = 85–100%). This similarity between sites may be due in Bengolea to a higher proportion of labile organic fractions (23% of POC_f) enabling good practices by rapidly increasing carbon contents in the soil, and, in turn, inadequate management practices reduce it (Fig. 5a and b). On the other hand, due to high content of expandable clays in Viale, a large amount of contributions of organic residues may be physically protected by microbial decomposition.

The reductions in SOC caused by agricultural practices were mainly found in the coarse fraction (>105 μm) in the surface layer. In general, POC_c, represented by the CPI, presented between 34–52% and 50–74% of the natural contents in PAP and GAP,

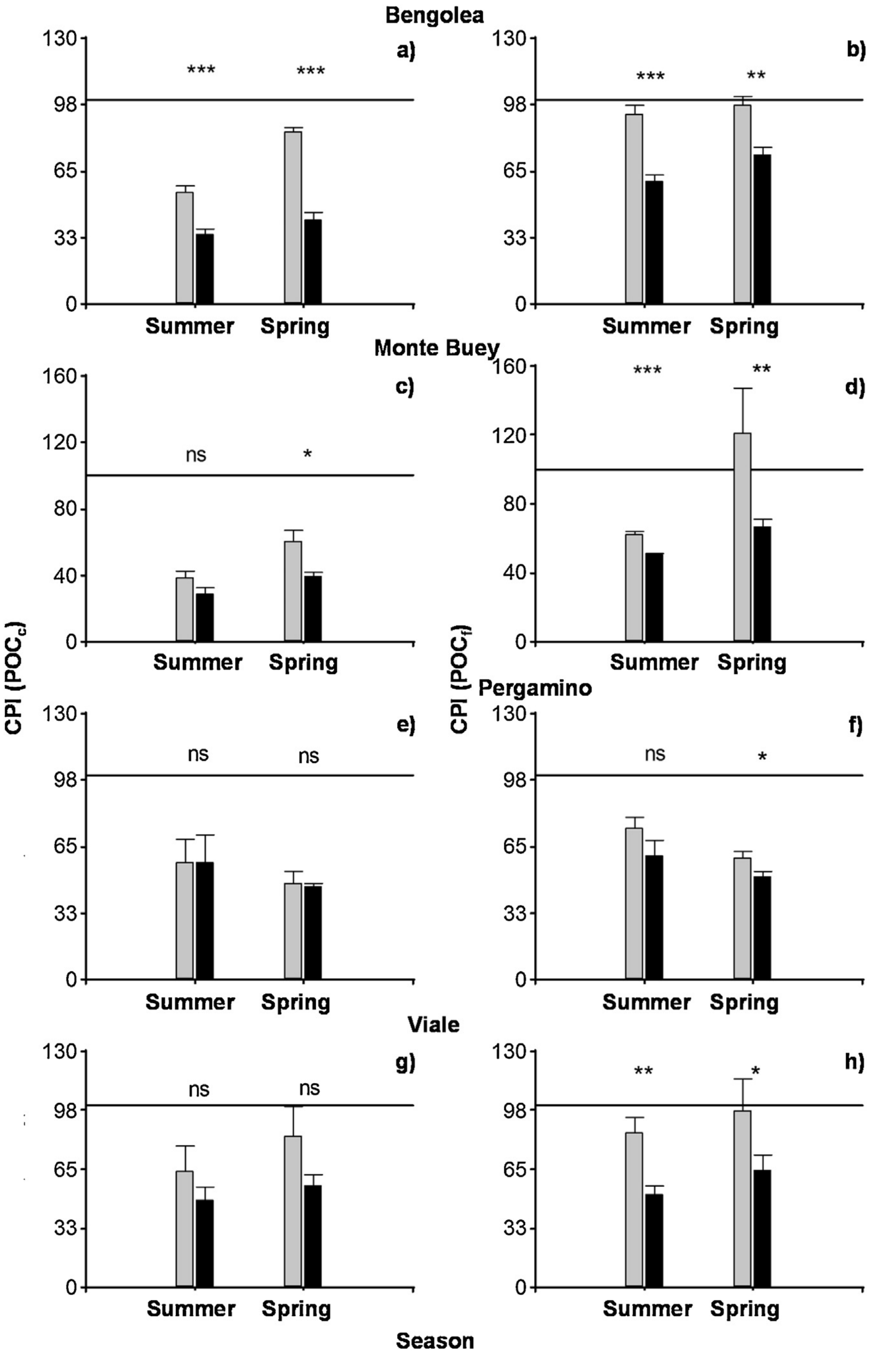

Fig. 6. Effect of management practices on the carbon pool index for coarse particulate organic carbon (POC_c) (a, c, e, g) and fine particulate organic carbon (POC_f) (b, d, f, h) at different sites. Natural environment was taken as reference (CPI = 100).
The bars represent standard errors. (***), (**), (*) and ns indicate significant differences at $P < 0.001$, $P < 0.01$, $P < 0.05$ and not significant, respectively between treatments. Good agricultural practice (gray); poor agricultural practice (black).

respectively. Changes in land use frequently affect mainly the carbon of the sand fraction, which includes the labile carbon (Tiessen and Stewart, 1983). Figueiredo et al. (2010) in Brazil reported a reduction of 46% in the organic fraction >53 μm in Oxisols compared with a soil under native vegetation. In a Typic Argiudoll, with monoculture and rotation cropping systems, Duval et al. (2014) determined that reductions in POC_c due to anthropic effects were higher compared with the other organic fractions, with reductions of up to 50% in the POC_c and no visible changes in the SOC, revealing high susceptibility of POC_c to degrade.

3.3. Carbohydrates fractions (CHt and CHs)

The CHt, in general, showed higher differences among treatments in the spring samplings. In this season for the sites Bengolea, Monte Buey and Pergamino significant differences (between 28 and 38% lower in PAP) (Fig. 7a, c and e) were observed between NE and PAP in the CHt content. In turn, the highest differences between agricultural treatments were also observed (GAP vs PAP), with significant differences in Bengolea and Pergamino (GAP > PAP), while in Monte Buey and Viale were not

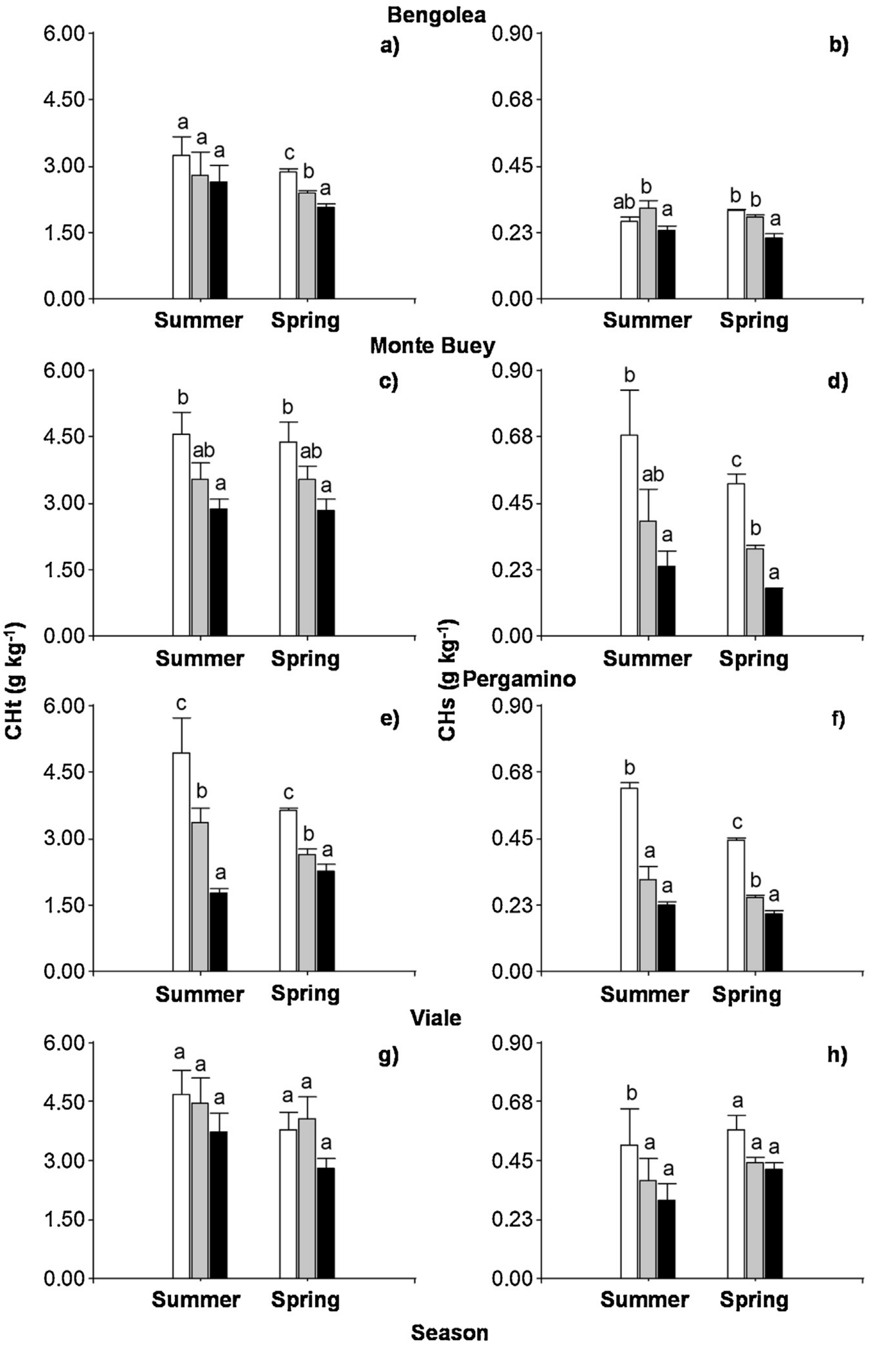

Fig. 7. Content of total carbohydrates (CHt) (a, c, e, g) and soluble carbohydrates (CHs) (b, d, f, h) to summer (2010 and 2011) and spring (2010 and 2011) at different sites. The bars represent standard errors. Different letters each time between treatments indicate significant differences ($P < 0.05$). Natural Environment (white); Good agricultural practice (gray); poor agricultural practice (black).

significant (Fig. 7a, c, e and g). The variability of CHt throughout the two years of study was higher than that of SOC (Tables 3 and 4). This is attributed to the labile nature of this fraction, which is composed mainly of plant debris and microorganisms (Gregorich et al., 1994). In general, a higher variability (CV 26–35%) in NE than in agricultural treatments (CV 19–29%) was observed possibly due to a greater diversity of plant debris incorporated to the soil (Hevia et al., 2008). Conversely, in Bengolea variability was higher in agricultural treatments (CV >31%) than in NE (CV 24%) (Table 4). In this case, NE presented bermudagrass as a dominant species, therefore the amount of debris contribution was lower than in the agricultural treatments.

The differences among treatments in the CHs and CHt, were better observed in spring, where significant differences between NE and PAP in all the sites were found, with higher contents in NE (Fig. 7b, d, f and h). Differences between agricultural treatments were also observed in Bengolea, Monte Buey and Pergamino, with higher contents of CHs in GAP. The differences in the contents of CHs in soils under different agricultural treatments indicated differences in the amount and type of carbon inputs to soil (Campbell et al., 1999). Higher production of aboveground biomass associated with GAP (Table 2), probably helped to maintain CHs contents similar to NE in Bengolea (Fig. 7b). The CHs presented a great variability in the different sites, with monoculture situations

(PAP-Pergamino), low temporal differences (CV 15%) and situations with large amounts and types of contributions (GAP-Monte Buey) with high temporal variability (Table 4). This indicates that the CHs are affected by both the amount and the type of residues incorporated to the soil throughout rotation. The CHs responded rapidly to changes in the carbon provision and were a major indicator of soil quality (Gregorich et al., 1994).

The impact of the agricultural practices on the soil quality, through CPI for CHt and CHs presented significant differences between GAP and PAP, with no fluctuations between seasons spring and summer (Fig. 8). In GAP, the CPI for CHt was higher, showing values between 72 and 82% of the levels observed in NE for Monte Buey and Pergamino, while in PAP values were significantly lower (57 to 62%). In Bengolea, the CPI-CHt was 83–84% and 71–82% for GAP and PAP, respectively, while in Viale higher values to NE in GAP (100–113%) and significantly lower in PAP (85–88%) were found. In general, an increase in the CHt in GAP was observed, with 7, 15, 20 and 21% for Bengolea, Monte Buey, Pergamino and Viale, respectively.

For CHs, the CPI showed higher reductions in those sites with medium to fine textures (Monte Buey, Pergamino and Viale) compared with those of CHt. This is attributed to the effect of agricultural practices (Fig. 8). In turn, CPI for CHs detected significant differences among the agricultural treatments, where

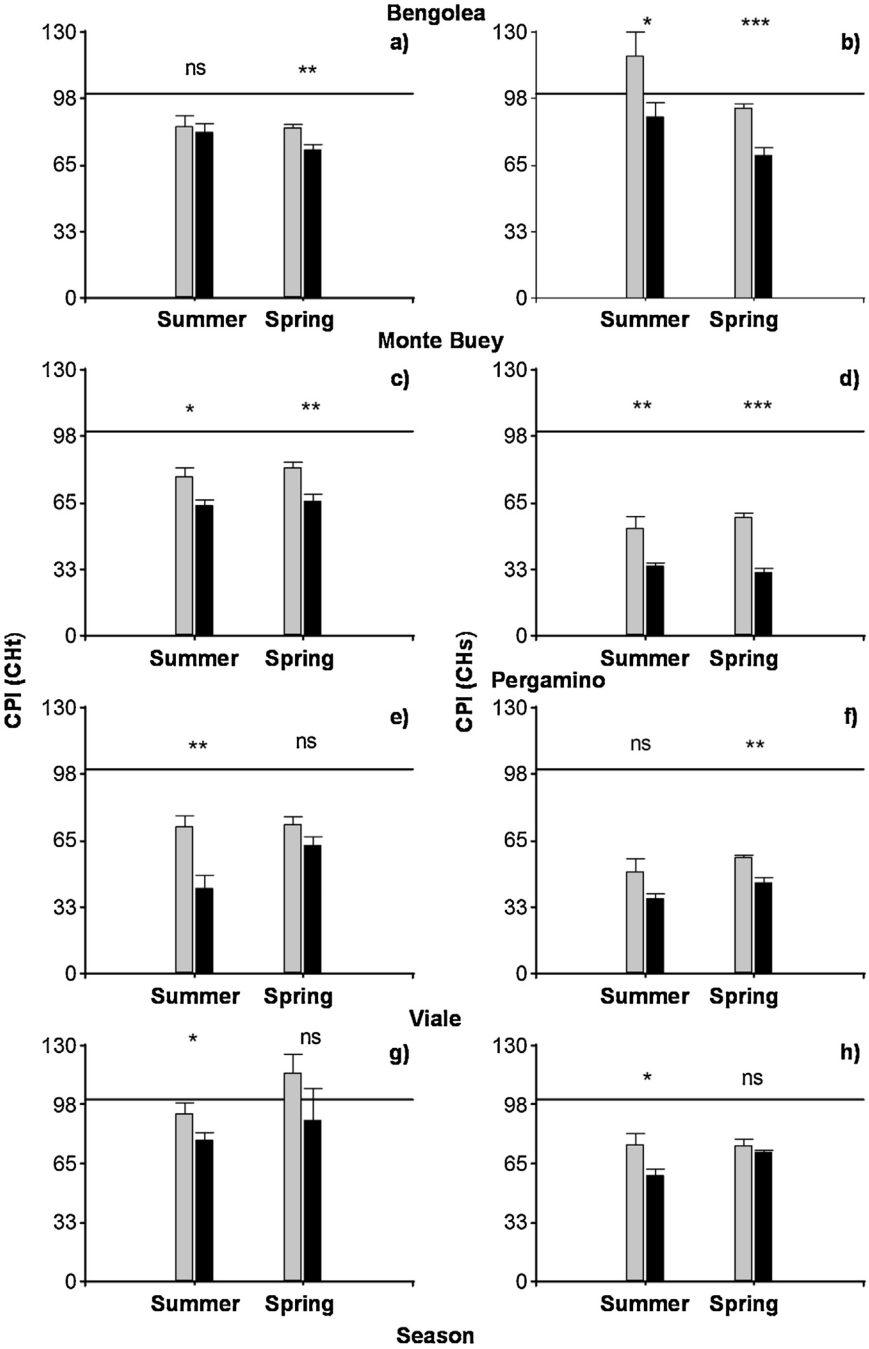

Fig. 8. Effect of management practices on the carbon pool index for total carbohydrates (CHt) (a, c, e, g) and soluble carbohydrates (CHs) (b, d, f, h) at different sites. Natural environment was taken as reference (CPI = 100).
The bars represent standard errors. (***), (**), (*) and ns indicate significant differences at $P < 0.001$, $P < 0.01$, $P < 0.05$ and not significant, respectively between treatments. Good agricultural practice (gray); poor agricultural practice (black).

GAP presented an increase of 27, 22, 13 and 10% for Bengolea, Monte Buey, Pergamino and Viale, respectively. Therefore, the reduction in CH contents observed in PAP indicates that no-tillage as a conservationist practice of the soil was not sufficient to maintain or improve the soil quality. These results agree with those reported by other authors (Vieira et al., 2007; de Oliveira Ferreira et al., 2013).

From the point of view of the maximum difference or sensitivity among treatments, for most of the organic fractions studied, early spring season seems to be the best period for soil sampling. The CPI shows that the agricultural treatments led to higher variations in all the labile organic fractions (POC_c, POC_f, CHt and CHs) compared with SOC and MOC. Independently of the soil type, the CPI was a sensitive indicator in these systems under no-tillage. Other studies have also demonstrated changes in the labile organic contents due to changes in the management practices (Cambardella and Elliott 1992; Banger et al., 2010). For the soils analyzed in the present study the POC_f was the most sensitive fraction between different uses (NE vs agricultural practices) and management practices (GAP vs PAP).

3.4. Soil total nitrogen and C:N ratio

The soil total nitrogen (Nt) contents varied widely among land uses and soil managements (from 0.99 to 2.40 g kg^{-1}). The Nt contents showed an increasing trend in NE, with significant differences compared with GAP in Monte Buey and Pergamino and with PAP in Monte Buey Pergamino and Viale. In average, the Nt contents in NE were 5, 41, 31 and 12% higher than those in the agricultural treatments in Bengolea, Monte Buey, Pergamino and Viale, respectively. In turn, differences between GAP and PAP were only observed in Monte Buey and Viale with approximately 25% more of Nt in GAP. A significant correlation was found between the values of SOC and Nt ($r = 0.88$, $P < 0.001$), therefore, the effect of the treatments and sites on the C:N ratio was the same as for such variables.

3.5. Principal components analysis of soil properties and management practices

To synthesize the results and help understand the effects of the different treatments, we conducted a principal components analysis (PCA) of some of the physical (BD, TP, $P_{>30}$) and chemical properties, mainly associated with SOC and its fractions (Nt, POC_f, MOC, CHt and CHs) and indices associated with the soil properties (C:N, POC_{c+f}:SOC, SOC:clay, IEE) and the management (ISI) for the surface layer of the soils (0–20 cm) (Fig. 9). The two first PCs (PC1 and PC2) of the PCA account for 71% of the total variability provided by the parameters studied. The PC1 explained 44% of the variance, in which the organic fractions of the SOC (POC_f and CHt), aeration capacity ($P_{>30}$) and the indices (IR, SI) were positively weighted and were counteracted by BD (Table 5). PC1 mainly separates the different treatments (NE, GAP and PAP). Soil quality improved when vegetation remained for a longer time (higher ISI), generating a higher amount of residues to the soil. This contribution increased the different labile organic fractions (POC_f and CHt), enhanced carbon storage (higher SI) and affected physical properties positively ($P_{>30}$) or negatively (BD). PC2 explained 27% of the variance, in which TP, MOC and C:N ratio showed positive associations in that component, while BD, SOC:clay and POC_{c+f}:SOC associated negatively (Table 5). This second PC allowed distinguishing among the different sites (Viale, Monte Buey, Pergamino, Bengolea). These differences among sites (PC2) were based on the fact that the variables with higher variability values in that component were those related to typical characteristics of each site. In other words, the upper part of the soils is characterized by the presence of high C:N ratio, TP and MOC, which are typical of soils with higher contents of clays (higher protection) and high annual rainfall (higher carbon inputs) as those in Viale, while the lower part of the soils shows higher POC_{c+f}:SOC, SOC:clay and BD, which are associated with coarse-textured soils and lower rainfall values (Bengolea); Monte Buey and Pergamino showed intermediate characteristics (Fig. 9). In turn, Fig. 9 also indicates that GAP and PAP were further than NE in sites of loamy soil textures (Monte Buey and Pergamino) compared with those sites with contrasting textures (Bengolea and Viale) where separation among NE, GAP and PAP was gradual.

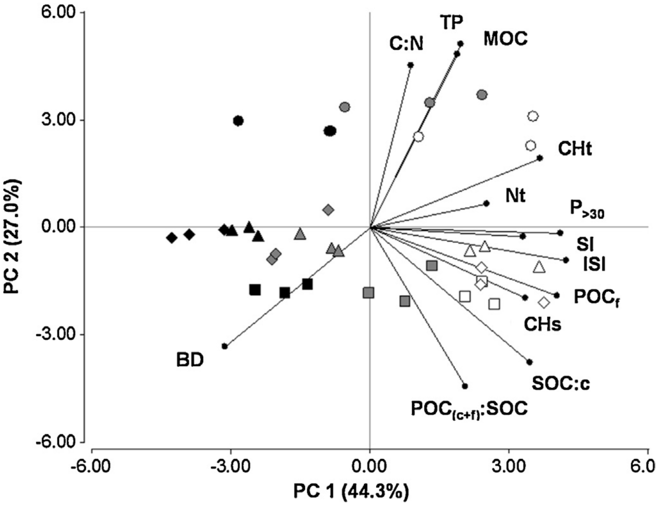

Fig. 9. Biplot of principal components analysis. Vectors indicate the relative weight of each variable on the axes. Good Agricultural Practice (GAP) (gray); Poor Agricultural Practices (PAP) (black) and Natural environment (NE) (white) for Bengolea (square), Monte Buey (triangles), Pergamino (diamonds) and Viale (circles).
Organic carbon associated with the mineral fraction (MOC); soil total nitrogen (Nt); total porosity (TP); intensification sequence index (ISI); structural index (SI); soluble and total carbohydrates (CHs and CHt); large pores (>30 μm) ($P_{>30}$); fine particulate organic carbon (POCf); bulk density (BD); coarse particulate organic carbon plus fine particulate organic carbon:soil organic carbon ($POC_{(c+f)}$:SOC); soil organic carbon:clay (SOC:c).

Table 5
Matrix of principal component analysis (PCA) obtained with spring soil samples.

Variance explained	PC1 44%	PC2 27%
Bulk density (BD)	−0.28***	−0.30***
Total porosity (TP)	0.17	0.45***
Pores >30 μm ($P_{>30}$)	0.32***	−0.02
Organic carbon 105–53 μm (POC_f)	0.36***	−0.17
Organic carbon <53 μm (MOC)	0.17	0.43***
Total carbohydrates (CHt)	0.33***	0.17
Soluble carbohydrates (CHs)	0.30***	−0.17
Soil total nitrogen (Nt)	0.22*	0.06
C:N	0.08	0.40***
POC_{c+f}:SOC	0.18	−0.39***
SOC/clay	0.31***	−0.33***
Structural index (SI)	0.38***	−0.02
Intensification sequence index (ISI)	0.37***	−0.08

* Indicate significant associations at $P < 0.05$.
*** Indicate significant associations at $P < 0.001$.

The multivariate analysis has proven to be effective in identifying soil properties that responded to agricultural practices and offered a clear alternative to univariate analysis of ratios for evaluating changes in soil quality (Monreal and Bergstrom, 2000). Also, the analysis has shown to be a useful tool to reduce the number of variables to be considered in the evaluation of soil quality. Results from this analysis revealed that to differentiate among treatments, chemical (POC_f and CHt), physical (BD and $P_{>30}$), and indices (SOC: clay, SI and ISI) were the best variables to explain the total variance of the dataset in the four sites. Therefore, these indicators/indices should be included in any minimum data set to assess agricultural soil quality under NT in the central Pampean Region.

4. Conclusions

The sensitivity or temporal variations of the different organic fractions of SOC (POC_c, POC_f, CHt and CHs) were much higher than those of SOC in all the treatments. In turn, magnitude of variability differed among the fractions, where temporal fluctuations increased in the following order $MOC < SOC < POC_f \leq CHt < CHs \leq POC_c$.

The POC_f, through the CPI, was the most sensitive organic fraction for differentiating agricultural practices, with the greatest differences in early spring. With regard to the time of sampling to detect differences among treatments, the spring sampling period appeared to be the best time for collecting samples.

Multivariate analysis allowed discriminating among sensitive variables that characterize each site. Among the group of variables evaluated in the present study, chemical (POC_f and CHt), physical properties (BD and $P_{>30}$) and indices (SOC: clay, SI and ISI) were the best in showing the differences among treatments for the four sites. Therefore, these indicators/indices, should be included in any minimum dataset to assess agricultural soil quality under NT in the studied zone.

Based on these results it is possible to select indicators/indices more sensitive to agricultural practices with lower seasonal variation, while the most dynamic organic fractions will allow a better understanding of soil biological changes (i.e.,: Figuerola et al., 2012, 2015; Agaras et al., 2014; Ferrari et al., 2015). The present article and those mentioned above show a set of variables for characterizing and diagnosing different soil managements in order to increase agricultural productivity keeping the sustainability of the process and preserving soil source.

Acknowledgements

The authors gratefully acknowledge the financial support granted by the Ministerio de Ciencia, Tecnología e Innovación Productiva (Grant FONCyT PAE-36976-PID53). The authors wish to thank the following institutions which provided infrastructure and equipments for this research: Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Centro de Recursos Naturales Renovables de la Zona Semiarida (CERZOS) and Departamento de Agronomía. We also want to thank to María Cecilia MORENO, Comisión Investigaciones Científicas (Pcia. Buenos Aires) for her help in the article translation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.still.2016.01.004.

References

Agaras, B.C., Wall, L.G., Valverde, C., 2014. Influence of agricultural practices and seasons on the abundance and community structure of culturable pseudomonads in soils under no-till management in Argentina. Plant Soil 382 (1–2), 117–131.

Álvarez, R., 2005. Carbon stocks in Pampean soils: a simple regression model for estimation of carbon storage under non degraded scenarios. Commun. Soil Sci. Plant Anal. 36, 1583–1589.

Álvarez, R., Lavado, R.S., 1998. Climate, organic matter and clay content relationships in the Pampa and Chaco soils, Argentina. Geoderma 83, 127–141.

Álvarez, C.R., Taboada, M.A., Gutierrez Boem, F.H., Bono, A., Fernandez, P.L., Prystupa, P., 2009. Topsoil properties as affected by tillage systems in the rolling Pampa region of Argentina. Soil Sci. Soc. Am. J. 73, 1242–1250.

Balesdent, J., Balabane, M., 1996. Major contribution of roots to soil carbon storage inferred from maize cultivated soils. Soil Biol. Biochem. 28, 1261–1263.

Balesdent, J., Chenu, C., Balabane, M., 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil Tillage Res. 53 (3), 215–230.

Banger, K., Toor, G.S., Biswas, A., Sidhu, S.S., Sudhir, K., 2010. Soil organic carbon fractions after 16-years of applications of fertilizers and organic manure in a Typic Rhodalfs in semiarid tropics. Nutr. Cycl. Agroecosys. 86, 391–399.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pavinato, A., Dieckow, J., 2006. Carbon sequestration in two Brazilian Cerrado soils under no-tillage. Soil Tillage Res. 86 (2), 237–245.

Bayer, C., Diekow, J., Amado, T.J.C., Eltz, F.L.F., Vieira, F.C.B., 2009. Cover crop effects increasing carbon storage in a subtropical no-till sandy Acrisol. Commun. Soil Sci. Plant 40, 1499–1511.

Benbi, D.K., Boparai, A.K., Brar, K., 2014. Decomposition of particulate organic matter is more sensitive to temperature than the mineral associated organic matter. Soil Biol. Biochem. 70, 183–192.

Benbi, D.K., Brar, K., Toor, A.S., Singh, P., 2015. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. Geoderma 237–238, 149–158.

Blair, G.J., Lefroy, R.D.B., Lisle, L., 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index, for agricultural systems. Aust. J. Agric. Res. 46, 1459–1466.

Blair, N., Faulkner, R.D., Till, A.R., Poulton, P.R., 2006. Long-term management impactions on soil C, N and physical fertility: Part I: broad balk experiment. Soil Tillage Res. 91, 30–38.

Blake, G.R., Hartge, K.H., 1986. Bulk density, In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Agronomy. second ed. American Society of Agronomy, Madison, WI, USA, pp. 363–375.

Bol, R., Poirier, N., Balesdent, J., Gleixner, G., 2009. Molecular turnover time of soil organic matter in particle-size fractions of an arable soil. Rapid Commun. Mass Spectrom. 23 (16), 2551–2558.

Bolinder, M.A., Angers, D.A., Giroux, M., Laverdiere, M.R., 1999. Estimating C inputs retained as soil organic matter from corn (*Zea mays* L.). Plant Soil 215, 85–91.

Bremner, J.M., 1996. Nitrogen-total. In: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnson, C.T., Sumner, M.E. (Eds.), Methods of Soil Analysis. Part 3. Chemical Methods. SSSA Book Series, vol. 5. Soil Science Society of America, Madison, WI, pp. 1085–1121.

Cambardella, C.A., Elliott, E.T., 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56, 777–783.

Campbell, C.A., Lafond, G.P., Biederbeck, V.O., Wen, G., Schoenau, J., Hahn, D., 1999. Seasonal trends in soil biochemical attributes: effects of crop management on a Black Chernozem. Can. J. Soil Sci. 79, 85–97.

Caviglia, O.P., Sadras, V.O., Andrade, F.H., 2004. Intensification of agriculture in the south-eastern Pampas: I. Capture and efficiency in the use of water and radiation in double cropped wheat–soybean. Field Crops Res. 87, 117–129.

Caviglia, O.P., Andrade, F.H., 2010. Sustainable intensification of agriculture in the argentinean pampas: capture and use efficiency of environmental resources. Am. J. Plant Sci. Biotechnol. 3, 1–8.

Caviglia, O.P., Sadras, V.O., Andrade, F.H., 2011. Yield and quality of wheat and soybean in sole- and double-cropping. Agron. J. 103, 1081–1089.

de Oliveira Ferreira, A., Amado, T.J.C., Nicoloso, R.S., Sa, J.C.M., Fiorin, J.E., Hansel, D.S. S., Menefee, D., 2013. Soil carbon stratification affected by long-term tillage and cropping systems in southern Brazil. Soil Tillage Res. 133, 65–74.

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. Int. J. Agric. Biol. Eng. 3, 1–25.

Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L., Tablada, M., Robledo, C.W., 2013. InfoStat. Grupo InfoStat, FCA. Universidad Nacional de Córdoba, Argentina.

Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D.P., Kogel-Knabner, I., 2005. Carbon and nitrogen stocks in physical fractions of a subtropical Acrisol as influenced by long-term no-till cropping systems and N fertilization. Plant Soil 268, 319–328.

Dubois, M., Gilles, K., Hamilton, J., Rebers, P., Smith, R., 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28, 350–356.

Duval, M.E., Galantini, J.A., Iglesias, J.O., Canelo, S., Martinez, J.M., Wall, L., 2013. Analysis of organic fractions as indicators of soil quality under natural and cultivated systems. Soil Tillage Res. 131, 11–19.

Duval, M., de Sa Pereira, E., Iglesias, J.O., Galantini, J.A., 2014. Efecto de uso y manejo del suelo sobre las fracciones de carbono orgánico en un Argiudol. Ci. Suelo 32 (1), 105–115.

ECAF (European Conservation Agricultural Federation), 1999. Conservation Agriculture in Europe: Environmental, Economic and EU Policy Perspectives. ECAF, Brussels 23 pp..

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

Ferrari, A.E., Ravnskov, S., Larsen, J., Tønnersen, T., Maronna, R.A., Wall, L.G., 2015. Crop rotation and seasonal effects on fatty acid profiles of neutral and phospholipids extracted from no-till agricultural soils. Soil Use Manage. 31 (1), 165–175.

Figueiredo, C.C., Resck, D.V.S., Carneiro, M.A.C., 2010. Labile and stable fractions of soil organic matter under management systems and native cerrado. Rev. Bras. Cienc. Solo 34, 907–916.

Figuerola, E.L.M., Guerrero, L.D., Rosa, S.M., Simonetti, L., Duval, M.E., Galantini, J.A., Bedano, J.C., Wall, L.G., Erijman, L., 2012. Bacterial indicator of agricultural management for soil under no-till crop production. PLoS One 7 (11), e51075. doi:http://dx.doi.org/10.1371/journal.pone.0051075.

Figuerola, E.L., Guerrero, L.D., Türkowsky, D., Wall, L.G., Erijman, L., 2015. Crop monoculture rather than agriculture reduces the spatial turnover of soil bacterial communities at a regional scale. Environ. Microbiol. 17 (3), 678–688.

Franzluebbers, A.J., Hons, F.M., Zuberer, D.A., 1995. Soil organic carbon, microbial biomass and mineralizable carbon and nitrogen in sorghum. Soil Sci. Soc. Am. J. 59, 460–466.

Franzluebbers, A.J., Stuedemann, J.A., 2002. Particulate and non-particulate fractions of soil organic carbon under pastures in the Southern Piedmont USA. Environ. Pollut. 116, S53–S62.

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.

Gee, G.W., Bauder, J.W., 1986. Particle size analysis, In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Agron. Monograph No. 9. 2nd ed. ASA, Madison WI, pp. 337–382.

Graham, M.H., Haynes, R.J., Meyer, J.H., 2002. Soil organic matter content and quality: effects of fertilizer applications: burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biol. Biochem. 34, 93–102.

Grant, F., Juma, N., Robertson, J., Izaurralde, R., Mcgill, W., 2001. Long-term changes in soil carbon under different fertilizer, manure, and rotation: testing the mathematical model ecosys with data from the Breton plots. Soil Sci. Soc. Am. J. 65, 205–214.

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 soils. Can. J. Soil Sci. 74, 367–385.

Hassink, J., Bouwman, L.A., Zwart, K.B., Bloem, J., Brussaard, L., 1993. Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. Geoderma 57, 105–128.

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.

Hevia, G.G., Buschiazzo, D.E., Díaz Raviña, M., 2008. Variación estacional de compuestos orgánicos del suelo en diferentes sistemas de labranza. In: Galantini, J. (Ed.), Estudio de las fracciones orgánicas en suelos de la Argentina. Editorial Universidad Nacional del Sur., pp. 147–170.

Johnson, J.M.F., Reicosky, D.C., Allmaras, R.R., Sauer, T.J., Venterea, R.T., Dell, C.J., 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. Soil Tillage Res. 83, 73–94.

Kay, B.D., Vanden Bygaart, A.J., 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil Tillage Res. 66, 107–118.

Klute, A., 1986. Water retention: laboratory methods, In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph No. 9. 2nd ed. ASA and SSSA, Madison, WI pp. 635–660.

Lal, R., Blum, W.H., Valentine, C., Stewart, B.A., 1998. Methods for assessment of soil degradation. Advances in Soil Science. Lewis Publishers, Boca Raton, pp. p558.

Lal, R., 2004. Agricultural activities and the global carbon cycle. Nutr. Cycl. Agroecosyst. 70, 103–116.

Li, X.G., Li, Y.K., Li, F.M., Ma, M., Zhang, P.L., Yin, P., 2009. Changes in soil organic carbon, nutrients and aggregation after conversion of native desert soil into irrigated arable land. Soil Tillage Res. 104, 263–269.

Martin, A., Mariotti, A., Balesdent, J., Lavelle, P., Vuattoux, R., 1990. Estimate of organic matter turnover rate in a savanna soil by C-13 natural abundance measurements. Soil Biol. Biochem. 22 (4), 517–523.

Melero, S., López-Garrido, R., Madejón, E., Murillo, J.M., Vanderlinden, K., Ordóñez, R., Moreno, F., 2009. Long-term effects of conservation tillage on organic fractions in two soils in southwest of Spain. Agric. Ecosyst. Environ. 133, 68–74.

Monreal, C.M., Bergstrom, D.W., 2000. Soil enzymatic factors expressing the influence of land use, tillage system and texture on soil biochemical quality. Can. J. Soil Sci. 80, 419–428.

Noellemeyer, E., Quiroga, A.R., Estelrich, D., 2006. Soil quality in three range soils of the semi-arid Pampa of Argentina. J. Arid Environ. 65, 142–155.

Novelli, L.E., Caviglia, O.P., Melchiori, R.J.M., 2011. Impact of soybean cropping frequency on soil carbon storage in Mollisols and Vertisols. Geoderma 167–168, 254–260.

Paustian, K., Collins, H.P., Paul, E.A., 1997. Management controls on soil carbon. In: Paul, E.A., Paustian, K., Elliott, E.A., Cole, C.V. (Eds.), Soil Organic Matter in Temperate Ecosystems: Long Term Experiments in North America. CRC Press, Boca Raton, FL, pp. 15–49.

Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., Van Wesemael, B., Schumacher, J., Gensior, A., 2011. Temporal dynamics of soil organic carbon after land-use change in the temperate zone-carbon response functions as a model approach. Glob. Change Biol. 17 (7), 2415–2427.

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

Puget, P., Lal, R., 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. Soil Tillage Res. 80, 201–213.

Raiesi, F., 2006. Carbon and N mineralization as affected by soil cultivation and crop residue in a calcareous wetland ecosystem in Central Iran. Agric. Ecosyst. Environ. 112, 13–20.

Roldán, A., Salinas-García, J.R., Alguacil, M.M., Caravaca, F., 2005. Changes in soil enzyme activity, fertility, aggregation and C sequestration mediated by conservation tillage practices and water regime in a maize field. Appl. Soil Ecol. 30, 11–20.

Sá, J.C.D.M., Cerri, C.C., Dick, W.A., Lal, R., Filho, S.P.V., Piccolo, M.C., Feigl, B.E., 2001. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Sci. Soc. Am. J. 65, 1486–1499.

Sasal, M.C., Castiglioni, M.G., Wilson, M.G., 2010. Effect of crop sequences on soil properties and runoff on natural-rainfall erosion plots under no tillage. Soil Tillage Res. 108, 24–29.

Soil Survey and Staff, 2010. Keys to Soil Taxonomy, 11th ed. USDA-Natural Resources Conservation Service, Washington, DC.

Strong, D.T., Sale, P.W.G., Helyar, K.R., 1999. The influence of the soil matrix on nitrogen mineralization and nitrification. IV. Texture. Aust. J. Soil Res. 37, 329–344.

Tiessen, H., Stewart, J.W.B., 1983. Particle-size fractions and their use in studies of soil organic matter: II. Cultivation effects on organic matter composition in size fractions. Soil Sci. Soc. Am. J. 47, 509–514.

Verma, S., Sharma, P.K., 2007. Effect of long-term manuring and fertilizer on carbon pools, soil structure, and sustainability under different cropping systems in wet-temperate zone of northwest Himalayas. Biol. Fertil. Soils 19, 235–240.

Vieira, F.C.B., Bayer, C., Zanatta, J.A., Diekow, J., Mielniczuk, J., He, Z.L., 2007. Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. Soil Tillage Res. 96 (1), 195–204.

von Lützow, M., Kögel-Knabner, I., Ekschmitt, K., Flessa, H., Guggenberger, G., Matzner, E., Marschner, B., 2007. SOM fractionation methods: relevance to functional pools and to stabilization mechanisms. Soil Biol. Biochem. 39, 2183–2207.

Wall, L.G., 2011. The BIOSPAS consortium: soil biology and agricultural production. In: de Bruijn, F.J. (Ed.), Handbook of Molecular Microbial Ecology I. John Wiley and Sons, Inc., Hoboken, NJ, USA, pp. 299–306.

Zanatta, J.A., Bayer, C., Diekow, J., Vieira, F.C.B., Mielniczuk, J., 2007. Soil organic carbon accumulation and carbon costs related to tillage: cropping systems and nitrogen fertilization in a subtropical Acrisol. Soil Tillage Res. 94, 510–519.

Zimmermann, M., Leifeld, J., Abiven, S., Schmidt, M.W.I., Fuhrer, J., 2007. Sodium hypochlorite separates an older soil organic matter fraction than acid hydrolysis. Geoderma 139 (1–2), 171–179.

Zornoza, R., Mataix-Solera, J., Guerrero, C., Arcenegui, V., Mataix-Beneyto, J., Gómez, I., 2008. Validating the effectiveness and sensitivity of two soil quality indices based on natural forest soils under Mediterranean conditions. Soil Biol. Biochem. 40, 2079–2087.