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Application of Quality Indicators in the Evaluation of Subtropical Argiudolls and Hapludolls in Formosa (Argentina)

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Authors' contributions

This work was done in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The quality indicators are suitable tools to determine the state of the soil and the effects of different uses and management on it. The aim of the present work was to evaluate the quality of sub-tropical Argiudolls and Hapludolls subjected to different uses in Formosa, using a minimum set of indicators (MSI). Changes in soil use and the application of management techniques to maximize agricultural production are frequent in the world. In Formosa, Argentina, improvements in the productive infrastructure and low market value of the land, promote that these changes occur faster than the monitoring of the ones. The effects of 25 years of continuous agricultural use, extensive livestock in

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implanted pastures and fruit crops, in relation to the native forest were analyzed. The MSI consisted of five variables: total organic carbon, particulate organic carbon, total nitrogen, structural stability and bulk density. The baseline of the indicators was determined and threshold values were established. The standardized MSI was analyzed graphically. Particulate carbon and structural stability were the most sensitive indicators. Continuous agriculture degraded the edaphic system, resulting in lower values of indicators than the thresholds. It produced a decrease of 74% of the particulate organic carbon and 63% of structural stability, with possible impact on the resilience of the system. Fruit crops led to a decrease in soil quality causing particulate organic carbon and structural stability to approach values that compromise their natural recovery. The implanted pasture improved the quality of the soil with respect to the degraded native forest.

Keywords: Application; soil quality indicators; graphical analysis.

1. INTRODUCTION

Changes in soil use and the application of demand-driven management techniques to maximize agricultural production are becoming more frequent in various regions of the world. Some authors have named agriculturization the process that leads to the replacement of crops and conventional uses of the soil, by annual species [1,2,3]. The market value of the land in the province of Formosa, Argentina, is lower than other regions; but due to advances in its productive infrastructure, such as road network and electricity, these land use changes occur faster than the alterations produced on the soil that can be monitored. They affect the quality or health of soils and have been reported in different situations [3,4].

Ferreras et al. [5]; Rojas et al. [6]; Bravo-Medina et al. [7]; Rojas et al. [8], among others, agree in pointing out some quality indicators as tools to assess the state of the soil and the effects of different uses and management of it. 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. [9]. Quality indicators are those properties and processes of the soil with greater sensitivity to changes in their functions [10].

For more than 15 years it has been discussed which indicators are suitable for different regions, soils and agroecosystems. Its effective usefulness to monitor soil quality demands basic information, complementary to the identification of the indicators. Arshad and Martín [11], point out that different agro-ecological regions require the selection of a set of indicators and the establishment of their critical limits (threshold values). Segnestam [12] and Wilson and Sione [13] highlight the importance of establishing the reference baseline or starting point for each indicator, in order to reflect the generation of positive or negative impacts on the environment, together with the threshold values (TV) for the monitoring of negative impacts, which must not exceed a certain level or value. This allows to monitor the normal functioning of the soil, to detect changes and to determine the trends of improvement or deterioration in its quality.

The soil indicators interact with each other and, therefore, the value of one is affected by one or more of the selected parameters. A minimum set of indicators (MSI) is a small group of variables capable of synthesizing most of the total variability of a soil in a given site [14].

Some researchers have proposed procedures to evaluate soil quality functions by combining and integrating specific elements in the soil quality indices. These procedures allow us to weigh several functions, depending on the user's objectives and socioeconomic concerns [11]. The indicators are measured in different units, so it is necessary to transform the values of laboratory or field to a single scale, standardizing the results in order to integrate them, for example in indices or graphic representations [6]. Recent applications of indicators use methodologies based on scoring systems to standardize the values of the variables [7,8] and then integrate them mathematically, statistically and / or graphically for analysis.

The objective of the present work was to evaluate the quality of Argiudolls, and subtropical Hapludolls subjected to different uses, using a minimum set of indicators.

2. MATERIALS AND METHODS

We worked in an area of 24,000 ha, with an approximate centre at 25° 00' South latitude, 58°

30' West longitude, in the departments of Pilagás and Pilcomayo, province of Formosa, Argentina, Fig. 1.

Data obtained by Baridón and Casas [3] on Argiudolls and Hapludolls [15], of the marginal fluvial hill of El Porteño river, subject to different uses were used. Twelve sampling sites were incorporated following the technique used by these authors. Through satellite information, background and fieldwork, plots with 20 to 25 years of continuous agricultural use in conventional tillage (CA), extensive livestock in implanted pastures (P) and fruit crops (FC), as well as areas with degraded native forest were located (NF). In the first three uses the native forest was clearcut, with mechanical system, using bulldozer, extraction of few individuals for timber purposes, formation of cordons with forest stubble and burning. Then the stems and woody roots are removed by hand and two or more heavy disc harrow passes.

The general characteristics of these uses are the following:

- Continuous agriculture in conventional tillage (CA): Areas disassembled 25 years ago (± 2). The historical crops were corn (*Zea mays*) and cotton (*Gossypium spp)*; in the last 10 years they have decreased and soybean (*Glycine max*) has increased. The tillage system is conventional, heavy plowing is often used.
- Pasture (P): Areas disassembled 25 years ago (± 2) where monospecific pastures have predominated, used during average periods of 4 years. The most frequent species are the Dicantium (*Dichanthium* spp.).
- Fruit crops (FC). There are mainly two plurianual crops: grapefruit (*Citrus paradisi*) and banana (*Musa* spp). The most frequent is the plantation of more than 20 years (± 2) in both crops. There are commercial plantations of a younger age (10 years old) managed more intensively.
- Degraded native forest (NF): forest of degraded native species by grazing, opening of bites and thinnings of wood. The dominant trees are: quebracho colorado (*Schinopsis balansae*), quebracho blanco (*Aspidosperma* quebracho-blanco), guayacán (*Caesalpinia paraguariensis*), urunday (*Astronium balansae*), white carob (*Prosopis alba*) and black carob (*Prosopis nigra*), among others.

Soil sampling was carried out according to a stratified random design. The strata represented the three situations of use: CA; P; FC and the situation considered as a blank, NF, because it almost represents all the forests present in the study area. Thirty sampling points were randomly distributed on each stratum. A sample from 0 to 10 cm deep, composed of 3 subsamples was taken on each sampling point. A total of 120 soil samples were analyzed.

In order to determine the quality of the soil resulting from the different uses, a MSI was used, composed of five variables: total organic carbon (TOC), particulate organic carbon (POC), total nitrogen (TN), stability structural (SS) and bulk density (BD). The quality indicators of the studied soils indicated by Baridón and Casas [3] were TOC, POC and SS, accompanied by dehydrogenase activity. The latter of a more difficult determination was not used in this work. Both BD and TN have been used in the region as quality indicators [6] and have become routine determinations for technicians and laboratories.

The analytical methods used were: total organic carbon by Walkley Black; particulate organic carbon by physical fractionation [16]; Total nitrogen by Kjeldahl method; structural stability by Le Bissonnais method [17], and bulk density by the cylinder method [18].

The base line of the indicators, defined as "initial values" (IV), was established from the average values corresponding to a relic of native forest located within the Pilcomayo National Park, Formosa province, 25°04′ South latitude, 58°07′ West longitude. The TV were set based on bibliographic background and consultations with experts.

The laboratory results were characterized by descriptive statistics. The analysis of the variance and the comparison of means were carried out using Fisher's minimum significant difference test.

A systematization of the indicators was carried out: the data were normalized according to a scale of 0 to 8. The scale was estimated individually, for each indicator, considering optimal and critical reference levels. Table 1 presents the scales used for normalization.

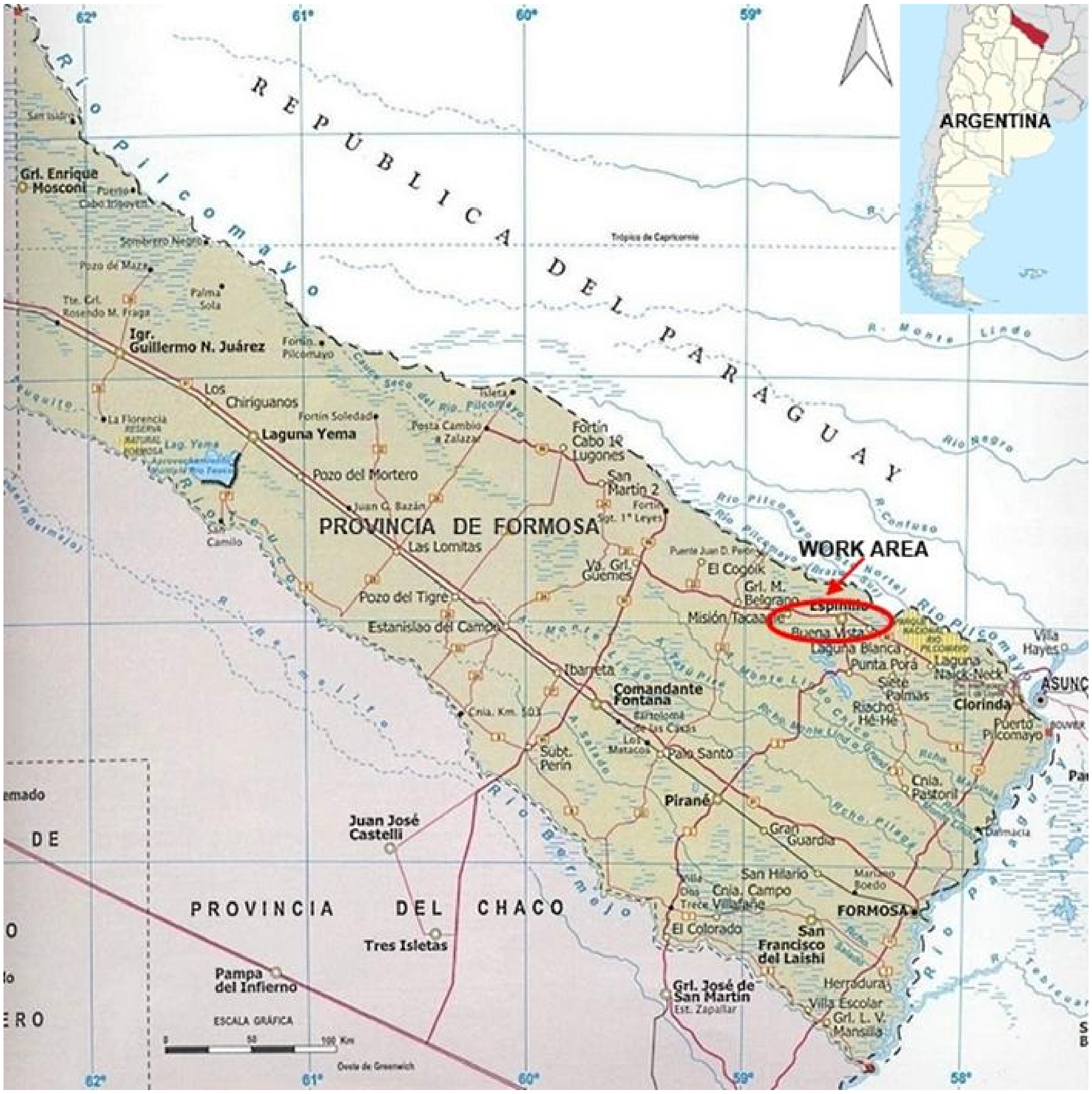

Fig. 1. Work area location

Table 1. Analytical data standardization criteria

TOC [g.kg^{-1}]		POC [g.kg^{-1}]		SS [WAD in mm]		BD [g.cm^{-3}]		TN [g.kg^{-1}]	
<2	0	<1	0	<0.9	0	> 1.7	0	<0.5	0
2 - 3.9	1	1 - 3	1	0.9 -1.1	1	1.61 - 1.70	1	0.5 - 0.7	1
4 - 6	2	3.1 - 5	2	1.2 - 1.4	2	1.51 - 1.60	2	0.8 - 1.0	2
6.1 - 10	3	5.1 - 7	3	1.5 - 1.7	3	1.41 - 1.50	3	1.1 - 1.3	3
10.1 - 15	4	7.1 - 9	4	1.8 - 2.0	4	1.31 - 1.40	4	1.4 - 1.6	4
15.1 - 20	5	9.1 - 11	5	2.1 - 2.3	5	1.21 - 1.30	5	1.7 - 1.9	5
20.1 - 25	6	11.1 a 13	6	2.4 a 2.6	6	1.11 a 1.20	6	2.0 a 2.4	6
25.1 - 30.4	7	13.1 a 15	7	2.7 a 2.9	7	1 a 1.10	7	2.5 a 2.9	7
>30.4	8	>15	8	> 2.9	8	<1	8	>2.9	8

TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD: bulk density; TN: total nitrogen; WAD: weighted average diameter

The assessment of the soil quality in the different uses was made by using a star diagram together with reference values and threshold for the MSI

3. RESULTS

The mean values of the indicators, the variance and the existence of statistically significant differences between the different land uses are presented in Table 2, where it is observed that all the indicators show statistical differences between the different land uses.

Table 3 shows the IV and the TV of the MSI.

In the present work, these IVs represent the pristine situation of the native forest on a marginal fluvial hill, obtained in the Pilcomayo National Park. They are considered as "base line", even though the blank was a degraded native forest, because these are currently the almost unique expression of the high forest in the area of work. The TV establish the limit values, which, if exceeded by each indicator, compromise the resilience of the system.

Figs. 2, 3, 4 and 5 shows, through star diagrams, the comparison between the MSI in the blank, NF; the IV of pristine native forest and the TV; the contrast between the MSI in different land uses and the current state of the indicators in the NF and the location of each indicator, in each land use, with reference to IV and TV.

4. DISCUSSION

A first analysis of Table 2 data indicates that continuous agriculture is the cause of the greatest loss of soil quality. In a similar way, although to a lesser extent, the fruit crops also produced negative effects in all the parameters evaluated. The extensive livestock with implanted pasture caused an increase in the total carbon content, total nitrogen and stability of the aggregates, with respect to the average values of these parameters in the native degraded forest. The lowest values of standard deviation were registered in almost all cases under fruit crops (Table 2), possibly due to the uniformity in the management of this productive system.

The joint presentation of the standardized indicators (Figs. 2, 3, 4, 5) allows the comparative evaluation of soil quality after 25 years of different uses. In almost all cases the separation of the MSI from the initial values (IV) is visualized, some of them exceeding the threshold values (TV), which could compromise the resilience of the edaphic system [13].

Fig. 2 shows the degradation of the soil in the native forests that now exist in the study area, as a result of selective interventions for the extraction of wood and firewood, together with grazing, mainly of goats and cattle. From the forestry point of view, the forests have reduced their specific heterogeneity, reduced their canopy, lost individuals from the upper strata and increased the density of plants in the lower strata. The natural regeneration of the forest has been compromised. The contributions of organic matter to the soil from natural forest, heterogeneous and with high nutrient contents have been modified. Prause et al. [19], when evaluating contributions of dry matter and composition of the litter of Quebracho colorado (*Schinopsis balansae*), reported contributions of 1.36 $Mg.ha^{-1}.year^{-1}$ of dry matter. This litter, containing 11.7 $mg.\ g^{-1}$ of nitrogen and 60 $g.\ kg^{-1}$ of phosphorus, for example, is practically not present in the NF, since the individuals of Quebracho colorado have been the most extracted. The decrease in TOC, POC and TN directly, as well as the loss of SS and the increase in BD associated with the deterioration of the porous soil system in the topsoil, are a consequence of unsustainable use of the forest resource.

Table 2. Quality indicators, statistical summary

	Quality indicators									
	TOC $[g.Kg^{-1}]$		POC $[g.Kg^{-1}]$		SS-WAD [mm]		BD $[g.cm^{-3}]$		TN $[g.Kg^{-1}]$	
Soil use	**Mean**	**S**	**Mean**	**S**	**Mean**	**S**	**Mean**	**S**	**Mean**	**S**
NF	27.04c	6.04	9.31d	3.15	1.98c	0.42	1.17a	0.10	2.21b	0.57
P	32.50d	6.42	7.32c	1.90	2.29c	0.51	1.27b	0.09	3.12c	0.76
FC	22.59b	3.46	4.52b	1.34	0.97ab	0.31	1.23ab	0.07	1.90a	0.37
CA	18.03a	5.16	2.30a	0.93	0.71a	0.25	1.36c	0.09	1.81a	0.45

TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; WAD: weighted average diameter; BD: bulk density; TN: total nitrogen; S: standard deviation. Different letters indicate statistical differences between means (p= 0.05)

Table 3. Reference values of soil quality indicators

Indicator	Unit	Analytical method	Initial values (IV)	Threshold values (TV)
TOC	$g.Kg^{-1}$	Walkley Black	39,5	6 (min) †
POC	$g.Kg^{-1}$	Galantini (2005)	18,6	4 (min) ‡
SS (WAD)	mm	Le Bissonnais (1996)	2,5	1‡
TN	g.Kg-1	Kjeldahl	2,8	1‡
BD	$g.cm^{-3}$	Cylinder method (Forsythe 1975)	1,1	1,6 (max)‡

† Minimum value of TOC established as a requirement for a mollic epipedon [15]. ‡Background and consultation with experts. TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; WAD: weighted average diameter; BD: bulk density; TN: total nitrogen

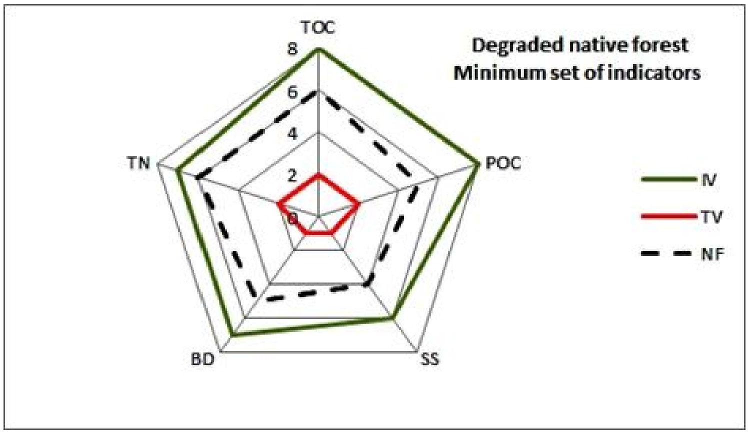

Fig. 2. Comparison of MSI. Degraded native forest in relation to reference values
TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD: bulk density; TN: total nitrogen; IV: initial values; TV: threshold values; NF: native forest

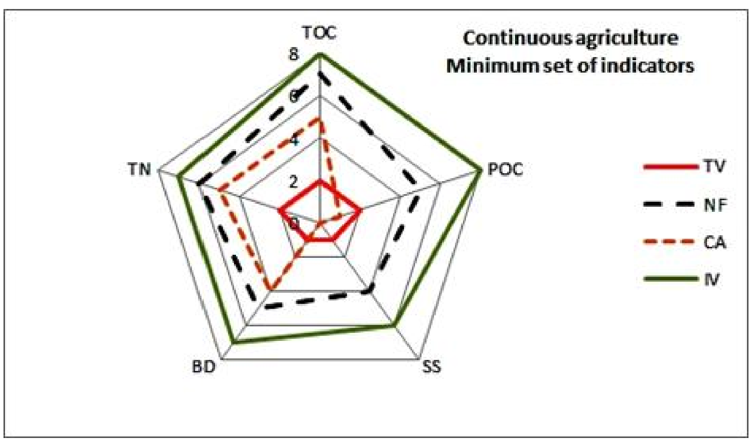

Fig. 3. Comparison of MSI. Continuous agriculture, native forest and reference values
TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD: bulk density; TN: total nitrogen; TV: threshold values; NT: native forest; CA: continuous agriculture; IV: initial values

After 25 years of continuous agriculture, in conventional sowing, the deterioration of soil quality has increased, as shown in the graph of the MSI, Fig. 3. Cantú et al. [9]; Piccolo et al. [20]; Ferreras et al. [5]; Moges et al. [21]; among others, have evaluated the organic carbon content as an indicator in different soils and regions. In the study area, the continuous realization of conventional tillage in CA use has favoured the mineralization of organic matter, which would justify the decrease of 29% in the content of TOC with respect to NF. This loss is somewhat lower than that reported by Moges et al. [21], for subtropical soils of Ethiopia and similar to that reported by Ferreras et al. [5] in Argiudolls in the provinces of Santa Fe and Córdoba, Argentina. Fig. 3 shows that the values of POC and SS have exceeded the threshold values. The POC has decreased 74% with respect to the NF, and 87% with respect to the pristine native forest; thus also the SS has been reduced 63% with respect to NF degraded, and 70% with respect to the pristine forest. TOC, TN and BD also point to a loss of soil quality; however they are still in the range of values in which the degradation process could be reversed. The implementation of direct sowing and the use of crops to maximize the amount of surface residues are frequent practices in order to increase the organic carbon content in the soil [22]. Céspedes et al. [23], working in a drier area of the Chaco region, reported that the highest contributions of surface carbon were produced by meadows, and by the forest in the first 15 cm of the soil. The rotation of crops allows to improve the soil carbon balance [24]; rotations that include pastures and service crops should be applied immediately in this situation of use.

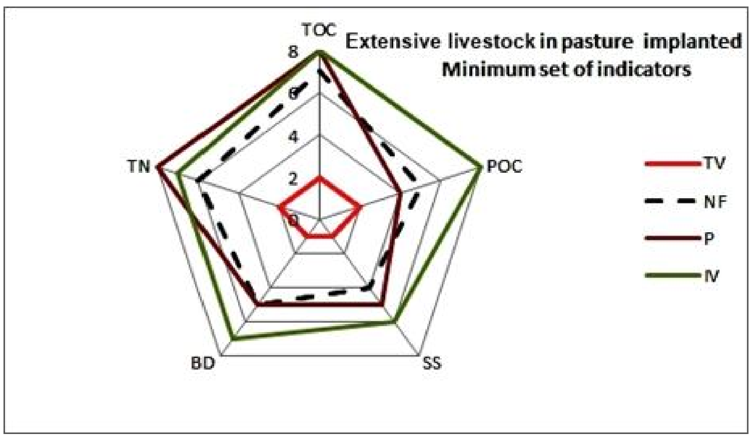

Fig. 4. Comparison of MSI. Extensive livestock in pasture implanted, native forest and reference values

TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD: bulk density; TN: total nitrogen; TV: threshold values; NF: native forest; P: pasture; IV: initial values

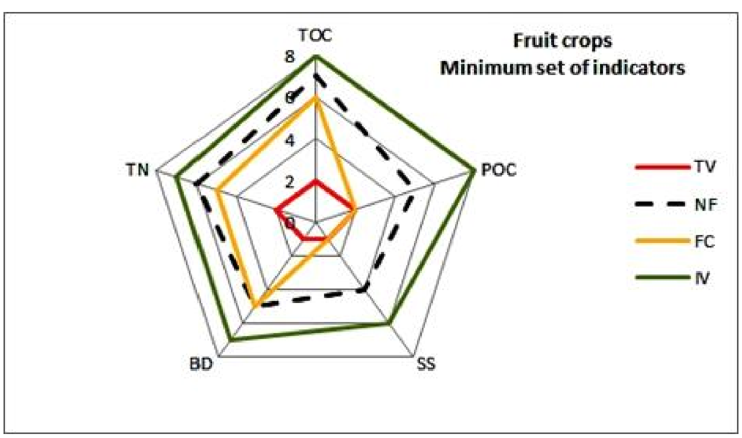

Fig. 5. Comparison of MSI. Fruit crops, native forest and reference values

TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD: bulk density; TN: total nitrogen; TV: threshold values; NF: native forest; FC: fruit crops; IV: initial values

The MSI in the fruit crops, (Fig. 5) indicates a loss of soil quality. The decrease with respect to NF in the POC content is highlighted, 48%, and 47% of SS; in both indicators reaching values close to the thresholds. Ferreras et al. [5] and de Figueiredo et al. [25], agree in pointing to the particulate fraction of organic carbon as the one where the greatest changes occur in the face of different managements. After the clearing and preparation of the soil for the implantation of the fruit tree, soil tillage is generally limited to weed control by means of disc harrowing between rows during the first years. This would have caused the decrease of 15% of TOC with respect to NF; the TN has accompanied this trend. Although there were statistical differences in BD values, they do not seem agronomically relevant.

Contrary to other land uses, the implanted pasture, (Fig. 4), has achieved an improvement in the TOC, TN, and SS indicators, recomposing the blank values, NF degraded, and even exceeding the content of TN to the pristine native forest. The increase in the content of TN for use P, 30.6% on degraded NF and 9.6% on the initial values, is related to the quantity, quality and distribution of the organic matter that the prairies incorporate into the soil every year. The content of TN in NF (2.35 $g.Kg^{-1}$) is coincident with the behavior of TN under scrub vegetation, even in conditions of lower humidity, reported by Albanesi et al. [26] in Argiustolls and Haplustolls of the semiarid Chaco region. The IV of TN corresponding to the pristine situation of the native forest are related to the high contributions by leaf litter of species such as *Schinopsis balansae*, which are around 11.7 mg. g^{-1} of N in the humid Chaco region [19].

The decrease of the content of TN in CA and FC situations would be associated with the elimination of superficial microbial crusts composed of cryptogams, cyanobacteria, lichens and microscopic fungi, present in the first centimeters of the forest floor [26] since they constitute a dynamic source of nitrogen in the Chaco region.

The POC was a sensitive indicator in all evaluated soil uses confirming its ability to respond to different management reported by other authors [5,25]. Duval et al. [27] confirm that the labile forms of carbon are sensitive to soil management: they obtained sensitive indicators in short periods of time and direct sowing conditions when separating the fractions of coarse particulate carbon and fine particulate carbon.

As the graphical analysis of the MSI indicates (Fig. 2) the use of continuous agriculture with conventional tillage and fruit monoculture has produced the degradation of soil quality.

Wilson and Sione [13] point out that when quantifying the deterioration of the edaphic qualities it is essential to establish the reference base line or starting point for each indicator, to reflect the generation of positive or negative impacts. Based on the results obtained, it is necessary to reconsider some of the threshold values used. The required TOC content for the mollic epipedon, 6 $g.kg^{-1}$ [15], for example, is a very low threshold if we want to consider that degradation compromises the resilience of the system.

5. CONCLUSION

The use of continuous agriculture with conventional tillage and fruit monoculture has produced the degradation of soil quality in Argiudolls, and subtropical Hapludolls. In both cases all indicators accused the degradation.

Continuous agriculture in conventional sowing degraded the edaphic system with possible affectation of its resilience, associated to the loss of labile forms of carbon and to the decrease of the structural stability, with these indicators below the critical levels.

Fruit crops use led to a decrease in soil quality with the particulate carbon and the stability of the aggregates to approach values that compromise their natural recovery.

The implanted pasture favored the improvement in the quality of the soil with respect to the degraded native forest, however the contents of the light carbon fractions continued below those of the degraded native forest.

The MSI used and its statistical and graphical analysis allowed to evaluate the quality of Hapludolls and Argiudolls against 25 years of agricultural, fruit and pastoral use.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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