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# Organic C, N and P in size fractions of virgin and cultivated soils of the semi-arid pampa of Argentina

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Nutrient and organic carbon (OC) losses are important components of the soil degradation processes produced by continuous agriculture. It was hypothesized that coarse textured soils will be more affected by cultivation than fine textured ones. The purpose of this study was to evaluate the status of OC, total nitrogen (Nt), and three phosphorous fractions (total inorganic, Pi; organic, Po; and available, Pa) in different textured virgin (under *Prosopis caldenia* forest) and cultivated soils of the semi-arid pampa of Argentina. Three virgin and non-fertilized cultivated soil pairs, representative from soils of the region, were selected for this study: two fine sandy loam Entic Haplustolls and a sandy Typic Ustipsamment. The element content of each soil was analysed from the $< 0{\cdot}1$-mm to 0·1–2-mm sized aggregates. Results indicated that cultivation decreased the OC, Po and Pi contents in fine aggregates of the fine textured soils, and in coarse aggregates of the coarse textured soil. Plant absorption and wind erosion were probably the main processes which decreased element contents in both textural soil types. It was speculated that in the sandy soil the elements lost from fine sized aggregates were restored by the break down of the weak coarse aggregates produced by tillage. The C/N ratios showed mostly small changes due to cultivation, indicating that no changes of organic matter quality occurred. Only the sandy soil showed C/N increases in the fine sized aggregates and decreases in the coarse sized aggregates. The C/Po quotients were not changed by cultivation, indicating that the qualitative composition of P organic compounds remained unchanged. Large OC decreases and Pa increases after cultivation detected in one of the fine textured soil were apparently linked to the occurrence of natural fires.



**Keywords:** particulate organic matter; soil degradation

## Introduction

Nutrient and OC losses are important soil degradation processes in many parts of the world (Rasmussen & Collins, 1991). When soils are cultivated, an initial and rapid loss of nutrients and OC decay occur, mainly due to plant uptake and organic matter oxidation. Following several years of cultivation, soil organic matter tends to stabilize (Casanovas *et al.*, 1995) reaching a minimum level that corresponds to organomineral

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complexes (Rasmussen & Collins, 1991). At this stage of soil degradation, plant nutrient deficiencies normally occur. Nutrient and OC losses can also exceed these minimum stabilization levels, if soil erosion or nutrient dilution by mixture of the topsoil with underlying horizons by ploughing occurs (Tiessen & Stewart, 1983; Elliott *et al.*, 1991).

In slight developed soils of the semi-arid pampa of Argentina it has been demonstrated that continuous agriculture decreases organic matter, nitrogen (N) and phosphorus (P) content especially in finer textured soils (Buschiazzo *et al.*, 1991). The annual crops, of wheat (*Triticum aestivum*), maize (*Zea mays*) and sorghum (*Sorghum* sp.) have been cultivated without fertilization in the semi-arid pampa of Argentina more than 80 years, resulting in N and P deficiencies (INTA *et al.*, 1980, Prüeß *et al.*, 1992). The extent of nutrient loss in these soils has not been well quantified, and it can be assumed that will be dependent upon soil texture, the basic soil compound of these soils (Buschiazzo *et al.*, 1991). Angers *et al.* (1993), Elliott *et al.* (1991) and Zhang *et al.* (1988) found that cultivation produced larger decreases of OC, N and P in the coarse compared to the fine-textured soils. In the semiarid pampa of Argentina the humified organic matter content was positively related to clay contents and therefore not highly variable among soils, whereas the amount of recently incorporated residues were high in no till systems and low in conventional tillage systems and therefore highly variable among soils (Quiroga *et al.*, 1996).

This study evaluated the status of the organic C, N, and P fractions in the different aggregate size classes of topsoils from the semiarid pampa of Argentina, as affected by soil management.

## Materials and methods

This study was carried out in the semi-arid pampa of Argentina, placed between 35° and 37° S latitude, and 64·5° W longitude (Fig. 1). The annual precipitation averages

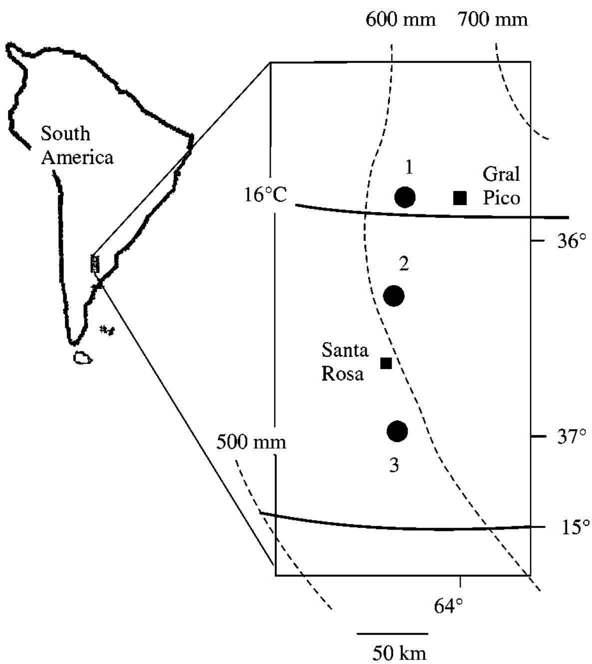


**Figure 1.** Placement of studied soils (●); Mean annual temperature (——); mean annual rainfall (— —).

**Table 1.** *Main characteristics of the studied soils*

| Soil | Management | Sand | Silt | Clay | pH* | OC (< 2mm)* | Nt (<2 mm)* |
|---|---|---|---|---|---|---|---|
| | | | % | | | % | % |
| 1 | Virgin | 36·5 | 49·3 | 14·2 | 6·0 | 2·81 | 0·23 |
| (Entic Haplustoll) | Cultivated | 32·1 | 43·6 | 24·3 | 6·1 | 1·90 | 0·13 |
| 2 | Virgin | 36·0 | 49·5 | 14·5 | 5·4 | 1·89 | 0·15 |
| (Entic Haplustoll) | Cultivated | 39·4 | 44·1 | 16·5 | 6·5 | 1·46 | 0·11 |
| 3 | Virgin | 53·6 | 37·4 | 9·0 | 5·1 | 2·79 | 0·21 |
| (Typic Ustipsamment) | Cultivated | 69·2 | 22·0 | 8·8 | 6·7 | 1·28 | 0·11 |

*Values are means of triplicate soil samples.

620 mm, and the mean annual temperature varies between 15·5 and 16·5°C. Precipitations concentrate in autumn (March to June), and spring (September to December). The relief in this region is flat and the altitude varies among 80 and 120 m a.s.l. The parent material of the soils are pleistocenic and holocenic eolian sands. These sediments can be in the present time retransported by wind and water. Most common soils of this region are Entic Haplustolls and Typic Ustipsamments (INTA *et al.*, 1980). Virgin soils are still present in many sites of this region in the savanna-like Caldenal ecosystem, and are covered by autochthonous *Prosopis caldenia Burkart* trees and grasses such as *Stipa tennuis Phil.*, *Stipa speciosa Trin.* and *Rupr.*, or *Panicum sp*, which are grazed extensively by cattle. Forest clearance was very intense from 1930 to 1940, when the soils were brought into cultivation, and used for winter (wheat and oats) and summer (maize and sorghum) crop production.

This study was carried out in three sites (Fig. 1). At each site two paired pedons of the same soil undergoing two management systems, placed 50 m apart, were compared. Management systems were virgin (under *P. caldenia* forest), and a cultivated (more than 50 years under continuous agriculture without fertilization). The soils of two sites were classified as Entic Haplustolls with a sandy loam texture (SOIL 1 and SOIL 2). The soil at the third site was a loamy sand Typic Ustipsamment (SOIL 3). Selected physical and chemical properties of the soils used in this study are given in Table 1. Triplicate samples of topsoil (0–10 cm) for each soil were randomly taken from three 100 $m^2$ sampling areas. In the laboratory, soil samples were air-dried and sieved through a 2-mm sieve to determine particle size distribution by the combined wet sieving and pipette method (Schlichting *et al.*, 1995), and pH in a 1 : 2·5 soil-water relation extract. Soil samples were separated in < 0·1 mm (fine aggregates) and 0·1–2-mm-sized aggregates (coarse aggregates) by dry sieving, following the method of Andriulo *et al.* (1990). This sieving was done gently by hand to avoid aggregate breakdown during aggregate size separation. In the fractions < 0·1 and < 2-mm the following determinations were made: organic- (Po) and inorganic (Pi) phosphates using the calcination and acid ($H_2SO_4$, 0·2 N) extraction method of Kaila (1962); available phosphate (Pa) by the Bray and Kurtz 1-method (Olsen & Sommers, 1982). Phosphorus concentration in each extracting solution was determined by the ascorbic acid and ammonium molybdate blue method (Schlichting *et al.*, 1995); organic carbon (OC) by Walkley–Black procedure (Walkley & Black, 1934), and total N (Nt) by semimicro Kjeldahl procedure (Bremner & Mulvaney, 1982). Element contents in the 0·1–2-mm aggregates were calculated from the difference between element contents in the < 2 and < 0·1-mm sized aggregates.

The combined effect of soil management, site and aggregate-size on element contents was analysed with ANOVA. When the interaction was significantly the LSD test was done.

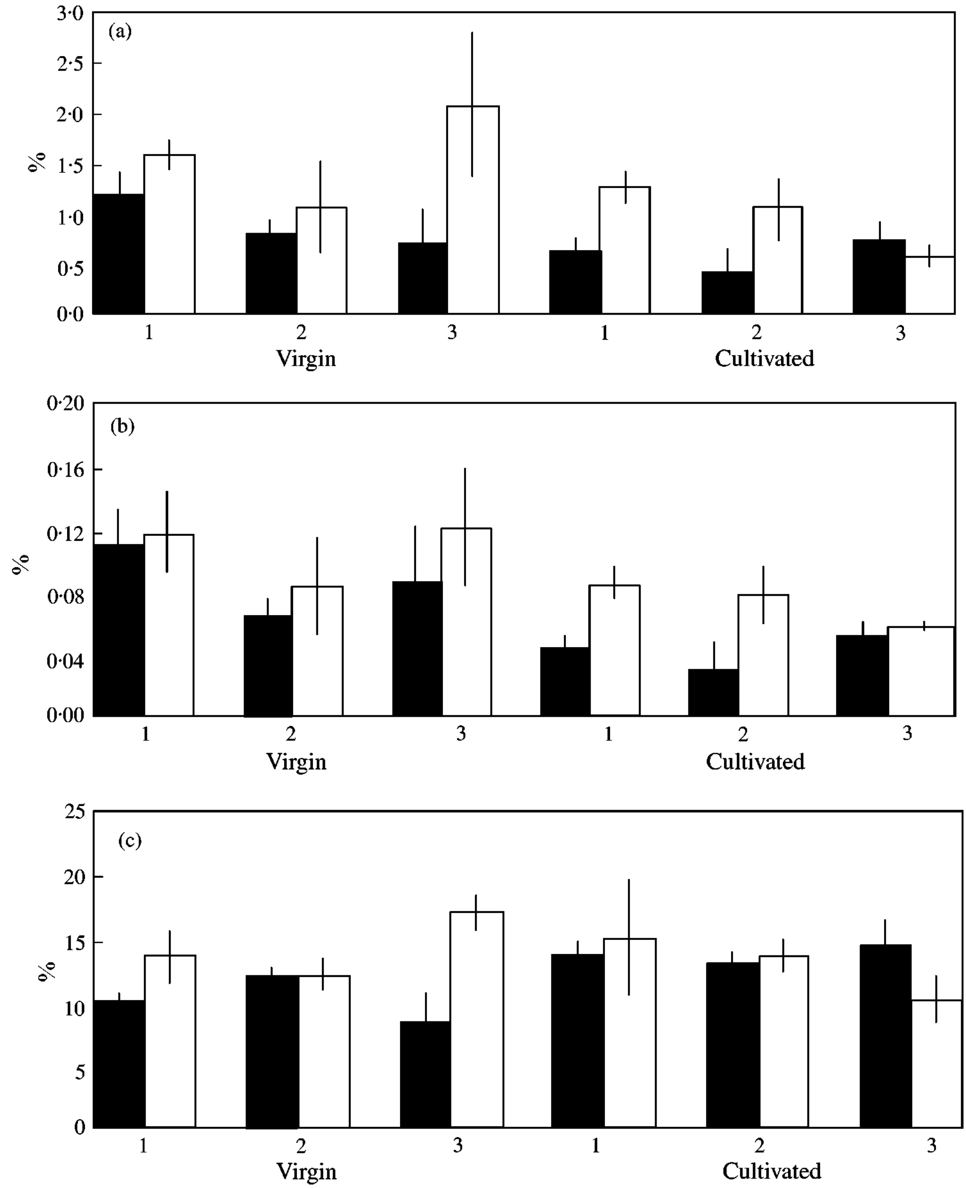


**Figure 2.** (a) Organic C (b) total N content, and (c) C/N ratios in $< 0{\cdot}1$ mm (■) and 0·1–2-mm (□) sized fractions of virgin and cultivated soils of three sites from the semiarid Pampa of Argentina. Vertical bars indicate S.D.

## Results and discussion

A significantly interaction between aggregate size, site and management for OC contents ($p < 0{\cdot}0009$) allowed the mean comparison test. The LSD analysis showed a higher accumulation of OC in the coarse aggregates (52% of total OC) than in fine aggregates of virgin SOIL 3 ($p < 0{\cdot}001$) (Fig. 2). Absolute OC content of the fine aggregates was higher in the virgin SOIL 1 than in virgin SOIL 3 ($p < 0{\cdot}05$). These results were in agreement with those of Dalal & Mayer (1986), Cambardella & Elliott (1992), and

Zhang *et al.* (1988), and indicate an accumulation of partially degraded residues of the native vegetation.

The OC contents of coarse aggregates of SOIL 2 were lower than in both SOIL 1 and SOIL 3 ($p < 0{\cdot}05$). According to its fine texture, a higher OC content of SOIL 2 was expected (Buschiazzo *et al.*, 1991). Evidence of natural fires (burned branches of Calden-trees) was detected at this site, which may have resulted in the gaseous loss of $CO_2$, and can explain the low OC contents of this soil. Rasmussen & Collins (1991) found significant losses of OC due to high temperatures produced by natural fires. It must be further studied if the lack of OC losses in fine sized aggregates was linked to a higher resistance of fine particulate organic compounds against high fire temperatures.

Cultivation significantly ($p < 0{\cdot}05$) decreased the OC content in the fine aggregates ( < 0·1 mm) of SOIL 1 (47%), as well as in the coarse aggregates (0·1–2 mm) of SOIL 3 (73%) (Fig. 2). Organic C losses produced by cultivation in SOIL 1 may have been produced by organic matter mineralization or by wind erosion of fine aggregates. Buschiazzo & Taylor (1993) found that coarse silt and fine sand aggregates, both with sizes < 0·1 mm, were blown by wind in the semi-arid Pampa of Argentina. Organic C losses in SOIL 3 can have been produced by the breakdown of weak structured coarse aggregates which transformed them in fine aggregates susceptible to be eroded by wind. Tiessen & Stewart (1983), Dalal & Mayer (1986), and Zhang *et al.* (1988) described the breakdown of large aggregates in sandy soils. Cambardella & Elliot (1992) and Angers *et al.* (1993) attributed the larger losses of OC in the sand fraction to a higher turnover rate of organic matter in an Pachic Haplustoll and an Aeric Haplaquept, respectively.

The ANOVA analysis did not show significant interactions between site, management, and aggregate size for Nt contents ($p > 0{\cdot}05$), but it showed that Nt contents were higher in coarse than in finer aggregates ($p < 0{\cdot}05$), and that cultivation decreased Nt contents in cultivated soils in relation to virgin soils ($p < 0{\cdot}05$).

A significant interaction between site, management, and aggregate size exists for C/N ratios ($p < 0{\cdot}001$). The LSD test showed that only the C/N of coarse aggregates were higher ($p < 0{\cdot}001$) than of fine aggregates in the virgin SOIL 3 (Fig. 2). This indicates a relative lower amount of nitrogenous compounds in the organic matter of the sandy soil in the coarse aggregates. The lack of significant differences in both fine textured soils should be related to a similar qualitative composition of organic matter in both size aggregates.

In SOIL 3 cultivation significantly increased the C/N ratios in the fine aggregates, and decreased the C/N ratios in the coarse aggregates ($p < 0{\cdot}001$). These results suggest that cultivation had a greater effect on the Nt content than the OC content of the fine aggregates, and the OC content of the coarse aggregates of SOIL 3. Dick (1983) indicated that the higher C/N ratios of cultivated soils are due to the greater mineralization rates of organic N *vs.* OC. According to Cameron & Postner (1979) organic N shows lower rates of mineralization in the sand fraction of the soil. Christensen (1987) attributes this phenomena to the mineralization of organic matter coupled with immobilization of mineral N. This process may have occurred in the sandy SOIL 3.

No significant interaction between site, management and aggregate size for Pa contents ($p > 0{\cdot}05$) was found, but interaction was significant between site and management ($p < 0{\cdot}01$). This indicates that Pa contents of virgin SOIL 2 was significantly higher than in the other two virgin soils ($p < 0{\cdot}001$) in both size aggregates (Fig. 3). This can possibly be related to the effect of fires, since burning temperatures below 500°C can transform organic P into inorganic phosphates, while temperatures above 500°C can volatilize P compounds (Olsen & Sommers, 1982). Iglesias *et al.* (1990) reported similar increases of available P after 300°C fires in the Caldenal ecosystem, and Overby & Perry (1996) in Arizona Chaparral watershed.

When cultivated and virgin soils were compared only the SOIL 2 showed a significantly decrease of Pa in both the fine (81%, $p < 0{\cdot}001$) and coarse aggregates (55%, $p < 0{\cdot}001$) (Fig. 3). Pa decreases can be related to both a Pa accumulation in the virgin

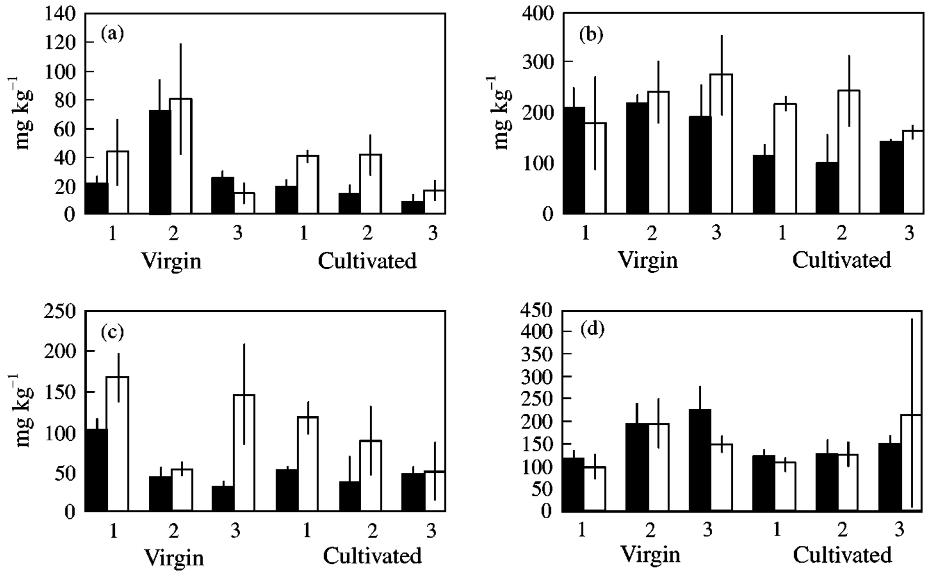


**Figure 3.** (a) Available- (Pa), (b) inorganic- (Pi), and (c) organic phosphorus (Po) contents, and (d) C/Po ratios in < 0·1 mm (■) and 0·1–2-mm (□) sized fractions of virgin and cultivated soils of three sites from the semi-arid pampa of Argentina. Vertical bars indicate S.D.

soil due to the natural fires, and also to a decrease of Pa in the cultivated soil by wind erosion and plant uptake. The existence of both processes simultaneously in SOIL 2 can explain the large differences in Pa contents among soils under both management conditions. A breakdown of weak structured coarse aggregates by tillage and its transformation in fine aggregates may have increased Pa blown by wind or Pa sorption by plants (Buschiazzo *et al.*, 2000).

A significant site, management and aggregate size interaction ($p < 0{\cdot}01$) was found for Po contents. LSD analysis showed that Po accumulated more in coarse than in fine aggregates of virgin SOIL 1 and 3 ($p < 0{\cdot}01$) (Fig. 3). This is probably due to the accumulation of Po associated with the mulch residues of the virgin soils, indicating that this fraction of P is highly dependent on the variation in the amount of mulch applied to the soil surface. Absolute Po content of the fine aggregates were higher in the finest virgin textured soils, while the Po content of the coarse aggregates did not follow the same trend for the coarser textural soils. The lack of a correlation between Po in the coarse aggregates and texture was probably due to the lower Po content of SOIL 2 according to its texture, which correspond with the lower OC contents of this soil and the apparent occurrence of natural fires.

When virgin and cultivated soils were compared a significantly decrease of Po in both the fine (50%) and coarse aggregates (31%) of SOIL 1 ($p < 0{\cdot}05$) as well as in the coarse aggregates of SOIL 3 ($p < 0{\cdot}001$) were detected. SOIL 1 received the greatest frequency of tillage for seedbed preparation due to its finer texture. This may have lead to higher mineralization rates of organic P compounds.

The ANOVA analysis for Pi showed a significant site, management, aggregate size interaction ($p < 0{\cdot}05$). LSD analysis showed that Pi contents were similar ($p > 0{\cdot}05$) in both the coarse and fine sized aggregates of the virgin soils (Fig. 3). This did not agree with the tendencies of OC to accumulate in coarse aggregates. Inorganic phosphorus may have concentrated at a slower rate than OC in the partially degraded mulch residues which were associated to a large extent with the coarse aggregates. As a result, the Pi fraction would be less affected by the variation in the amount of much applied to the soil.

When virgin and cultivated soils are compared a significantly decrease of Pi was found only in the fine aggregate of SOIL 1 (45%) and 2 (55%) ($p < 0{\cdot}05$) and coarse aggregates of SOIL 3. These decreases did not agree with the Pa losses of the fine aggregates of SOIL 2, which represented a Pi loss of less than 50%. The lack of correlation between the Pi and Pa losses in this soil was probably due to the transformation of reserve P forms into labile phosphates following plant uptake and depletion of Pa.

Losses of Pi by wind erosion should also be considered, since cultivation may have resulted in the breakdown of aggregates, making the finer particles highly susceptible to wind erosion. As Pi accumulates in the finer textural fractions (Prüeß *et al.*, 1992) loss of P by wind erosion probably occurred.

The ANOVA analysis showed that no interaction among site, management and aggregate size exists for the C/Po ratio. C/Po values were similar in all treatments, which indicates that cultivation did not produce any effect on the quality of organic P compounds in the studied soils.

## Conclusions

Results indicated that cultivation decreased mostly the OC, Po and Pi contents in fine aggregates of fine textured soils, and in coarse aggregates of the coarse textured soil. Plant absorption and wind erosion were probably the processes which caused these depletion of nutrient contents in the fine textured soils. These same processes may have also occur in the coarse textureds oil but the largest breakdown of the weak coarse aggregates via tillage in the sandy soil probably compensated the element loss from fine-sized aggregates.

The C/N ratio only varied with cultivation in the coarse textured soil: it increased in the fine aggregates, and decreased in the coarse aggregates. This indicated a general low effect of cultivation on organic matter quality, as well as a decrease of nitrogenous rather than carbonous organic compounds by tillage in the fine aggregates, and the carbonous rather than nitrogenous compounds in the coarse aggregates.

C/Po ratios remained unchanged indicating that cultivation did not affect the quality of organic P.

Large OC decreases and Pa increases after cultivation detected in one of the studied soils were apparently linked to the occurrence of natural fires.

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