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Cultivation effects on the distribution of organic carbon, total nitrogen and phosphorus in soils of the semiarid region of Argentinian Pampas

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Abstract

Cultivation of native land can reduce the quality of soil by decreasing topsoil contents of organic carbon, total nitrogen, and phosphorus in the semiarid Pampas of Argentina. The objective of this study was to analyze the changes produced by cultivation on organic carbon (OC), total nitrogen (TN) and phosphate (inorganic and organic fractions) in two aggregate sizes of three different semiarid soils of Argentina as a function of soil depth. The study was carried out on three soils (loamy Hapludoll, loamy Haplustoll and sandy loam Haplustoll), with two uses compared at each site. Generally, the Caldenal savanna-like ecosystem (native soil) and a cultivated counterpart with annual crops for more than 60 years (cultivated soil) were compared. Results showed that all soils had similar distribution patterns with depth of OC, TN, total inorganic phosphorus (Pi), organic phosphorus (Po) and available phosphorus (Pa) in the 100–2000 μm and <100 μm aggregates of both the native and cultivated soils. Contents of OC, TN and Pi in the whole soil (<2000 μm) decreased sharply with depth in native soils (OC: 50%, TN: 45% and Pi: 23%), but they had a more homogeneous distribution in cultivated soils. These tendencies were attributed to the stratification occurring in non-disturbed native soils and the mixing of the upper 20 cm in cultivated soils. Cultivation produced losses of OC (73%) and Po (64%) from the 100–2000 μm aggregates at both depths in the sandy loam Haplustoll, while it produced losses of TN (52%) and Pi (42%) from the <100 μm aggregates in the upper 10 cm of the loamy Hapludoll. OC and Po losses of the sandy loam Haplustoll were probably produced by the mineralization of organic compounds, whereas TN and Pi losses of the loamy Hapludoll were produced by wind erosion and plant uptake. Larger relative decreases of OC and Po than TN in coarse aggregates (100–2000 μm) and Pi in fine aggregates (<100 μm) with cultivation indicate that coarse aggregates are less stable than fine aggregates (<100 μm), and therefore more sensitive to changes in soil quality due to changes in land use. We concluded that management practices that tend to improve the formation of large aggregates as no-till or permanent pastures should be used in coarse textured Haplustolls in order to prevent large OC and Po losses. Management practices that include soil plowing will produce a breakdown of coarse aggregates and will moderately decrease OC, Po, TN, Pa and Pi contents in loamy Haplustolls and Hapludolls. Nevertheless, the destruction of coarse aggregates will increase the risk of losses of these elements by wind erosion.

Keywords: Organic carbon; Total nitrogen; Phosphorus; Particle size; Soil depth; Semiarid soils

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1. Introduction

Cultivation decreases topsoil contents of organic carbon, total nitrogen, and phosphorous in semiarid regions of the world (Elliott, 1986; Dalal and Henry, 1988; Rasmussen and Collins, 1991) including the Semiarid Argentinean Pampas (SAP) (Buschiazzo et al., 1991; Hepper et al., 1996; Quiroga et al., 1996; Buschiazzo et al., 2000). Such losses constitute a great concern for sustainable soil use in most ecosystems because it does not only affects soil productivity but also it has negative environmental consequences. Thus, many studies deal with the selection of management practices that can contribute to the increases in soil C pools for C-sequestration. However C losses from the soil increase the atmospheric CO_2 concentration, which is known to contribute to the so-called greenhouse effect. It has been demonstrated that nitrogen and phosphorus have important roles in improving C-sequestration by soils (Reeder et al., 1998; Bronson et al., 2004).

Decreases of carbon and nitrogen have been commonly attributed to processes such as mineralization of organic matter, plant uptake, water or wind erosion, volatilization or lixiviation, but little is known about the probable loss from the topsoil as a consequence of their accumulation at deeper soil layers because of their redistribution along the profile due to plowing.

The original distribution pattern of a nutrient along the profile can define its redistribution and accumulation at deeper layers, as well as the rate of net losses by any of the processes mentioned above. It may be assumed that elements with higher accumulation in the topsoil than in the subsoil will be more susceptible to loss by wind or water erosion than elements that are uniformly distributed with depth. Dilution occurs when subsoil layers are mixed with the topsoil by plowing. This will also be larger for the topsoil-accumulated elements than for elements uniformly distributed along the soil profile. Dick (1983) reported that the concentration of organic C decreased more sharply with depth in no-tilled than in conventional-tilled plots in Ohio soils. Tillage practices decreased organic carbon and nitrogen contents to a larger extent from the topsoil than from the subsoil, whereas changes for organic phosphates behaved inversely (Bronson et al., 2004). Tillage operations have a large effect on element losses in the surface soil horizons. Angers et al. (1993), however, observed that plowing of a meadow soil and further continuous cultivation did not result in a net loss of organic carbon compared with the meadow but rather only in a redistribution of this nutrient within the Ap horizon. Changes in the element status of virgin soils occur mainly close to the soil surface (Dick, 1983).

The susceptibility of an element to loss by erosion also depends on its tendency to accumulate in finer soil aggregates in association with labile organic matter. It is well known that the breakdown of aggregates occurs in cultivated soils as a consequence of plowing (Tiessen and Stewart, 1983), which increases the amount of finer aggregates. The larger the aggregate size where the element accumulates, the lower will be its susceptibility to loss by erosion. It has also been demonstrated that larger aggregates of a given soil are less stable than finer aggregates. On the other hand, aggregates of sandy soils are less stable than same-sized aggregates of finer textured soils (Smith et al., 1978). Plowing breaks down larger amounts of coarse aggregates in sandy soils than in fine-textured soils. Buschiazzo et al. (2001) reported that because of cultivation, the accumulation of organic carbon and organic and inorganic phosphates was lowest in fine aggregates (<100 μm) of fine-textured soils and in coarse aggregates (100–2000 μm) of coarse-textured soils. These authors attributed such trends to the accumulation of these elements in fine aggregates that are relatively more abundant in sandy soils.

The particle-size fractionation has been successfully used to evaluate the changes caused to soil organic matter by different management practices (Dalal and Mayer, 1986; Zhang et al., 1988; Angers and Mehuys, 1990; Angers et al., 1993). Cambardella and Elliott (1992) and Angers et al. (1993) reported that native soils contained more OC in the coarse size aggregates than cultivated soils. This OC was rapidly lost from the soil by mineralization but also through the breakdown and transformation of coarse into fine aggregates.

We hypothesized that differences in organic carbon, total nitrogen and organic and inorganic phosphates between native and cultivated soils will be larger within the 0–10 cm depth than in the subsoil and that these differences will be more pronounced in coarse than in fine aggregates. The objective of this study was to analyze possible changes produced by cultivation on organic carbon, total nitrogen and phosphate inorganic and organic fractions in two soil aggregate sizes as a function of soil depth in representative soils of the SAP.

2. Materials and methods

This study was carried out in the SAP, where mean annual temperature averages 16 °C and mean annual rainfall is 550 mm. Mean annual wind velocity of this region varies between 10 and 15 km/h, and higher speeds occur between late winter (August and October)

and spring months, averaging 20 to 25 km/h, with frequent peaks of 50 to 60 km/h (Casagrande and Vergara, 1996).

The soils of the region develop on Pleistocene and Holocene loessial sediments and are mostly fine sandy loam Entic Haplustolls with an A–AC–C_1–C_{2k} horizon sequence.

We selected three sites with representative soils of this region, and compared two paired soils, a native and a cultivated counterpart, submitted to contrasting management conditions. The Caldenal savanna-like ecosystem is an almost undisturbed environment under extensive grazing since more than 60 years. This ecosystem is composed by a bush strata dominated by "Caldén" trees (*Prosopis caldenia* Burkart) and a grass strata dominated by *Stipa tennuis* Phil., *Stipa speciosa* Trin. et Rupr., or *Panicum* sp. Cultivated soils were tilled with conventional tillage systems (disks and harrow disk up to 18 to 20 cm depth) for more than 60 years. Most commonly crops were non-fertilized and dryland wheat (*Triticum aestivum*), oats (*Avena sativa*), corn (*Zea mays*), sunflower (*Helianthus annus*) and sorghum (*Sorghum* sp.). A typical crop rotation carried out on these soils is wheat–cattle grazed oat–summer crop (sunflower, corn or sorghum).

Native soil of site 1 (loamy Hapludoll) was classified as an Entic Hapludoll, and had 4.8% organic matter, 36% sand, 14% clay and pH 6.0. Native soils of site 2 (loamy Haplustoll) and site 3 (sandy loam Haplustoll) were Entic Haplustolls. The loamy Haplustoll had 3.2% organic matter, 37% sand, 15% clay and pH 5.4, and the sandy loam Haplustoll had 4.8% organic matter, 54% sand, 9% clay and pH 5.1. All these data represents values from the top 10 cm depth of the soils.

More information on the previous management carried out at each cultivated soil was not available, but it is known that tillage practices carried out in the loamy Hapludoll are more intense than in the other two soils.

The soil samples were randomly collected from the 0–10 cm and the 10–20 cm layers from a 10 m^2 area. After air drying and passing through a 2 mm sieve (whole soil), samples were analyzed for particle size distribution by the combined wet sieving and pipette method (Schlichting et al., 1995), and pH was measured in the saturated paste. Soil aggregate fractions were separated according to the method described in Andriulo et al. (1990), which involved passing the dry <2000 μm soil (whole soil) through a 100 μm sieve. This allowed the differentiation of fine aggregates (<100 μm) and coarse aggregates (100–2000 μm). The following determinations were carried on the whole soil (<2000 μm) and fine aggregates (<100 μm). Organic carbon (OC) was determined by the Walkley and Black (1934) procedure, total nitrogen (TN) by the semimicro Kjeldahl method (Bremner and Mulvaney, 1982), organic (Po) and inorganic (Pi) phosphates by calcination and extraction method with H_2SO_4 (ac) 0.4 mol/L (Kaila, 1962), and extractable phosphate (Pa) by the Bray and Kurtz P1-method (Olsen and Sommers, 1982). P concentration in each extracting solution was determined with the ascorbic acid and ammonium molybdate blue method (Schlichting et al., 1995).

Contents of OC, TN, Pi, Po and Pa in the coarse aggregates (100–2000 μm) were calculated from the differences between element contents in whole soil (<2000 μm) and fine aggregates (<100 μm). Contents of elements in fine aggregates (<100 μm) were corrected on the whole soil basis (<2000 μm).

Table 1
Organic carbon (OC), total nitrogen (TN), inorganic (Pi), organic (Po) and available phosphate (Pa) contents and OC/N ratios in whole soils (<2000 μm) of native and cultivated soils of three sites from the semiarid Pampas of Argentina

Soil	Depth (cm)	Management	OC (g/kg soil)	TN (g/kg soil)	OC/N	Pi (mg/kg soil)	Po (mg/kg soil)	Pa (mg/kg soil)
Loamy Hapludoll	0–10	Native	28.1	2.3	12.3	386	271	65
		Cultivated	19.0	1.3	14.2	329	168	59
	10–20	Native	17.8	1.5	12.3	325	201	42
		Cultivated	17.3	1.1	15.2	329	146	42
Loamy Haplustoll	0–10	Native	18.9	1.5	12.3	456	98	152
		Cultivated	14.6	1.1	13.4	340	125	55
	10–20	Native	9.2	9.0	10.8	314	72	27
		Cultivated	11.4	1.0	11.6	321	79	38
Sandy loam Haplustoll	0–10	Native	27.9	2.1	13.5	463	176	37
		Cultivated	12.8	1.1	11.9	303	97	24
	10–20	Native	11.1	9.0	11.9	360	99	29
		Cultivated	12.0	1.0	12.1	332	68	21

Values are means of triplicate soil analysis.

Values were expressed on a soil mass basis taking into account that Quiroga and Buschiazzo (1988) found that the bulk density of these soils is quite constant under the conditions of soil sampling of our study (samples taken after harvesting of crops in cultivated soils in all cases).

The values obtained from each aggregate size fraction were statistically analyzed by means obtained by the analysis of variance, using a split–split–plot design with the combination of management treatment (two levels) and soils (three levels) as the main-plot units and sampling depths (two levels) as the subplot units. The least significant difference (LSD) at a 0.05 probability level was determined when the *F*-test was significant for each interaction.

3. Results and discussion

3.1. Whole soil (<2000 μm)

A significant interaction between soil depth and management was found for OC, TN and Pi (Tables 2 and 3). Contents of OC, TN, Pi, Po and Pa were higher in native than in cultivated soils in the upper 10 cm (Table 1). Significant decreases were found with depth in OC (50%), TN (45%) and Pi (23%) in native soils while there were no changes with depth in cultivated soils. Larger changes of OC, TN and Pi with soil depth in native soils may have been produced by the accumulation of large amounts of plant residues on the soil surface under undisturbed conditions. In cultivated soils plowing mixed the upper 20 cm of soil, thus making their distribution more uniform within the topsoil, which is in agreement with the results of other authors (Dick, 1983; Wander et al., 1998; Needelman et al., 1999).

Cultivated soils had 38% less OC and 41% less N than native soils within the 0–10 cm depth (Fig. 1a and b). These results are similar to those found by Six et al. (2000) for soils of Australia, and can be attributed to the negative impacts of less surface cover and tillage practices on soil microbial biomass and processes such as soil aggregation and organic matter formation. These factors together lead to higher soil erosion potential in the cultivated soils compared to the native soils, which lowered OC and TN contents, and to greater nitrogen sorption by plants in the surface layers of cultivated soils (Dick, 1983). Cultivated soils had lower Pi contents than native soils (25.5%) within the upper 10 cm (Fig. 1c), probably as a consequence of greater losses due to wind erosion, plant uptake (Buschiazzo et al., 2001) or dilution due to mixing of the soil by tillage (Tiessen and Stewart, 1983).

The OC/N ratio was higher than 10 in all cases (Table 1) and did not significantly change with depth. The lack of OC/N variation indicates that organic matter quality was constant with soil depth (Stevenson, 1986).

The soil-management interaction was significant for OC/N (Table 2), indicating that the effect of management was different for each soil, independently of soil depth. When the 0 to 20 cm depth was considered only the loamy Hapludoll showed OC/N ratios significantly higher in the

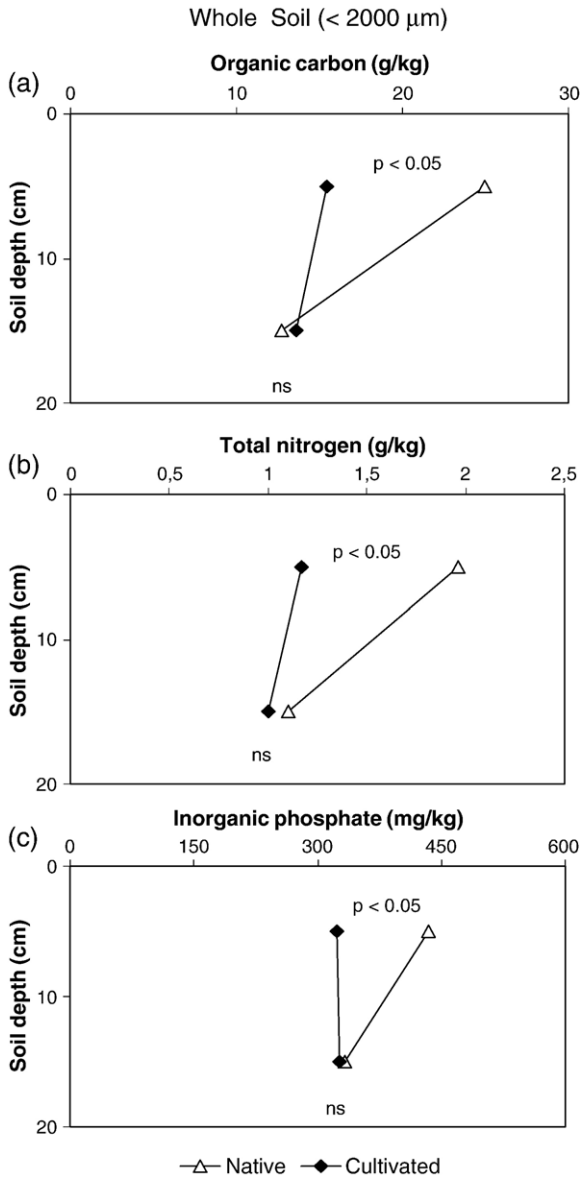

Fig. 1. Overall effect of management on the vertical distribution and concentration of (a) OC, (b) TN and (c) Pi in whole soil (<2000 μm). Symbols representing the management treatment are means of data from three experiment sites. The *p* values are within depth statistical contrasts between management treatments.

Table 2
Variance analysis of organic carbon (OC), total nitrogen (TN) and OC/N ratios in whole soils (<2000 μm), fine (<100 μm) and coarse aggregates (100–2000 μm)

Source	OC	TN	OC/N	OC	TN	OC/N	OC	TN	OC/N
	<2000 μm			<100 μm			100–2000 μm		
	F value and level of significance								
Soil	14.54***	7.42***	5.68**	6.80**	7.21**	0.21 ns	4.87**	1.58 ns	5.15*
Management	16.04***	18.08***	5.38**	10.76***	33.95***	15.62***	4.13 ns	1.85 ns	2.50 ns
Soil * management	0.11 ns	1.87 ns	5.49**	10.56***	4.64**	3.89**	7.27***	1.64 ns	8.53**
Depth	42.2***	42.25***	2.66 ns	7.19**	15.45***	0.07 ns	49.85***	35.21***	1.99 ns
Depth * soil	0.67 ns	0.65 ns	2.82 ns	0.14 ns	0.48 ns	0.27 ns	2.02 ns	0.44 ns	1.86 ns
Depth * management	22.96***	22.90***	1.14 ns	3.47*	7.5**	0.06 ns	27.9***	25.59***	0.01 ns
Depth * management * soil	11.75 ns	1.31 ns	0.61 ns	0.42 ns	0.5 ns	0.08 ns	4.1**	1.63 ns	0.09 ns

*, **, ***Significant at the 0.1, 0.05 and 0.01 probability levels, respectively.

cultivated than in the native soil. This is in agreement with larger decreases of TN (37%) than of OC (21%), which indicate higher mineralization rates of TN than of OC. These trends were probably produced by more intense tillage practices carried out in the loamy Hapludoll.

Po contents were significantly higher at the 0–10 cm depth than at the 10–20 cm depth, and independent of management and soil type, as deduced from the lack of interactions between the soil depth factor and other factors (Table 3).

The interaction between soil type and soil management was significant only for Po concentration in soils (Table 3). This indicates that the effect of management was different in each soil independent of soil depth. At the 0–20 cm depth, Po contents of both the cultivated loamy Hapludoll and sandy loam Haplustoll were lower than in native soils, with the difference being larger in the sandy loam Haplustoll (Table 5). These results are in agreement with those of Anderson (1980) and Buschiazzo et al. (2000), who found that cultivation decreases Po, and these decreases were larger in coarse textured soils. Probably, the lack of differences of Po between the cultivated and the native loamy Haplustoll were due to the occurrence of natural fires in the native, which may have affected the contents of organic P.

The interaction between soil depth, soil type and management was significant for Pa contents (Table 3). This allowed the analysis of management and depth effects on Pa in each soil. Pa contents only decreased significantly with depth ($p<0.05$) in the native loamy Haplustoll. Pa contents were also lower in the cultivated than in the native soil in the upper 10 cm (Table 1). The large Pa differences between cultivated and native loamy Haplustoll can be partially attributed to net phosphorus losses resulting from plant uptake or erosion. In this case these differences can be mostly attributed to the occurrence of natural fires (Buschiazzo et al., 2000), which may have increased Pa contents of the native soil.

3.2. Fine and coarse aggregates (<100 μm and 100–2000 μm, respectively)

At 0–10 cm depth, native soils showed higher OC and TN contents in the coarse aggregates (100–

Table 3
Variance analysis of inorganic (Pi), organic (Po) and available phosphate (Pa) in whole soils (<2000 μm), fine (<100 μm) and coarse aggregates (100–2000 μm)

Source	Pi	Po	Pa	Pi	Po	Pa	Pi	Po	Pa
	<2000 μm			<100 μm			100–2000 μm		
	F value and level of significance								
Soil	0.27 ns	29.44***	11.76***	0.57 ns	18.53***	10.38***	0.14 ns	11.02***	8.50***
Management	5.58**	10.85***	7.36**	25.38***	7.44**	21.39***	0.42 ns	3.86 ns	0.99 ns
Soil * management	0.62 ns	6.03**	3.22 ns	1.55 ns	14.26***	8.52***	3.36 ns	4.11**	0.54 ns
Depth	8.12**	15.71***	25.03***	10.42***	8.81**	24.96***	4.89**	7.90**	21.13***
Depth * soil	0.83 ns	0.18 ns	9.62***	1.01 ns	0.86 ns	14.20***	2.04 ns	0.40 ns	6.19**
Depth * management	9.27**	1.24 ns	9.77***	5.41**	0.01 ns	15.24***	8.75**	1.14 ns	5.81**
Depth * management * soil	0.42 ns	1.03 ns	7.06***	2.81 ns	0.48 ns	14.27***	0.47 ns	1.32 ns	3.18*

*, **, ***Significant at the 0.1, 0.05 and 0.01 probability levels, respectively.

2000 μm) than in the fine aggregates (<100 μm) (Table 4). The OC contents of coarse aggregates were higher with increasing sand contents of the soils, i.e. loamy Hapludoll<loamy Haplustoll<sandy loam Haplustoll, while TN content did not present a definite trend with this textural fraction. At the 10–20 cm depth, contents of OC and TN were similar in both aggregate sizes.

The interaction between the factors soil type, depth and management was significant only for OC contents in coarse aggregates (100–2000 μm) (Table 2). Soil OC contents decreased significantly with depth to a larger extent in native soils with higher sand content (loamy Hapludoll: 47%, loamy Haplustoll: 58% and sandy loam Haplustoll: 67%). In cultivated soils OC contents of coarse aggregates (100–2000 μm) were not different between depths. This was probably produced by the homogenization of the soil to a depth of 20 cm by plowing, as it occurred with the whole soil.

OC contents of coarse aggregates of the 0–10 cm layer were significantly lower (73%) in the cultivated than in the native sandy loam Haplustoll (Fig. 3a). At least two processes could have produced these changes: the breakdown of coarse aggregates (100–2000 μm) by tillage or the greater mineralization of OC in these aggregate sizes. The breakdown by tillage transforms the coarse aggregates (100–2000 μm) into fine aggregates (<100 μm), therefore, making them easily transportable by wind. Tiessen and Stewart (1983) described the breakdown of large aggregates in sandy soils. Previous work found OC decreases were more significant in coarse aggregates compared to smaller aggregates due to more intense mineralization of the labile carbon accumulated in these fractions, mainly plant residues which are easily degraded. An analysis of texture for the soils studied showed that the sandy loam Haplustoll suffered the greatest decreases of silt+clay fractions (47% to 31%), which are the fractions most easily transported by wind, indicating that the first process may have been more important in decreasing OC contents of the sandy loam Haplustoll. In finer soils, OC losses were lower probably as a consequence of the accumulation of more recalcitrant organic matter in the fine aggregates. That organic matter is composed of physically protected and resistant compounds (Hassink, 1995).

Soil OC content of fine aggregates and TN content of both sizes of aggregates resulted in an interaction between depth and management (Table 2). In native sites fine aggregates (<100 μm) suffered a significant decrease of OC with depth (34%), while both aggregate sizes suffered significant TN decrease with depth (34% in fine and 53% in coarse aggregates). For cultivated soils, differences in OC and TN contents between depths did not occur for any aggregate size.

For the three soils the average OC of fine aggregates (<100 μm) of the 0–10 cm layer was 35% lower in cultivated soils than in native soils (Fig. 2a). For the same conditions TN was lower in cultivated than in native soils in both aggregate sizes (52% in fine and 33% in coarse aggregates) (Figs. 3b and 2b).

For the 10–20 cm depth, cultivation resulted in TN losses only from fine aggregates (34%) (Fig. 2b). These results indicate an OC fraction more labile and potentially more susceptible to mineralization (Andriulo et al., 1990) predominating under native rather than in cultivated soils. This agrees with the larger decrease of these fractions in cultivated than in native soils. OC of

Table 4
Organic carbon (OC), total nitrogen (TN) contents and OC/N ratios in fine (<100 μm) and coarse aggregates (100–2000 μm) of native and cultivated soils of three sites from the semiarid Pampas of Argentina

Soil	Depth (cm)	Management	OC (g/kg soil)		TN (g/kg soil)		OC/N	
			<100 μm	100–2000 μm	<100 μm	100–2000 μm	<100 μm	100–2000 μm
Loamy Hapludoll	0–10	Native	12.1	16.0	1.10	1.18	10.93	13.82
		Cultivated	6.4	12.6	0.45	0.84	13.62	14.88
	10–20	Native	9.3	8.5	0.86	0.61	10.87	14.87
		Cultivated	4.5	12.9	0.34	0.79	13.00	16.32
Loamy Haplustoll	0–10	Native	8.2	10.7	0.67	0.85	12.22	12.29
		Cultivated	4.1	10.5	0.31	0.77	12.89	13.37
	10–20	Native	4.7	4.5	0.41	0.44	11.78	9.96
		Cultivated	4.5	6.8	0.33	0.65	13.10	10.55
Sandy loam Haplustoll	0–10	Native	7.2	20.7	0.87	1.21	8.54	16.95
		Cultivated	7.2	5.6	0.51	0.56	14.05	9.86
	10–20	Native	4.1	6.9	0.46	0.47	9.10	14.72
		Cultivated	7.0	4.9	0.45	0.55	15.86	8.65

Values are means of triplicate soil analysis.

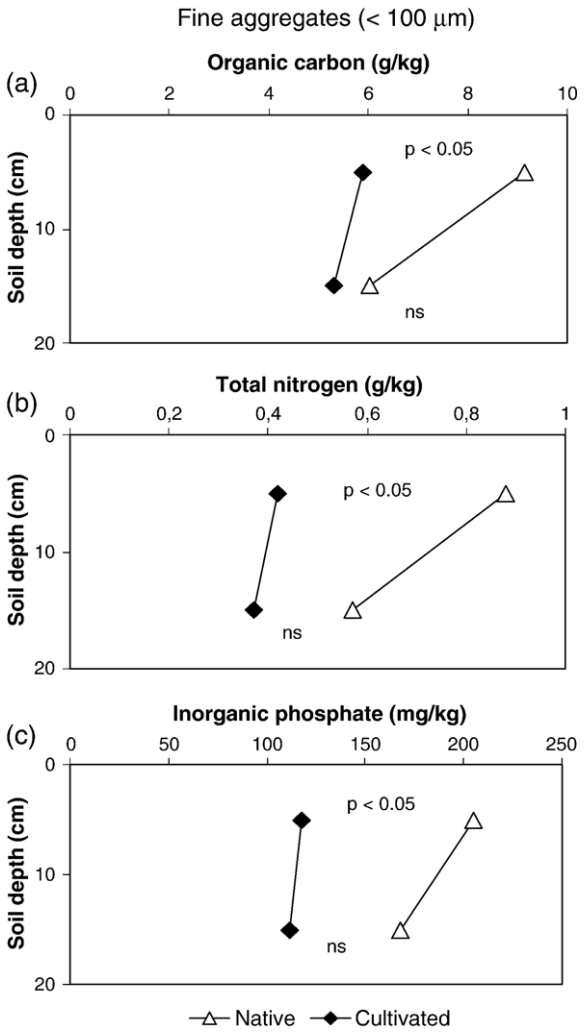

Fig. 2. Overall effect of management on the vertical distribution and concentration of (a) OC, (b) TN and (c) Pi in fine aggregates (<100 μm). Symbols representing the management treatments are means of data from three experiment sites. The *p* values are within depth statistical contrasts between management treatments.

both aggregate sizes were mostly lower in cultivated than in native soils, but its distribution within the upper 20 cm was more homogeneous in cultivated soils, as a consequence of homogenization due to plowing. These results are in agreement with those of Dick (1983).

The OC/N ratio of both aggregate sizes was mostly higher than 10 (Table 4). The OC/N did not change significantly with depth in both aggregate sizes, indicating that relative changes of OC and TN were similar, and lack changes of organic matter quality. The OC/N of both soil depths considered together was higher in coarse (13.8) than in fine aggregates (10.5). This suggests that organic matter of fine aggregates has a stronger humification (Tiessen and Stewart, 1983; Zhang et al., 1988).

The interaction between soil type and management was significant for OC/N in both aggregate sizes (Table 2). When the 0–20 cm depth was considered, it was seen that cultivation increased OC/N in fine aggregates and decreased it in coarse aggregates only in the sandy loam Haplustoll.

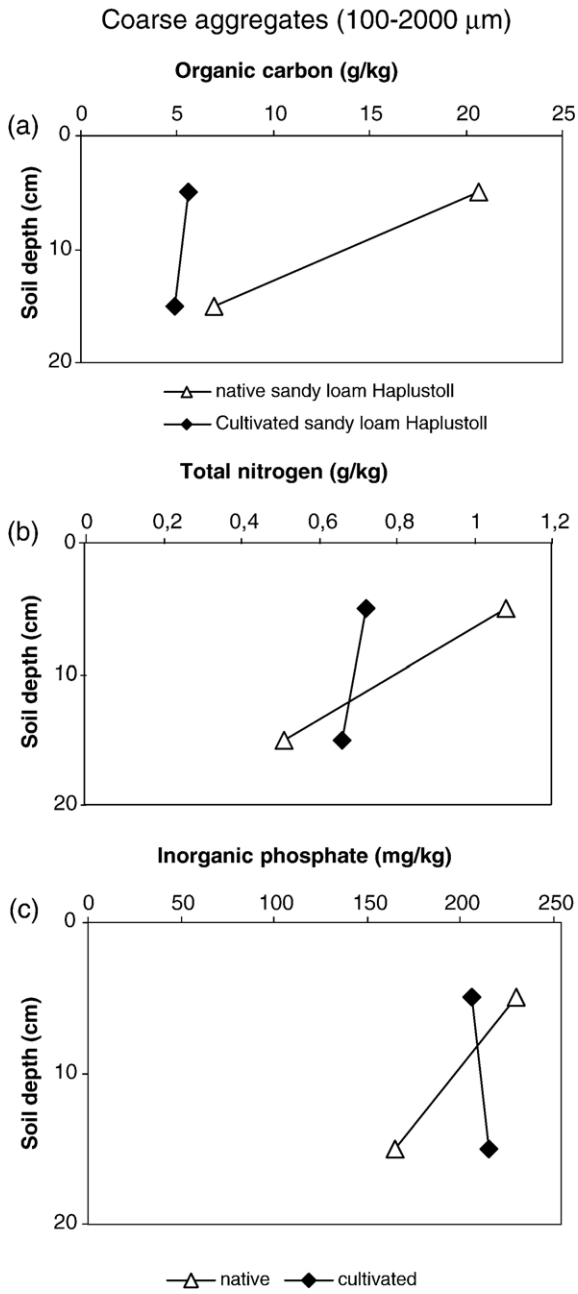

Fig. 3. Overall effect of management on the vertical distribution and concentration of (a) OC in sandy loam Haplustoll soil, (b) Nt and (c) Pi in coarse aggregates (100–2000 μm). Symbols representing the management treatments are means of data (a) from sandy loam Haplustoll soil and (b, c) from three experiment sites. The *p* values are within depth statistical contrasts between management treatments.

This can be attributed to an effect of cultivation on the breakdown of coarsest aggregates in the sandy loam Haplustoll. It is known that same sized aggregates are less stable in sandy than in fine-textured soils (Smith et al., 1978). Plowing probably resulted in a breakdown of the coarsest aggregates, which contained a large amount of fresh organic residues (Elliott, 1986), producing the accumulation of these organic matter compounds in the finest aggregates.

Pi contents of native soils were mostly similar in both aggregate sizes at both depths (Table 5), while Po and Pa contents were higher in coarse than in fine aggregates at both depths.

The interaction between soil depth and management was significant for Pi (Table 3). Pi of native soils decreased with depth in both aggregate sizes (18% in fine and 28% in coarse aggregates), while there were no differences between depths in cultivated soils.

In relation to the effect of management, Pi of fine aggregates was significantly lower in cultivated than in native soils at both depths (Fig. 2c). Decreases of Pi from this sized aggregates can be mainly attributed to wind erosion, because particles between 50 and 100 μm in diameter are the most susceptible to be eroded by wind (Chepil, 1958). At the 10–20 cm depth Pi contents of coarse aggregates were higher in cultivated than in native soils (Fig. 3c). This can be attributed to the mixing of the first 20 cm by plowing in cultivated soils, which homogenized Pi contents within the plow layer. On the other hand, the sharp decrease of Pi with depth in native soils can explain its lower Pi contents in the subsoil.

When all soils and managements were considered together, Po contents decreased significantly with depth in coarse (33%) as well as in fine aggregates (21%).

The interaction between soil type and management was significant for Po (Table 3). When Po was analyzed for the 0–20 cm depth it was found that cultivation decreased its contents in coarse aggregates of the sandy loam Haplustoll (64%) and in fine aggregates of the loamy Hapludoll (55%). This agrees with results of Buschiazzo et al. (2001) who found that cultivation decreased the Po in fine aggregates of the fine-textured soil, and in coarse aggregates of the coarse-textured soil. The high Po contents of coarse aggregates of native soils and the large Po decreases from these aggregates due to cultivation can be related to the lower humification rate of their organic phosphorous compounds (Tiessen and Stewart, 1983).

The interaction between soil type, depth and management was significant for Pa in coarse and fine aggregates (Table 3). Available phosphorus (Pa) contents decreased with depth only in the native loamy Haplustoll at same rates in both aggregates sizes (80%). In the upper 10 cm depth of the loamy Haplustoll, Pa contents of the cultivated soil were lower than that of the native soils in both aggregate sizes (80% in fine, and 48% in coarse aggregates). These results can be also attributed to the occurrence of natural fires of grasses and trees, which may have increased Pa in native soils due to the deposition of P-enriched ashes produced by plant burning (Buschiazzo et al., 2001).

4. Conclusions

The set of soils studied from of the semiarid Pampas showed similar distribution patterns with depth of OC, TN, Pi, Po and Pa accumulated in the 100–2000 μm and

Table 5
Inorganic (Pi), organic (Po) and available phosphate (Pa) contents in fine (<100 μm) and coarse aggregates (100–2000 μm) of native and cultivated soils of three sites from the semiarid Pampas of Argentina

Soil	Depth (cm)	Management	Pi (mg/kg soil)		Po (mg/kg soil)		Pa (mg/kg soil)	
			<100 μm	100–2000 μm	<100 μm	100–2000 μm	<100 μm	100–2000 μm
Loamy Hapludoll	0–10	Native	208	179	103	168	21	44
		Cultivated	114	215	51	117	19	40
	10–20	Native	176	149	90	111	12	30
		Cultivated	79	250	34	112	10	32
Loamy Haplustoll	0–10	Native	216	240	44	53	72	80
		Cultivated	98	242	37	88	140	41
	10–20	Native	158	155	26	46	13	14
		Cultivated	113	208	28	50	12	26
Sandy loam Haplustoll	0–10	Native	190	272	31	145	16	20
		Cultivated	141	161	47	49	8	16
	10–20	Native	169	191	31	68	18	11
		Cultivated	143	188	39	28	10	11

Values are means of triplicate soil analysis.

<100 μm sized aggregates of both native and cultivated sites. Contents of OC, TN and Pi in the whole soil (<2000 μm) decreased sharply with depth in native soils (OC: 50%, TN: 45% and Pi: 23%), but they had a homogeneous distribution in cultivated soils. These tendencies were attributed to the stratification occurring in undisturbed soils and the mixing to a depth of 20 cm by plowing in cultivated soils.

Cultivation resulted in losses of OC (73%) and Po (64%) from the 100–2000 μm sized aggregates at both depths in the sandy loam Haplustoll, while it resulted in losses of TN (52%) and Pi (42%) from the <100 μm aggregates in the upper 10 cm of the loamy Hapludoll. OC and Po losses of the sandy loam Haplustoll were probably produced by the higher mineralization of organic compounds, while TN and Pi losses of the loamy Hapludoll were probably produced by wind erosion and plant uptake.

Larger relative decreases of OC and Po in coarse aggregates compared with TN and Pi in fine aggregates with cultivation indicate that coarse aggregates are less stable than fine aggregates, and therefore more influenced by management practices and/or land use changes.

Management practices that tend to improve the formation of large aggregates as no-till or permanent pastures should be used in coarse-textured Haplustolls in order to prevent large OC and Po losses. Management practices that include soil plowing will produce a breakdown of coarse aggregates and will moderately decrease OC, Po, TN, Pa and Pi contents in loamy Haplustolls and Hapludolls. Nevertheless, the destruction of coarse aggregates will increase the risk of losses of these elements by wind erosion.

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