FORTY YEARS OF SOIL DEGRADATION IN VERTIC ARGIUDOLLS IN ENTRE RÍOS PROVINCE, ARGENTINA

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ABSTRACT

In the last decade the land use in Entre Ríos Province (Argentina) has suffered a very important increase characterized by an intensive and continuous agriculture in a region with high water erosion susceptibility. Forty percent of province surface suffers water erosion in different degrees. This study was undertaken to assess the extent and nature of degradation in some physical and chemical properties of vertic Argiudolls through the comparison of a pristine situation and three situations with increasing years of land use after deforestation. Organic carbon (OC), light carbon (LC), pH, electrical conductivity (EC), labile organic phosphorus (P_{lo}), structural stability (ΔMWD), size aggregate distribution in the A horizon were determined. After 40 years from deforestation the OC, LC, P_{lo}, decreased 26, 72 and 17% respectively meanwhile EC and pH had minor variations. The structural stability declined with time and there was a significant correlation between organic carbon and ΔMWD ($r = - 0.985$; $P < 0.02$; $n = 4$). Sixty two percent of the A-horizon was lost and as a consequence, 75.5% in carbon sequestration. A mean annual erosion rate of 60 Mg ha^{-1} yr^{-1} after 40 years was estimated.

Key words. Erosion, vertic soils, aggregate stability, deforestation.

CUARENTA AÑOS DE DEGRADACIÓN DE ARGIUDOLES VÉRTICOS EN LA PROVINCIA DE ENTRE RÍOS

RESUMEN

En la última década el uso de la tierra en la provincia de Entre Ríos (Argentina) ha sufrido un incremento muy importante basado en la agricultura contínua e intensiva en una región con alta susceptibilidad de erosión hídrica. Cuarenta por ciento de la superficie de la Provincia posee erosión hídrica de diferentes grados de severidad. Este trabajo fue llevado a cabo para examinar el grado y la naturaleza de la degradación en algunas propiedades físicas y químicas en suelos vérticos a través de la comparación de una situación prístina con tres situaciones con diferentes años de agricultura luego de su deforestación. El carbono orgánico (OC), carbono liviano (LC), pH, conductividad eléctrica (EC), fósforo orgánico lábil (P_{lo}), estabilidad estructural (ΔMWD) y la distribución del tamaño de agregados en el horizonte A fueron determinados. Luego de 40 años de la deforestación el OC, LC y el P_{lo}, disminuyeron 26, 72 y 17% respectivamente, comparados con la situación prístina mientras que la EC y el pH tuvieron sólo variaciones menores. La estabilidad de los agregados disminuyó con el tiempo y hubo una correlación significativa entre el OC y ΔMWD ($r = - 0,985$; $P < 0,02$; $n = 4$). Sesenta y dos por ciento de la profundidad del horizonte A fue erosionada y, como consecuencia, el 75,5% del carbono secuestrado originalmente fue perdido. Fue estimada una tasa de erosión anual promedio de 60 Mg ha^{-1} $año^{-1}$ luego de 40 años.

Palabras clave. Degradación, suelos vérticos, estabilidad de agregados, deforestación.

INTRODUCTION

The Entre Ríos Province, Argentina, is characterized by a high unequal land distribution, 62% of farms are less than 100 ha (17,000 cases) and just the 8.9 % has more than 500 ha (2,436 cases). This feature leads to an intensive and continuous agriculture in a region with high water erosion susceptibility (SAGYP, 1995). Forty percent of province surface (2.5 Mha) suffers water erosion in different degrees (20% severe). Concordia city, the second one in population rate of the province, is just an example of the critical social situation with one of the highest unem-ployment rate of the country.

The soils of Entre Ríos province are mainly vertisols, Vertic Argiudolls, Vertic Argiacuolls, Vertic Ocracualfs and Vertic Natracualfs (3.5 Mha), with a high percentage of expandable clay, low phosphorous content and high water erosion susceptibility because of very dense subsoil horizon with low permeability.

In the last decade the land use in Entre Ríos Province, has suffered a very important increase. As a consequence of the agriculture expansion, limited to the Molisols at the beginning, vertisols and soils with vertic characteristics has been deforested and cultivated with cereals and oil seeds (Tasi, 2000). The soils became unstable and the erosive process was triggered. According to estimations from satellites images, 33.2% of province surface was covered by natural forest (SAGYP, 1995). Its substitution by continuous agriculture increases water erosion susceptibility. The loose of organic matter, that could be a very gradual process, affects the nutrient cycles and the whole functioning of soil (Park & Cousins, 1995). In general, this process is associated with a decrease in cropping yields.

The aim of this work was to quantify the extent and nature of degradation in some physical and chemical properties of vertic Argiudolls in the Paraná Department, Entre Ríos Province, Argentina. Comparisons were made among cropped soils with different land uses and an adjacent virgin native forest soil to assess the rate of degradation.

MATERIALS AND METHODS

The site of study

The study was performed in farmer plots sited in the department of Paraná, Entre Ríos province, Argentina (31° 31' S, 59° 50' W). The climate of the area is a transition between subtropical and temperate, humid, with an annual mean rainfall of 1003 mm, the mean temperature for the warmest month (January) is 25.3 °C and the coolest (July) is 11.9 °C (De Fina, 1992). The rainfall exhibits high year-to-year variation and events of high rain intensity (> 80 mm h^{-1}) commonly occur in summer (Scota *et al*., 1986).

The soil under study was classified as fine, montmorillonitic, termic Vertic Argiudoll (USDA, 1999), serie "Arroyo Carrasco". This serie is located in the Valleys of Alcazar and Hernandarias rivers generally in low slopes (< 0.5%) or flat areas. The A horizon of the serie is deep (up to 30 cm), very dark, silty clay loam with slickensides. Has a granular and blocky structure with 2.5 to 5% of organic matter. The argilic horizon has 40 to 55 cm depth with colors among 10 YR 3/2 to 10 YR 4/2, 40 to 50% of clay and prismatic structure with cuneiforms and angular blocks. The Bt_2 has notorious clay skins, slickensides and cracks up to 2.5 cm when dry. The $CaCO_3$ appears at 60-80 cm.

Soil sampling

In a representative farm of the Paraná department, four parcels, one adjacent each other, were selected according to the years from deforestation from 0 (natural forest) to 40. They are named as situations 1 to 4: 0; 15; 26 and 40 years respectively (Table 1). Each parcel had 20 ha which were divided in 4 homogeneous sectors considered as repetitions.

From each repetition three composite samples were obtained from ten sub samples each one and three additional samples were used for physical measurements. All soil samples were taken to 10 cm depth and brought to the laboratory and air-dried at 25 °C.

Soil measurements

The chemical properties analyzed were: Organic Carbon (OC) by Walkley & Black method (Nelson & Sommers, 1982); Light Carbon (LC) (Richter *et al.*, 1975); pH in 1:2.5 soil:water; Electrical

Table 1. Natural and agronomics precedents of the analyzed situations.
Tabla 1. Antecedentes culturales de las situaciones analizadas.

Situation	Description
1	Natural xerophyte's forest. Based on Ñandubay (*Prosopis affinis* Spreng.), Algarrobo (*Prosopis nigra* Griseb.) and Quebracho blanco (*Aspidosperma quebracho-blanco* Schltdl.).
2	15 years after deforestation. 5 years cropped with conventional tillage and 10 years with spontaneous pasture.
3	26 years after deforestation. Continuous conventional tillage, based in moldboard plowing as primary tillage operation. The crops included in the rotation were maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), soybean (*Glycine max* (L.) Merr.) and sunflower (*Heliantus annus* L.).
4	40 years after deforestation. Idem Situation 3.

Conductivity (EC) and labile organic phosphorus (P_{lo}) (Negrin *et al.*, 1995, modified by Giuffré *et al.*, 2000).

In order to quantify the structural stability, about 100 g of air dried aggregates (< 8 mm) were weighed and placed on top of a nest of sieves (203 mm diameter) of 4.76-3-2 mm apertures and dry sieved for 5 min with a Cosacovâ mechanical shaker. After dry-sieving 3 sieves were added: 1-0.5-0.3 mm and wet sieved for 30 min (modified from De Leenheer & De Boodt, 1958). The structural stability was expressed in terms of the change of mean weight diameter (ΔMWD) between dry and wet condition of total soil. The dry aggregate size distribution was obtained shaking 5 min the net of sieves of apertures of 4.76-3-2-1-0.5-0.3 mm.

An ANOVA was performed to evaluate the differences among treatments. Tukey's mean separation test was used with a 0.05 significance level.

RESULTS AND DISCUSSION

Chemical properties

The chemical variables that showed greater changes were those related to soil organic carbon (Table 2). The OC showed a significant ($P<0.05$) decrease after 26 and 40 years after cultivation as compared with the original situation, 20 and 26% respectively. Nevertheless, this variable couldn't distinguish the effect of 15 years of cultivation.

The LC significantly declined 63.9% after 15 years of deforestation (situation 2), however, it kept relatively constant after 26 and 40 years of continuous cultivation. The relation LC/OC shows the same tendency as LC with a high decrease in situation 2 and with no variations as the years of cultivation increase. This highlighted the fact that more labile fractions of the soil organic carbon were lost as a result of cropping. This means that deforesting and cropping these soils has an immediate impact of the most labile pool of carbon with a weak effect over the total content. This effect happened even when the situation 2 had ten years under spontaneous pasture.

The natural forest is characterized by organic matter stratification with depth caused by vegetal debris surface accumulation. Coincident with Carter (1986), Saffigna *et al.* (1989) and Cosentino & Costantini (2000) in the same soil, the long-term impact was to decrease the organic carbon content keeping constant the proportion between labile and non-labile fractions. Briefly, the LC was very sensible to indicate changes in the short term while the OC was in the long term.

The mean pH increment of the cropped soils was 0.2 units than that of the virgin soil (Table 2). The little increment in pH could be related to the exchangeable cations increase due to turn over of cations released in the debris decomposition process. It is well kwon that agricultural practices create conditions that change the turn over of organic compounds because of the increasing in the mineralisation rate of labile substances (Álvarez *et al.*, 1995; Arrigo *et al.*, 1997). The cations released are adsorbed in the clay-humic complexes increasing the soil pH.

Table 2. Organic carbon (OC), light carbon (LC), LC/OC, pH, electrical conductivity (EC), labile organic phosphorus (P_{lo}) and Δ mean weight diameters (ΔMWD) of analyzed situations.

Tabla 2. Carbono orgánico (OC), carbono liviano (LC), LC/OC, pH, conductividad eléctrica (EC), fósforo orgánico lábil (P_{lo}) y Δ del diámetro medio ponderado (ΔMWD) de las situaciones analizadas.

Situations	OC ($g\ kg^{-1}$)	LC ($g\ kg^{-1}$)	LC/OC	pH	EC ($dS\ m^{-1}$)	P_{lo} ($mg\ kg^{-1}$)	ΔMWD (mm)
1 Natural Forest	31.2 a	6.1 a	0.20	6.1 b	0.48 a	11.04 a	0.25 a
2 15 years after deforestation	30.3 a	2.2 b	0.07	6.3 a	0.38 b	8.48 b	0.30 b
3 26 years after deforestation	25.0 b	1.8 b	0.07	6.3 a	0.42 ab	9.09 b	0.63 c
4 40 years after deforestation	23.0 c	1.7 b	0.07	6.3 a	0.35 b	9.14 b	0.66 c

Values followed by the same letter do not present significant differences (Tukey test, $P<0.05$).

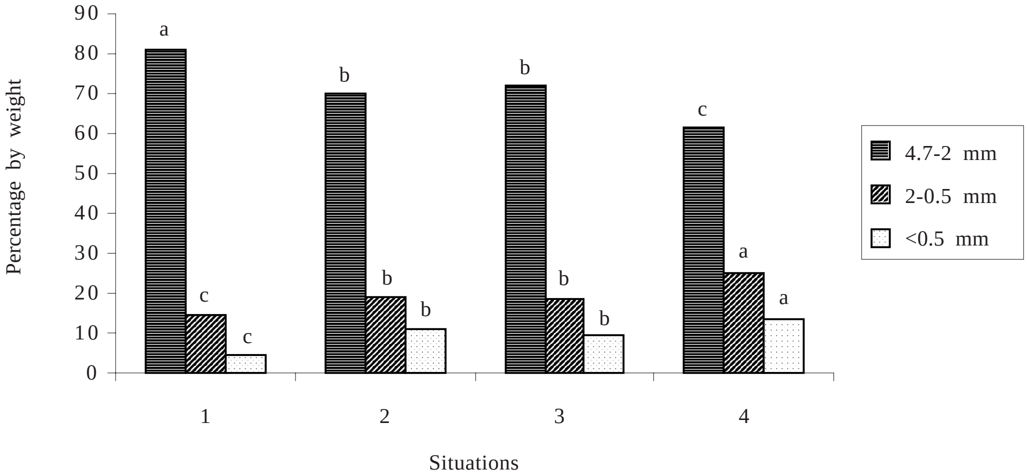
Los valores seguidos por la misma letra no presentan diferencias significativas (Test de Tukey P<0,05).

Electrical conductivity of soils solutions is generally lower in farmed soils than in undisturbed soils (Naidu *et al.*, 1996). The reduction of EC contributes to increase the sensitivity of the farmed soils to dispersion (Amézketa, 1999). Nevertheless, there were no differences in electrical conductivity among treatments and all values were less than 0.5 dS m^{-1} (Table 2), showing the insensitivity of this variable with regards of vertic soils degradation.

We evaluated the phosphorus, as is one of the most limiting nutrients in the area, the organic phosphorus range between 60- 70% of total phosphorus (Boschetti *et al.*, 2000) and 70% of soils present less than 15 mg kg^{-1} extractable phosphorus according to local researchers (Quintero *et al.*, 2000). Tendencies of extractable P (P_{ext}) forms could be influenced by phosphate fertilization, so they couldn't be used as valid indicators of soil degradation. Organic labile fraction is determined as the difference between Olsen extractable P with and without oxidation with free of P Perhyrol (H_2O_2). Organic labile P behaved as a sensitive indicator related to soil quality decrease, as its variation was directly related to C decrease in soil (Andersohn, 1996). In our work, the labile organic phosphorus (P_{lo}) declined when the soil was cultivated (Table 2), meanwhile the P_{ext} increased probably as a consequence of fertilization (values not shown). The P_{lo} decreased 23.2% after 15 years of deforestation, no significant differences among 15, 26 and 40 years after deforestation were found. As the CL, these data suggest that the light/labile C fractions were good indicators of the changing from natural forest to cropping but they couldn't distinguish the effect of the years of cultivation or cropping-pasture rotation vs. continuous cropping.

Structural stability and aggregate size distribution

From physical variables, we selected the ones that were closely related with the destruction of aggregates by tillage as the aggregate size distribution and structural stability. The aggregate size distribution (Figure 1) shows that as the years of agriculture increase the macroaggregates tend to reduce their size and, as a consequence, the percentage of smaller aggregates tend to increase. The situation 4 has diminished 24% of aggregates from 4.7 to 2 mm and increased from 4.7 to 13.5% the smallest aggregates (< 0.5 mm). The change in aggregate size distribution is an index of the transformation in pores size



Situations: 1. Native forest; 2, 3 and 4, 15-26 y 40 years after deforest, respectively.
Values followed by the same letter do not present significant differences (Tukey test, P<0.05) comparing among situations.
Situaciones: 1. Bosque nativo; 2, 3 y 4, 15-26 y 40 años de uso agrícola luego de la deforestación, respectivamente. Los valores seguidos por la misma letra no presentan diferencias significativas entre situaciones (Test de Tukey P<0,05).

Figure 1. Aggregate size distribution of analyzed situations.
Figura 1. Distribución del tamaño de agregados de las situaciones analizadas.

and distribution as a consequence of the collapse of macroaggregates by alteration of organic fractions by the land use. There was a strong negative correlation between organic carbon and ΔMWD ($r = -0.985$; $P < 0.02$; $n = 4$).

The structural stability shows that as the years after deforestation increase the difference in mean weight diameter (ΔMWD) also increases (Table 2). As ΔMWD is a difference between dry and wet size aggregates distribution, its increments mean a more unstable soil.

Even when the ΔMWD relative difference between the extreme treatments is high (264%), the absolute difference was only 0.41 mm after 40 years; which is low compared with similar experiments carried out in silty soils of the rolling pampa (Argentina) with similar organic matter contents. Its calcium content and the physiochemical protection exerted by the clay determine the high natural structural stability of soils with vertic characteristics. The smectitic clays should be more efficient on aggregation than other clays because of their large specific surface area, high cation exchange capacity, and consequently, physiochemical interaction capacity (Amézkta, 1999). Very stable aggregates can only be moved by splash and this effect only happens in high-intensity rain events, common in the region, in which runoff may occur without seal formation and large aggregates and coarse fragments may be transported and eroded. The aggregate stability is not a good indicator of soil erodibility in this case (Le Bissonnais, 1996).

As Wilson *et al.* (2000) the organic and physical variables have distinguished very well the extreme situations (1 and 4) and moderately well the intermediate ones. Nevertheless, as a consequence of erosion the A horizon depths were very different among situations [1: 27.1 cm (CV: 5.1%); 2: 25.6 cm (CV: 12.2%); 3: 11.2 cm (CV: 5.8%) and 4: 10.3 cm (CV: 7.2%)] and the differences in absolute contents in some variables are too much higher. Thus, taking into account the bulk densities, the Mg ha^{-1} of OC in the A horizon are 112.3; 90.2; 32.5 and 27.6 from situation 1 to 4 respectively showing a decreasing of 75.5 % in carbon sequestration after 40 years of cultivation.

CONCLUSIONS

As a result of deforesting and cropping, the native soil has lost a huge quantity of the A-horizon. Less notorious but significant, has been the decline in soil chemical and physical properties of the vertic soils in the department of Parana. The latter and the fact of applying fertilizers and other inputs has leaded to a minor decrease in crop yields over the time (farmers personal communication) that masked a 60 Mg ha^{-1} yr^{-1} mean annual erosion rate after 40 years.

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