INTERNATIONAL
SOIL AND WATER
CONSERVATION RESEARCH

Quality indicators in subtropical soils of Formosa, Argentina: Changes for agriculturization process

Juan Esteban Baridón[1,2] and Roberto Raúl Casas[3]

Abstract

The agriculturization process has been defined as the advance of annual crops in different environments, in competition with traditional land uses such as agriculture rotations with pastures. In Argentina and other countries agriculturization has different degrees of impact on natural resources. In the northeast region of the province of Formosa, Argentina, agriculturization includes deforestation (clear cutting, slash burning and plowing), technological improvements and changes in land use. Because of these alterations, it is necessary to define the state of the soil to evaluate its sustainability. This can be done by means of indicators, which are not universal; they differ according to the use, management and type of soils, weather conditions and ecosystems.

The objectives of this paper are: (1) To identify quality indicators for subtropical Argiudolls and Hapludolls; (2) To determine which indicators related to organic matter are most affected during agriculturization.

The changes produced in the Typic Hapludolls and Typic Argiudolls after 25 years of continuously using native forests, agriculture, fruit plantations and pastures were analyzed. These changes were in pH, electrical conductivity, total organic carbon, particulate organic carbon, total nitrogen, structural stability, hydraulic conductivity, respiration and dehydrogenase and urease and enzyme activity. Variables with significant differences between diverse uses were evaluated by multivariate methods, Principal Component Analysis, and Correlation Analysis. The results of this study showed that total organic carbon, particulate organic carbon, structural stability and dehydrogenase activity are the quality indicators most affected by agriculturization. All are related to organic matter.

Key Words: Hapludolls, Argiudolls, Soil quality, Soil use

1 Introduction

The negative impact of agriculture on soil quality and the changes that different agricultural managements cause on their physical, chemical and biological properties have been evaluated and confirmed (Caravaca et al., 2002; Marzaioli et al., 2010; García Orenes et al., 2010). The tillage and the reduction or elimination of vegetal cover accelerates the erosive processes (Cerdà et al., 2009). Herbicide application with the consequent reduction of organic matter input determines a decrease in biological soil activity (García Orenes et al., 2010). Some soil properties such as aggregate stability decrease in agricultural managements as compared to native vegetation coverage. This effect is accentuated in adverse climatic conditions (Cerdà, 2000). Thus, in semi-arid areas of the province of Formosa, in Argentina, with severe weather, and for ten years of continuous agriculture, the losses of organic carbon, total nitrogen and light carbon have been significant (Baridón et al., 2012a).

---

[1] Prof., Forestal engineer, Facultad de Ciencias Agrarias y Forestales. Universidad Nacional de La Plata. Calle 60 y 119 s/n. La Plata (CP 1900), Buenos Aires, Argentina. Corresponding author: E-mail: jbaridon@agro.unlp.edu.ar

[2] Laboratorio de Suelos, Aguas y Forrajes. Centro de Validación de Tecnologías Agropecuarias Ibarreta. Ruta Nacional 81 Km 1375, Ibarreta (CP 3624), Formosa, Argentina

[3] Agronomist engineer, Magister Scientiae, Prof., Centro de Investigación de Recursos Naturales. Instituto Nacional de Tecnología Agropecuaria: Dr. Nicolás Repetto (ex Las Cabañas) y Los Reseros, Castelar (CP1712), Buenos Aires, Argentina. E-mail: casas.roberto@inta.gob.ar

The agriculturization process has been defined as the advance of annual crops in different environments, in competition with traditional land uses such as agricultural rotations with pastures (Duhour et al., 2009; Manuel-Navarrete et al., 2009). In the northern, subtropical region of Formosa, the agriculturization process includes clearing (clear-cutting, burning of stubble, and plowed) for enabling new areas and changes from livestock-farming systems to farming systems, and from farming systems to fruit plantations and horticultural systems. The latter occurs in high-quality soils (Argiudolls and Hapludolls), in the elevated areas of rivers and in seasonal rivers which were cleared several years ago.

The current land-use planning of this province implies the possibility of expanding the present cultivated land from 400,000 ha to more than 2.5 million ha. These changes in land management make it necessary to examine the effects that will be produced in soil quality.

According to most definitions, "soil quality" is "the soil's ability to perform certain functions". These functions vary depending on each author. Thus, for Doran & Parkin (1994) and Karlen et al. (1997), those functions would be to promote the system's productivity without losing its physical, chemical and biological properties (sustainable biological productivity); to minimize environmental and pathogenic pollutants (environmental quality) and to promote health of plants, animals and human beings. Andrews et al. (2004) adds more functions to the list, saying that the soil also contributes to the nutrient cycling, water movement, structural support, filtering and buffering, resistance-resilience, and habitat-biodiversity. These functions must be quantified by measuring the most representative edaphic properties (Giuffré et al., 2006). One possibility to evaluate soil quality is by means of indicators (Doran & Parkin, 1994). An indicator is a variable which summarizes or simplifies relevant information so that the phenomenon or condition of interest can be perceived. It quantifies, measures and makes that information available in a comprehensible way (Cantú et al., 2007). The appropriate indicators to assess soil functions are not universal; they differ according to the use, management, and type of soils, weather conditions and evaluated ecosystems.

There are different approaches regarding how to select the appropriate indicators. However, they show certain remarkable aspects in common:

- It is necessary to define the objectives of soil management. Although most of the time the focus is on productivity, the goals can also be social and environmental (Andrews et al., 2004).
- Edaphic properties which are sensitive to changes with reference to the use of soils must be taken into account. Critical points regarding sustainable development must be identified (Astier et al., 2002; Cruz et al., 2004).
- The number of indicators used to evaluate soil quality must be kept to a minimum (Cantú et al., 2007; Ideángelo et al., 2007).
- The indicators must vary so as to represent physical, chemical and biological properties and different edaphic processes (Astier et al., 2002; Karlen et al., 2003).

Cosentino et al. (2007) and Ideángelo et al. (2007), among other researchers, have contributed to the definition of soil quality and to its control in different regions of the country. Cantú et al. (2007) developed a group of indicators and created a quality index for the Hapludolls of the province of Córdoba.

There already are studies concerning the subtropical region of the northeast of Argentina: Albanesi et al. (2003), Piccolo et al. (2004), Dalurzo et al. (2005) and Baridón et al. (2012a), among others. These researchers differ in environmental and edaphic indicators of the subtropical Mollisols of Formosa, which are the object of study of the present paper. However, those changes related to the organic matter's content, components, dynamics and functions have been evaluated as possible indicators and successfully used to define the quality and control of tropical and subtropical soils in this and other countries (Albanesi et al., 2003; Espinosa, 2004; Dalurzo et al., 2005; Díaz et al., 2005; Oluwatosin et al., 2006; Piccolo et al., 2008; Gómez et al., 2008; Dkhar et al., 2012). The applied variables range from those which are more common and discussed, such as organic carbon (OC) and total nitrogen (TN) components, to those which are related to biological activities and which are more recent, such as determining enzyme activity (EA). The latter are particularly useful for monitoring soil quality, since determining biochemical parameters is related to key microbial processes used to preserve its metabolic activity (Liborio Balota et al., 2004; Trasar-Cepeda et al., 2008).

Diverse groups of variables were proposed to characterize soil quality, monitor it and analyze the effects of these different uses. Nonetheless, when you come to the subtropical soils of the province of Formosa, there is no definitive answer regarding which variables could be considered as indicators. The objectives of this study were:

- To identify quality indicators for subtropical Argiudolls and Hapludolls.
- To check which indicators related to organic matter are most affected by agriculturization.

A broad knowledge of the physical, chemical and microbiological changes produced in subtropical Argiudolls and Hapludolls of Formosa facing diverse uses of the soil together with the quality indicators' selection, will substantially contribute to soil control throughout the agriculturization process. The developed methodology could be applied in other regions of the country and other parts of the world.

2 Materials and methods

2.1 *Studied area and soils*

21,000 ha of land were analyzed, mainly focusing on latitude 25º00′ S and longitude 58º30′ W, in the elevated coastal areas of the seasonal river "El Porteño", department of Pilagás, in the province of Formosa, in northeast Argentina (Fig.1). This zone is characterized by its agricultural, stockbreeding and horticultural activities and fruit plantations. The activities are more intense in soils that are in elevated coastal areas. These areas are composed of alluvial deposits with a central course of water which meanders longitudinally. In that zone there are, among others, Typic Hapludolls, Typic Argiudolls, Typic Udorthents, Typic Natrudalfs and Typic Natracualfs, which form soil complexes, with different participation degrees.

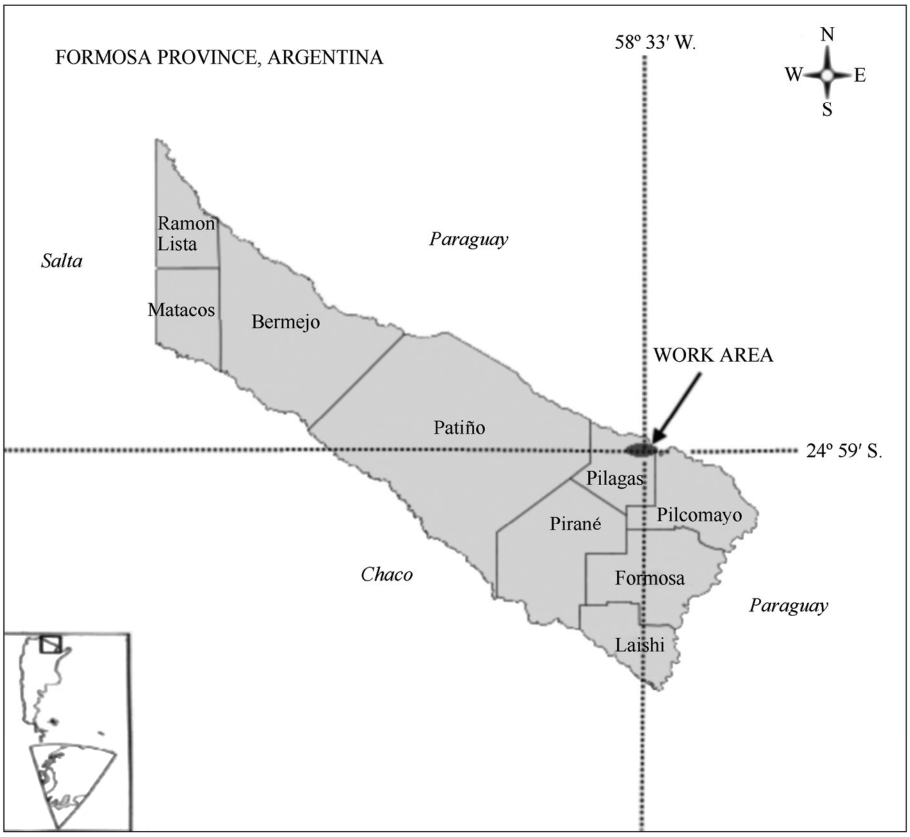

Fig. 1 Work area location

A preliminary zoning of the area was based on bibliographic review, interpretation of satellite images and fieldwork. Zones with more than 50% of Argiudolls and Hapludolls in the soil complex were selected. Soils were identified and classified as "great groups" according to the standards of recognition and soil sampling of the United States Department of Agriculture, USDA (NRCS, 2002) and Soil Taxonomy (NRCS, 2010).

2.2 *Representative productive systems (RPS)*

Based on the data retrieved from satellite images (CBERS-2B, China-Brazil Earth Resources Satellite) and Google Earth imagery, together with the fieldwork, the following representative productive systems (RPS) of different land uses, were identified in the area:

Native Forests (NF), Continuous Agriculture (CA), Pasture (P) and Fruit Plantations (F). Their general characteristics are:

- Native Forest (NF): Forest degraded by grazing and thinning wood. The commonest species found here are: pacará or timbó (*Enterolobium contortisiliquum* Morong & Britton), pink lapacho (*Tabebuia heptaphylla* Toledo), *guayaibí* (*Patagonula Americana* Linneo), *espina de corona* (*Gleditsia amorphoides* Grisebach), *laurel blanco* (*Ocotea diospyrifolia* Meisn), *ñandubay* (*Prosopis affinis* Sprengel), *urunday* (*Astronium balansae* Engler), *palo piedra* (*Diplokeleba floribunda* Brown) and white palms or *caranday* (*Copernicia alba* Morong).
- Continuous Agriculture (CA): Lands which were cleared 25 (±2) years ago. Certain historical plants here were corn (*Zea mays* Linneo) and cotton (*Gossypium spp*). The cultivation of these species has decreased during the last 10 years, while the cultivation of soybeans (*Glycine max* Linneo) has increased. This is a conventional tillage system, where disc plows are commonly used.
- Pasture (P): Lands which were cleared 25 (±2) years ago, where mono-specific pastures prevailed and were used during periods of 4 years. The commonest specie is *Dicantio (Dichanthium spp.)*.
- Fruit orchards (F): Fruit growing activity mainly focuses on two multi-annual crops: Grapefruits (*Citrus paradise* Macfadyen) and bananas (*Musa spp*). Fruit orchards generally are more than 20 (±2) years old. Most recent commercial fruit orchards, with a more intensive management, are younger (10 years old).

2.3 *Sampling design and analyzed variables*

Argiudolls and Hapludolls were sampled according to a stratified random design. The strata were consistent to the RPS: Native Forest (NF), taken as control; Continuous Agriculture (CA); Pasture (P); and Fruit orchards (F). In each stratum, 27 sampling sites were randomly distributed, where samples of 0 – 10 cm, 20 – 40 cm and 40 – 60 cm of depth were collected. 324 soil samples were analyzed (81 samples per RPS).

The selection of the analyzed variables was based on some of the aforementioned criteria (Astier et al., 2002; Karlen et al., 2003; Andrews et al., 2004; Cantú et al., 2007; Ideángelo et al., 2007).

- A sustainable biological productivity was established as a management aim. That is, the goal was to promote the system's productivity without losing its physical, chemical and biological properties.
- A small number of variables were selected, diverse enough so as to represent the previously mentioned physical, chemical and biological properties.

In the laboratory, for surface samples (0 – 10 cm), we determined: pH; electrical conductivity (EC), by conductometry of saturation extract; total organic carbon (TOC) and particulate organic carbon (POC), Walkley-Black method; total nitrogen (TN), Kjeldahl method; structural stability (Le Bissonnais, 1996); hydraulic conductivity (HC), using a constant head permeameter on disturbed samples; soil respiration (SR) and enzyme activity: and, dehydrogenase and urease (García et al., 2003).

In the deeper samples (20 – 40 cm, 40 – 60 cm), pH and EC were evaluated.

2.4 *Statistical analysis*

The obtained data was evaluated through descriptive statistical techniques. Those variables with statistical differences between their mean values for each specific use of the soil were analyzed in a multivariate way. With a Principal Component Analysis, the variables' relative weight was determined in relation to the sample's total variance. The correlation between the variables with more weight was analyzed as a parameter of their potential of acting as indicators, which were selected on the basis of the obtained data and agronomic criteria.

3 Results and discussion

3.1 *Physical, chemical and microbiological changes*

The mean values of the analyzed variables in the RPS, the existence of statistical differences and their standard deviations are shown in Table 1. Here one can see the surface pH values (pH), which are slightly acid in every case and show statistical differences. However, its variance range (6.3 – 6.6) has no agronomic relevance.

Table 1 Mean values of the variables according to land use

Use	pH	EC (dS m^{-1})	TOC [g (kg soil)$^{-1}$]	POC [g (kg soil)$^{-1}$]	TN [g (kg soil)$^{-1}$]	SR (μg CO_2 g^{-1} d^{-1})	DHA (μg ml^{-1})	URA (μg N-NH_4 $g^{-1}h^{-1}$)
NF	6.32_a σ=0.33	0.65_a σ=0.18	27.71_b σ=6.88	9.44_d σ=3.59	2.35_b σ=0.60	30.65_a σ=9.11	26.04_c σ=12.53	264.96_d σ=85.43
CA	6.30_a σ=0.26	0.71_a σ=0.33	19.19_a σ=5.37	2.61_a σ=1.27	1.78_a σ=0.49	59.27_b σ=14.5	10.63_a σ=2.26	95.00_a σ=19.84
P	6.65_b σ=0.53	0.63_a σ=0.31	34.56_c σ=12.99	7.57_c σ=2.27	3.07_c σ=0.80	76.88_c σ=26.2	17.59_b σ=2.90	198.93_c σ=37.68
F	6.62_b σ=0.49	0.86_a σ=0.43	22.90_a σ=3.67	4.84_b σ=1.66	1.83_a σ=0.35	23.41_a σ=13.54	13.78_a σ=4.96	140.40_b σ=44.17

Use	SS (MWD) (mm)	HC (cm h^{-1})	pH20	pH40	EC20 (dS m^{-1})	EC40 (dS m^{-1})
NF	1.97_c σ=0.41	1.18_b σ=0.44	6.11_a σ=0.52	6.64_a σ=0.65	2.20_b σ=2.43	2.45_b σ=3.92
CA	0.74_a σ=0.27	0.45_a σ=0.25	7.04_b σ=0.39	7.40_b σ=0.69	0.86_a σ=0.42	0.74_a σ=0.50
P	2.22_c σ=0.75	1.58_b σ=0.93	7.64_c σ=0.36	8.01_c σ=0.30	2.73_b σ=1.33	2.91_b σ=1.27
F	1.05_b σ=0.34	0.38_a σ=0.36	7.71_c σ=0.71	8.08_c σ=0.43	2.31_b σ=1.29	2.89_b σ=1.41

pH (pH); electric conductivity (EC); total organic carbon (TOC); particulate organic carbon (POC); total nitrogen (TN); soil respiration (SR); dehydrogenase activity (DHA); urease activity (URA); structural stability (SS) MWD: aggregates' mean weight diameter; hydraulic conductivity (HC); standard deviation(σ). Different letters show significant differences.

The surface EC (ECs) showed no differences among the diverse representative productive systems (RPS).

The total organic carbon content (TOC) showed significant differences among the diverse production systems. In CA and F, which have similar values, there was a decrease of the TOC in comparison to native forests (NF). The pasture (P) management has produced in the first 10 cm of soil after 25 years of grazing, an increase of 24.7% in the TOC. Oluwatosin et al. (2006), Cantú et al. (2007), Piccolo et al. (2008), Ferreras et al. (2009) and Moges et al. (2013), among others, have evaluated the organic carbon content as an indicator in different soils and regions. In this case, similarly to these reports, the continuous conventional tillage systems applied in continuous agriculture (CA) promote the organic matter's mineralization, which added to the different quantity and quality of biomass incorporated into the soil, could justify the 30.8% decrease in TOC content relative to native forests (NF). This loss of TOC is somewhat lower than that reported by Moges et al. (2013) for subtropical soils of Ethiopia and similar to that reported by Ferreras et al. (2009) in Argiudolls of other areas in Argentina. Fruit orchards, with less tillage of the soil, led to a decrease of 17.4% of the TOC present in NF. Land clearing, stubble burning, tillage the soil before planting fruits and subsequently, providing less organic matter could account for this result. Contrary to this, the increase of 24.7% in TOC when using P results from providing the edaphic system with more organic matter through the root biomass. This incorporated biomass has more chances to go through humification.

In all production systems the particulate organic carbon (POC) content decreased. The greatest loss occurred in CA, where the carbon related to the coarse fraction of the aggregates decreased by 72.4%, followed by F, with a 48.7% loss, and P, with a 19.8% loss of POC. The decrease shown in CA was larger than the one reported by Ferreras et al. (2009) for Argiudolls in a temperate, humid climate.

The RPS of Pasture produced an increase of TOC and a decrease of POC (Table 1). This is related to the fact that, with diverse uses of the soil, the content of "young forms" of carbon depends mostly on the differences between the accumulation of partially-decomposed labile forms and on decomposition rates (Janzen et al., 1998). According to these authors, high levels of young carbon can reflect a suppression of the decomposition rates.

Based on SR, it can be hypothesized that biological activity in NF and F, which show no significant differences between them, was lesser than the biological activities of the other RPS, resulting in lower decomposition rates.

The variance of the TN content was similar to the TOC's tendency. The high TN content in NF (2.35 g kg^{-1}) coincides with the TN's behavior in the forest's vegetation, which was reported by Albanesi et al. (2001), in

Argiustolls and Haplustolls, even under not so humid conditions. The loss recorded in CA and F, according to these authors, could be related to mineralization. Mineralization results from conventional tillage, and leads to the elimination of microbial soil crusts, which are formed by cryptogams, cyanobacteria, lichens and microscopic fungi, present in the surface layer of the forest's soil, which constitute a dynamic source of nitrogen in the region of Chaco.

In the pasture use (P), soil respiration (SR) increased by 150.8%; whereas in continuous agriculture (CA), it increased by 93.4%. When it comes to Fruit orchards (F), soil respiration (SR) was similar to the one in native forest (NF). The SR values were consistent with the range reported by Ferreras et al. (2009) for Argiudolls with natural vegetation in temperate, humid climate. As regards Agriculture, Fruit orchards and Pastures, respiration was always higher in this study than in studies reported by other authors.

Dehydrogenase activity (DHA) and urease activity (URA) showed significant differences, without taking into account the DHA between CA and P. DHA values were similar to those reported for Argiudolls and Hapludolls (Ferreras et al., 2009) for all their uses, except the mean value for NF (26.0 μg ml^{-1}), which was higher than what the reports noted.

The obtained URA values were higher than the ones reported by Albanesi et al. (2001) for the region of Chaco. However, when Dkhar et al. (2012) worked with soils in areas of India that had pristine forest vegetation (the latitude was similar to the one described in this paper), they reported URA values which were higher than 500 μg $N\text{-}NH_4$ $g^{-1}h^{-1}$. The most active enzyme activity in pristine soils or pastures coincides with the work done by Acosta Martínez et al. (2007), Ferreras et al. (2009). Through the majority of their results, they confirmed this behavior and posed that enzyme activity was one of the parameters capable of identifying changes of soil quality in the short term. Concurrently García Orenes et al. (2010) reported on the sensitivity of these variables with different agricultural managements during one year.

In analogous form to that reported by Cerdà (2000), Ferreras et al. (2007) and Álvarez et al. (2008), aggregate stability was a variable sensitive to the use of the soil. Assessed through the aggregates' mean weight diameter (MWD), it was noted that the use of P with aggregates of a MWD=2.22 mm was the most stable, with no significant differences regarding NF (MWD=1.97 mm). Álvarez et al. (2008) observed that, in Buenos Aires' Argiudolls, the greatest aggregate structural stability (SS) was present in those soils which had no previous farming or were even afforested with exotic species. The outer 10 cm of soil, after 25 years of CA, reduced its aggregate MWD by 62.4%, which was related to a decrease of 30.8% in the TOC content and of 72.4% in the POC content. Twenty years of F led to a decrease of 46.7% in the MWD.

There were no statistical differences between the hydraulic conductivity (HC) of NF and P, as opposed to the other RPS. The measuring of disturbed samples is associated to the porosity of aggregates and particles with less than 2 mm.

In every case, the HC measured in the laboratory was less than the HC measured in the field (Table 2).

Table 2 **Comparison Hydraulic Conductivity, HC (k) in field and laboratory**

	NF	CA	P	F
HC (k) (mm h^{-1}) field	$53.21_b \pm 12.79$	$14.64_a \pm 3.02$	$63.42_b \pm 12.33$	$18.75_a \pm 4.82$
HC (mm h^{-1}) laboratory	$11.8_b \pm 4.4$	$4.5_a \pm 2.5$	$15.8_b \pm 0.93$	$3.8_a \pm 3.6$

Different letters show significant differences

Ramírez Pisco et al. (2006), when evaluating the effects of no-till farming and conventional tillage on physical properties of silty-loam Argiudolls, found values of HC (K)=2.36 cm h^{-1}, a bit higher than the ones found in the present paper. For these authors, the HC and the aggregate instability were the physical parameters which were most sensitive to the differences between no-till farming and conventional tillage. Regardless of the method adopted for this determination, there could be significant differences between the HC of the outer 10 cm of soil in the analyzed RPS.

The pH of the deeper samples (20 – 40 cm and 40 – 60 cm) followed the same tendency. The lowest values were recorded in the reference pattern of NF with slightly acid pH; the use of CA led to a significant increase with neutral pH (7.04) and slightly alkaline pH (7.40). P and F production systems, which show no statistical differences between their pH values, had the highest pH values, which were slightly alkaline (20 – 40 cm depths) and moderately alkaline (40 – 60 cm depths).

The deeper samples' salt content, evaluated through the saturation extract's EC, only showed significant differences for CA, which led to a lower EC in comparison to those present in other production systems.

3.2 *Identification and selection of soil quality indicators*

Twelve variables with statistical differences among the diverse uses of the soil were analyzed. The original matrix and its data show those changes produced during 25 years of using the soil in different agricultural managements. The integrated evaluation, by means of a Principal Component Analysis (PCA), indicated that the three principal components accounted for 68% of the sample's total variance.

The PCA seeks to reduce data, by producing linear combinations of the original parameters, creating new variables (which are now independent) and identifying original variables, with more weight in the principal component. Each variable's weight and direction in the component are given by the sign and value of the corresponding coefficient. In Fig.2 it can be seen that TOC, POC, TN, DHA, URA, SS and HC are the variables with more weight in the principal component; while the deeper samples' pH (pH20 y pH40) have less influence and have a different direction.

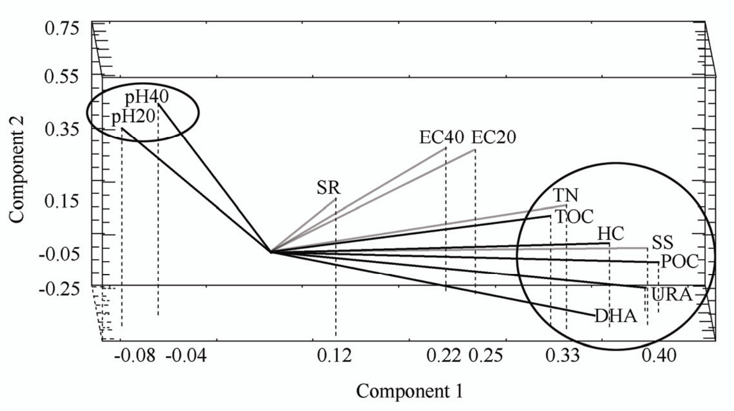

Fig. 2 Coefficients of the variables for component (12 variables)

To systematize the selection of variables, a limit under 0.05 of weight in the first component was arbitrarily established. The variables' weight turns out to be their coefficients' squares. Table 3 shows the variables' weights in the two principal components. Values under 0.05 for the component 1 are highlighted. Based on that value, pH20, pH40 and SR were discarded.

Table 3 Coefficients and weights of the variables in the first two components (PCA with 12 variables)

Variable	Component			
	Coefficient		Weights	
	1	2	1	2
TOC	0.33	–0.11	0.11	0.01
POC	0.39	0.15	0.15	0.02
TN	0.35	–0.16	0.12	0.03
SS	0.40	0.02	0.16	0.00
SR	0.12	–0.32	**0.01**	0.10
DHA	0.29	0.31	0.09	0.10
URA	0.37	0.24	0.14	0.06
HC	0.32	–0.35	0.10	0.12
pH20	–0.08	–0.50	**0.01**	0.25
pH40	–0.04	–0.51	**0.00**	0.26
EC20	0.25	–0.14	0.06	0.02
EC40	0.22	–0.15	0.05	0.02
Variance			1	1

Underlined values <0.05 in the first component

The weights of EC20 and EC40 within the established limits (but low in the first component, and under 0.05 in the second component) are of interest.

A new PCA with the nine selected variables noted three principal components, accounting for 72.3% of the variance. The coefficients of the variables in the first component are positive and have relatively uniform weights (Fig. 3). Nevertheless, EC20 and EC40 have the lowest values. Regarding the second component, these variables take part in linear combinations with signs opposite to the ones of the other variables. This is why they were dismissed.

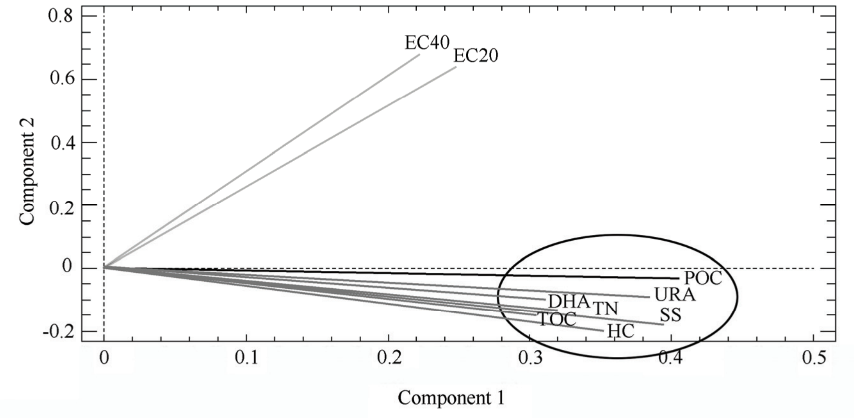

Fig. 3 Coefficients of the variables for component (9 variables)

TOC, POC, TN, URA, DHA, SS and HC were preselected as possible quality indicators, being correlated to each other in different degrees.

The number of indicators used to evaluate soil quality must be kept to a minimum (Cantú et al., 2007) so that changes can be monitored. The final selection of the variables capable of simplifying and reducing the information related to soil quality changes was based on the analysis of its correlations and agronomic criteria.

Table 4 shows correlations which are equal or superior to 50%. Within this range POC and SS are related to each other and to URA; POC is related to TOC; and SS to HC. TN surpasses this correlation value with TOC and DHA, but has a lower value than the other variables. Following this line of reasoning, POC and SS would be the first two variables to be considered as indicators.

Eiza et al. (2005), Ferreras et al. (2009) and de Figueiredo et al. (2010) agree that most of the changes which occur during different soil managements take place in the OC's particulate fraction. Eiza et al. (2005) says it is an indicator which is more effective than the TOC for identifying the effects on the soil.

The structural stability's sensitivity when facing diverse uses and management of Argiudolls in other regions has been verified (Cerdà, 2000; Ferreras et al., 2007; Álvarez et al., 2008). Baridón et al. (2012b) noted changes in SS after 20 years of continuous agriculture in the surface horizon of the Argiudolls in the studied area. These records, the present results, and the relation of the SS with macro and microporosity, organic carbon and biological activity, from the point of view of the creation of pores and the organic matter's humification (Reynolds et al., 2002; Dexter, 2004), could let us classify it as a soil quality indicator for that region.

The HC data were well correlated (64%) with structural stability, which was already selected as an indicator. Because of this, together with the operational effort needed for its determination, whether in the laboratory or in the field, led to its exclusion as a quality indicator.

It has been mentioned that the TOC's ability to identify changes in the management and quality of soils is inferior to the POC's ability. However, taking into account that its determination is a parameter commonly used around the world and that its value clearly correlates with TN content, TOC was selected as an indicator and TN was dismissed.

Nowadays it is accepted that biochemical, microbiological and biological soil properties would be most appropriate to detect changes in soil quality and therefore its degradation (Paz-Ferreiro and Fu, 2013). The microbial activity, the main source of edaphic enzymes, is essential for the maintenance of soil quality (Bastida et al., 2006; Trasar-Cepeda et al., 2008). These enzymes, even at low levels, have a fundamental role in the dynamics of nutrients (Bolinder et al., 1999).

Table 4 Correlation matrix between preselected variables

	TOC	POC	TN	SS	DHA	URA	HC
TOC		**0.50**	**0.60**	0.40	0.32	0.36	0.48
	1	−108	−108	−108	−108	−108	−108
		0	0	0	0.00	0.00	0
POC	**0.50**	1	0.42	**0.59**	0.46	**0.68**	0.42
	−108		−108	−108	−108	−108	−108
	0		0	0	0	0	0
TN	**0.60**	0.42	1	0.40	0.32	0.40	0.45
	−108	−108		−108	−108	−108	−108
	0	0		0	0.00	0	0
SS	0.40	**0.59**	0.40	1	0.49	**0.59**	**0.64**
	−108	−108	−108		−108	−108	−108
	0	0	0		0	0	0
DHA	0.32	0.46	0.32	0.49	1	0.42	0.31
	−108	−108	−108	−108		−108	−108
	0.00	0	0.00	0		0	0.00
URA	0.36	**0.68**	0.40	**0.59**	0.42	1	0.39
	−108	−108	−108	−108	−108		−108
	0.00	0	0	0	0		0
HC	0.48	0.42	0.45	**0.64**	0.31	0.39	1
	−108	−108	−108	−108	−108	−108	
	0	0	0	0	0.00	0	

Underlined correlation values⩾0.5

Urease is a hydrolase related to the transformation of organic nitrogen into ammonium. The enzyme is synthesized and secreted outside the cell by bacteria and fungi, and ends up being part of the soil matrix (Tripathi et al., 2007). Thus, urease activity can be regulated by the production and secretion of microorganisms (Aon et al., 2001) and by physical and chemical conditions which stimulate the enzyme to bind to soil's colloids. Urease enzyme activity showed high correlation with POC and SS, which were already considered as indicators. Dkhar et al. (2012) recorded significant seasonal changes in the activity of this enzyme throughout the year. These seasonal variations could compromise its use as soil quality indicator. Paz-Ferreiro and Fu (2013) note, among other factors, the lack of standardization of analytical methods as limiting its application in soil quality indices. Although URA turned out to be a parameter sensitive to different RPS, its use would be subject to sampling performed in the same season of the year.

Dehydrogenase is an oxidoreductase. Thus, it reflects the oxidative capacity of microbial mass, and it can represent its size and activity. It is an endoenzyme, so it is not stabilized by the organic and inorganic colloids of the soil (Rossel et al., 1997). The dehydrogenase activity, contrary to the URA, correlates with all the variables under 50%; so if it is not considered as an indicator, most of the information it provides regarding the analyzed edaphic changes would be lost.

From the preceding results and discussion it follows that, out of the seven variables selected because of their weight on the variability of the analyzed data, TOC, POC, SS and dehydrogenase activity could be used as quality indicators, for they synthesize some of the changes identified in the studied system.

4 Conclusions

The agriculturization of Argiudolls and Hapludolls for twenty five years in Formosa province, Argentina, has produced significant changes in the physical, chemical, and biological properties of soils. Total organic carbon, particulate organic carbon, structural stability and dehydrogenase activity are quality indicators for subtropical Argiudolls and subtropical Hapludolls in Formosa province, Argentina.Within the set of indicators identified, the most sensitive to the impact of agriculturization were those associated with organic matter.

The continuous agriculture system used has been the most aggressive for the edaphic sustainability since it leads to a decrease in soil quality.

The application of simple practices such as implementation of reduced tillage and using crop rotations that include grasses in the system of continuous agriculture and the use of grassland coverage in fruit orchards systems, mitigates the impact of agriculturization on these soils.

In order to quantify and monitor the soil quality and finally establish management standards, it would be necessary to develop a quality index based on these indicators.

References

Acosta Martínez, V., Mikha, M., & Vigil, M. (2007). Microbial communities and enzyme activities in soils under alternative crop rotations compared to wheat-fallow for the Central Great Plains. *App. Soil Ecol.*, *37*, 41-52. doi:10.1016/j.apsoil.2007.03.009

Albanesi, A., Anríquez, A., & Polo Sánchez, A. (2001). Efectos de la agricultura convencional sobre algunas formas del nitrógeno en una toposecuencia de la región chaqueña, Argentina. *Agriscientia*, *XVIII*, 3-11.

Albanesi, A., Anríquez, A., & Polo Sánchez, A. (2003). Efectos de la agricultura convencional sobre algunas formas del carbono en una toposecuencia de la región chaqueña, Argentina. *Agriscientia*, *XX*, 9-17.

Álvarez, M. F., Osterrieth, M., Laborde, V., & Montti, L. (2008). Estabilidad, morfología y rugosidad de agregados de Argiudoles Típicos sometidos a distintos usos: su rol como indicadores de calidad física en suelos de la provincia de Buenos Aires, Argentina. *CI. Suelo (Argentina)*, *26*(2), 115-129.

Andrews, S. S., Karlen, D. L., & Cambardella, C. A. (2004). The Soil Management Assessment Framework: A Quantitative Soil Quality Evaluation Method. *Soil Sci. Soc. Am. J., 68*, 1945-1962.

Aon, M. A., Cabello, M. N., Sarena, D. E., Colaneri, A. C., Franco, M. G., Burgos, J. L., & Cortassa, S. (2001). I Spatio-temporal patterns of soil microbial and enzymatic activities in an agricultural soil. *Appl. Soil Ecol., 18*, 239-254.

Astier, C. M., Mass-Moreno, M., & Etchevers, B. J. (2002). Derivación de indicadores de calidad de suelo en el contexto de la agricultura sustentable. *Agrociencia, 36*, 605-620.

Baridón, E., Pellegrini, A., Lanfranco, J., & Cattani, V. (2012a). Variación de la fracción orgánica por agriculturización en Alfisoles subtropicales de Argentina.*CienciAgro, Journal de Ciencia y Tecnología Agraria, 2*(3), 371-378.

Baridón, E., Merani, V., & Cattani, V. (2012b). Modificaciones en el carbono orgánico y la estabilidad estructural asociadas al uso del suelo en una zona subtropical de Argentina. *Ciencia, 7*(25), 7-15.

Bastida, F., Moreno, J. L., Hernández, T., & García, C. (2006). Microbiological degradation index of soils in semiarid climate. *Soil Biol. Biochem.,38*, 3463-3473. doi:10.1016/j.soilbio.2006.06.001

Bolinder, M. A., Angers, D. A., Gregorich, E. G., & Carter, M. R. (1999). The response of soil quality indicators to conservation management. *Can. J. Soil Sci.,79*, 37-45.

Cantú, M. P., Becker, A., & Bedano, J. C. (2007). Evaluación de la calidad de suelos mediante el uso de indicadores e índices. *CI. Suelo (Argentina), 25*(2), 173-178.

Caravaca, F., Masciandaro, G., & Ceccanti, B. (2002). Land use in relation to chemical and biochemical properties in semiarid Mediterranean environment. *Soil and Tillage Research, 68*, 23-30.

Cerdà, A. (2000). Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia. *Soil & Tillage Research, 57*, 159-166.

Cerdà, A., Giménez Morera, A., & Bodí Merche, B. (2009). Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean basin.*Earth Surf. Process and Landforms, 34*, 1822-1830.doi: 10.1002/esp.1889

Cosentino, D. J., Conti, M. E., & Giuffré, L. (2007). Forty years of soil degradation in Vertic Argiudolls in Entre Ríos province, Argentina. *CI. Suelo (Argentina), 25*(2), 133-138.

Cruz Bautista, A., Etchevers Barra, J., del Castillo, R. F., & Gutiérrez, C. (2004). La calidad del suelo y sus indicadores. *Ecosistemas,13*(2),90-97.

de Figueiredo, C. C., Siqueira Resck, D. V., & Carbone Carneiro, M. A. (2010). Labile and stable fractions of soil organic matter under management systems and native Cerrado. *R. Bras. Ci. Solo*, *34*, 907-916.

Dalurzo, M., Toledo, D., & Vázquez, S. (2005). Estimación de parámetros químicos y biológicos en Oxisoles con uso citrícola. *CI. Suelo (Argentina), 23*(2), 159-165.

Dexter, A. R. (2004). Soil physical quality. Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma, 120*, 201-214.

Dkhar, M., Dkhar, M. S., & Tynsong, H. (2012). Microbial activities and nutrients dynamics in sacred forest of Meghalaya. *Indian J. Innovations Dev., 1*(3), 175-185.

Díaz, B., Cairo, P., Rodriguez, O., Abreu, I., Torres, P., Jimenez, R., Dávila, A., & Colás, A. (2005). Evaluación de la sostenibilidad del manejo del suelo pardo con carbonato (Inceptisol) a través de indicadores de calidad del mismo. *Centro Agrícola,32*(2), 73-78.

Doran, W. J. & Parkin, B. (1994). Defining and Assessing Soil Quality. In Doran, J. W., D. C. Coleman, Bezdicek, D. F., & Stewart, B. A. (Eds.), *Defining Soil Quality for a Sustainable Environment* (pp. 3-21). SSSA.Special Publication Number 35. Madison, Wisconsin.

Duhour, A., Costa, C., Momo, F., Falco, L., & Malacalza, L. (2009). Response of earthworm communities to soil disturbance: Fractal dimension of soil and species' rank-abundance curves. *Applied Soil Ecology, 43*, 83-88. doi:10.1016/j.apsoil.2009.06.004

Eiza, M., Fioriti, N., Studdert, G., & Echeverría, H. (2005). Fracciones de carbono orgánico en la capa arable: efecto de los sistemas de cultivo y de la fertilización nitrogenada. *CI. Suelo (Argentina), 23*(1), 59-67.

Espinosa, Y. (2004). Calidad de la materia orgánica bajo diferentes prácticas de manejo en un suelo ácido tropical. *Rev. Fac. Agron. (Venezuela), 21*(2), 126-141.

Ferreras, L., Magra, G., Besson, P., Kovalevski, E., & García, F. (2007). Indicadores de calidad física en suelos de la región pampeana norte de Argentina bajo siembra directa. *CI. Suelo (Argentina), 25*(2), 159-172.

Ferreras, L., Toresani, S., Bonel, B., Fernández, E., Bacigaluppo, S., Faggioli, V., & Beltrán, C. (2009). Parámetros químicos y biológicos como indicadores de calidad del suelo en diferentes manejos. *CI. Suelo (Argentina), 27*(1), 103-114.

García, C., Gil, F., Hernández, T., & Trasar, C. (2003). Técnicas de Análisis de Parámetros Bioquímicos en Suelos: Medida de Actividades Enzimáticas y Biomasa Microbiana. Mundi-Prensa.

García Orenes, F., Guerrero, C., Roldán, A., Mataix-Solera, J., Cerdà, A., Campoy, M., Zornoza, R., Bárcenas, G., & Caravaca, F. (2010). Soil microbial biomass and activity under different agricultural management systems in a semiarid Mediterranean agroecosystem. *Soil and Tillage Research, 109*(2), 110-115. doi: 10.1016/j.still.2010.05.005

Giuffré, L., Romaniuk, R., Conti, M. E., & Bartoloni, N. (2006). Multivariate evaluation of no-tillage system quality indicators in Argiudolls of Rolling Pampa (Argentina). *Biology and Fertility of Soils, 42*, 556-560. doi:10.1007/s00374-005-0051-8

Gómez, Y., Paolini, J., & Hernández, R. M. (2008). Sustitución de la sabana nativa con plantaciones de *Pinus Caribaea* (*Pinaceae*) en Venezuela: efecto sobre parámetros indicadores de cambios en el carbono del suelo. *Rev. Biol. Trop.,56*(4), 2041-2053

Ideángelo, N., Wilson, M. G., & Tasi, H. A. (2007). Indicadores de calidad para dos suelos con características vérticas de Entre Ríos (Argentina). *Cadernos Lab. Xeolóxico de Laxe. Coruña,32*, 111-125.

Janzen, H., Campbell, C., Izaurralde, R., Ellert, B., Juma, N., McGill, W., & Zentner, R. (1998). Management effects on soil C storage on the Canadian praires. *Soil & Tillage Research, 47*, 181-195.

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., & Schuman, G. E. (1997). Soil quality: a concept, definition and framework for evaluation. *Soil Science Society of America J., 61*, 4-10.

Karlen, D. L., Andrews, S. S., Weinhold, B. J., & Doran, J. W. (2003). Soil quality humankind's foundation for survival. *J. Soil Water Cons.*, *58*, 171-179.

Le Bissonnais, Y. (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *European Journal of Soil Science, 47*, 425-437.

Liborio Balota, E., Kanashiro, M., Colozzi Filho, A., Souza Andrade, D., & Dick, R. P. (2004). Soil enzyme activities under long-term tillage and crop rotation systems in Sub Tropical Agro-Ecosystems. *Brazilian Journal of Microbiology, 35*, 300-306.

Manuel-Navarrete, D., Gallopín, G., Blanco, M., Díaz-Zorita, M., Ferraro, D., Herzer, H., Laterra, P., Murmis, M., Podestá, G., Rabinovich, J., Satorre, E., Torres, F., & Viglizzo, E. (2009). Multi-causal and integrated assessment of sustainability: the case of agriculturization in the Argentine Pampas. *Environment, Development and Sustainability, 11*(3), 621-638. doi:10.1007/s10668-007-9133-0

Marzaioli, R., D'Ascoli, R., De Pascale, R., & Rutigliano, F. (2010). Soil quality in a Mediterranean area of Southern Italy as related to different land use types. *Applied Soil Ecology, 44*, 205-212. doi:10.1016/j.apsoil.2009.12.007

Moges, A., Dagnachew, M., & Yimer, F. (2013). Land Use Effects on Soil Quality Indicators: A Case Study of Abo-Wonsho Southern Ethiopia. *Applied and Environmental Soil Science, 2013*. doi:10.1155/2013/784989

NRCS (Natural Resources Conservation Service). (2002). United State Department of Agriculture (USDA). Field Book for Describing and Sampling Soils. Version 2.0. September 2002.

NRCS (Natural Resources Conservation Service). (2010**).** United State Department of Agriculture (USDA). Keys to Soil Taxonomy. Eleventh Edition.

Oluwatosin, G. A., Adeyolanu, O. D., Ogunkunle, A. O., & Idowu, O. J. (2006). From land capability classification to soil quality: and assessment. *Tropical and Subtropical Agroecosystems (Méjico), 6*(2), 45-55.

Paz-Ferreiro, J. & Fu, S. (2013). Biological indices for soil quality evaluation: perspectives and limitations. *Land Degradation &*

Development, 2013. doi: 10.1002/ldr.2262

Piccolo, G. A., Andriulo, A. E., & Mary, B. (2008). Changes in Soil Organic Matter Under Different Land Management in Misiones Province (Argentina). *Sci. Agric. (Piracicaba, Braz.), 65*(3), 290-297.

Piccolo, G. A., Galantini, J. A., & Rosell, R. A.(2004). Organic carbon fractions in a yerba mate plantationon a subtropical Kandihumult of Argentina. *Geoderma, 123*, 333-341. doi: 10.1016/j.geoderma. 2004.02.017

Ramírez Pisco, R., Taboada, M. A., & Gil, R. (2006). Efectos a largo plazo de la labranza convencional y la siembra directa las propiedades físicas de un Argiudol Típico de la pampa ondulada argentina. *Rev. Fac. Nal. Agr. Medellín, 59*(1), 3237-3256.

Reynolds, W. D., Bowman, B. T., Drury, C. F., Tana, C. S., & Lu, X. (2002). Indicators of good soil physical quality: density and storage parameters. *Geoderma, 110*, 131-146.

Rossel, D., Tarradelas, J., Bitton, G., & Morel, J. (1997). Use of enzymes in soil ecotoxicology: a case for dehydrogenase and hidrolytic enzymes. In J. Tarradelas, G. Bitton & D. Rossel (Eds.), *Soil Ecotoxicology* (pp. 179-206). Lewis Publishers: Boca Raton, Florida.

Trasar-Cepeda, C., Leiros, M., Seoane, S., & Gil-Sotres, F. (2008). Biochemical properties of acid soils under crop rotation. *Appl. Soil Ecol., 39*, 133-143.

Tripathi, S., Chakraborty, A., Chakrabarti, A., & Bandyopadhyay, B. (2007). Enzime activities and microbial biomass in coastal soils of India. *Soil Biol. Biochem., 39*, 2840-2848. doi:10.1016/j. soilbio. 2007.05.027