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**Original Research Article**

**APPLICATION OF QUALITY INDICATORS IN  
THE EVALUATION OF SUBTROPICAL  
ARGIUDOLLS AND HAPLUDOLLS IN  
FORMOSA (ARGENTINA)**

**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 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

53 procedures allow us to weigh several functions, depending on the user's objectives  
54 and socioeconomic concerns [11]. The indicators are measured in different units, so  
55 it is necessary to transform the values of laboratory or field to a single scale,  
56 standardizing the results in order to integrate them, for example in indices or graphic  
57 representations [6]. Recent applications of indicators use methodologies based on  
58 scoring systems to standardize the values of the variables [7, 8] and then integrate  
59 them mathematically, statistically and / or graphically for analysis.

60 The objective of the present work was to evaluate the quality of Argiudolls, and  
61 subtropical Hapludolls subjected to different uses, using a minimum set of indicators.  
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## 63 2. MATERIALS AND METHODS. 64

65 We worked in an area of 24,000 ha, with an approximate centre at 25° 00' South  
66 latitude, 58° 30' West longitude, in the departments of Pilagás and Pilcomayo,  
67 province of Formosa, Argentina, Figure 1.

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

78 The general characteristics of these uses are the following:

79 - Continuous agriculture in conventional tillage (CA): Areas disassembled 25 years  
80 ago ( $\pm 2$ ). The historical crops were corn (*Zea mays*) and cotton (*Gossypium spp*); in  
81 the last 10 years they have decreased and soybean (*Glycine max*) has increased. The  
82 tillage system is conventional, heavy plowing is often used.

83 - Pasture (P): Areas disassembled 25 years ago ( $\pm 2$ ) where monospecific pastures  
84 have predominated, used during average periods of 4 years. The most frequent  
85 species are the Dicantium (*Dichanthium spp.*).

86 - Fruit crops (FC). There are mainly two plurianual crops: grapefruit (*Citrus*  
87 *paradisi*) and banana (*Musa spp*). The most frequent is the plantation of more than  
88 20 years ( $\pm 2$ ) in both crops. There are commercial plantations of a younger age (10  
89 years old) managed more intensively.

90 - Degraded native forest (NF): forest of degraded native species by grazing, opening  
91 of bites and thinnings of wood. The dominant trees are: quebracho colorado  
92 (*Schinopsis balansae*), quebracho blanco (*Aspidosperma quebracho-blanco*),  
93 guayacán (*Caesalpinia paraguariensis*), urunday (*Astronium balansae*), white carob  
94 (*Prosopis alba*) and black carob (*Prosopis nigra*), among others.  
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**Figure 1.** Work area location.



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

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

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

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

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

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

130

131 **Table 1.** Analytical data standardization criteria.

TOC [g.kg <sup>-1</sup> ]		POC [g.kg <sup>-1</sup> ]		SS [WAD in mm]		BD [g.cm <sup>-3</sup> ]		TN [g.kg <sup>-1</sup> ]	
<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

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

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

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### 139 3. RESULTS

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

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**Table 2.** Quality indicators, statistical summary.

Quality indicators										
Soil use	TOC [g.Kg <sup>-1</sup> ]		POC [g.Kg <sup>-1</sup> ]		SS-WAD [mm]		BD [g.cm <sup>-3</sup> ]		TN [g.Kg <sup>-1</sup> ]	
	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 ( $p=0.05$ )

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

**Table 3.** Reference values of soil quality indicators.

INDICATOR	UNIT	Analytical method	Initial values (IV)	Threshold values (TV)
TOC	g.Kg <sup>-1</sup>	Walkley Black	39,5	6 (min) †
POC	g.Kg <sup>-1</sup>	Galantini (2005)	18,6	4 (min) ‡
SS (WAD)	mm	Le Bissonnais (1996)	2,5	1 ‡
TN	g.Kg <sup>-1</sup>	Kjeldahl	2,8	1 ‡
BD	g.cm <sup>-3</sup>	Cylinder method (Forsythe 1975)	1,1	1,6 (max) ‡

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† Minimum value of TOC established as a requirement for a mollic epipedon [15].

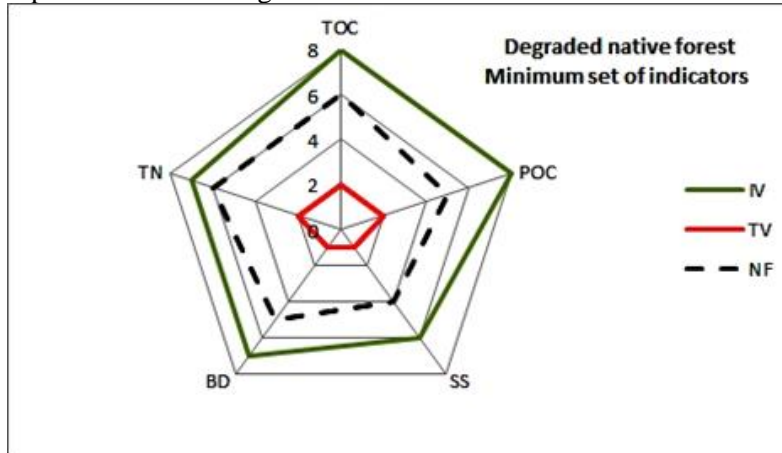
‡ Background and consultation with experts. TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; WAD: weighted average diameter; BD: bulk density; TN: total nitrogen.

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.

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

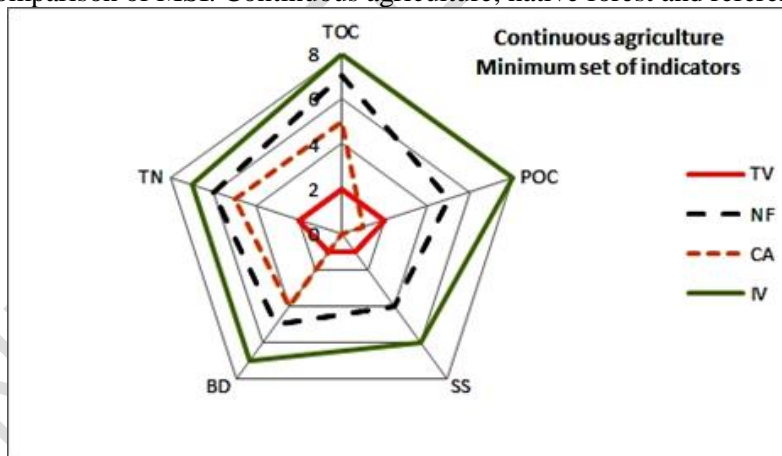
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**Figure 2.** Comparison of MSI. Degraded native forest in relation to reference values.



176 TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD:  
 177 bulk density; TN: total nitrogen; IV: initial values; TV: threshold values; NF: native forest.  
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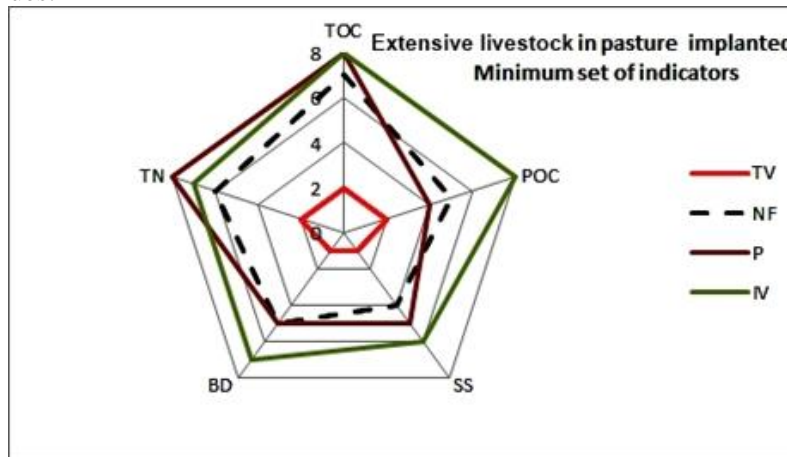
179 **Figure 3.** Comparison of MSI. Continuous agriculture, native forest and reference values.  
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181 TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD:  
 182 bulk density; TN: total nitrogen; TV: threshold values; NT: native forest; CA: continuous  
 183 agriculture; IV: initial values.

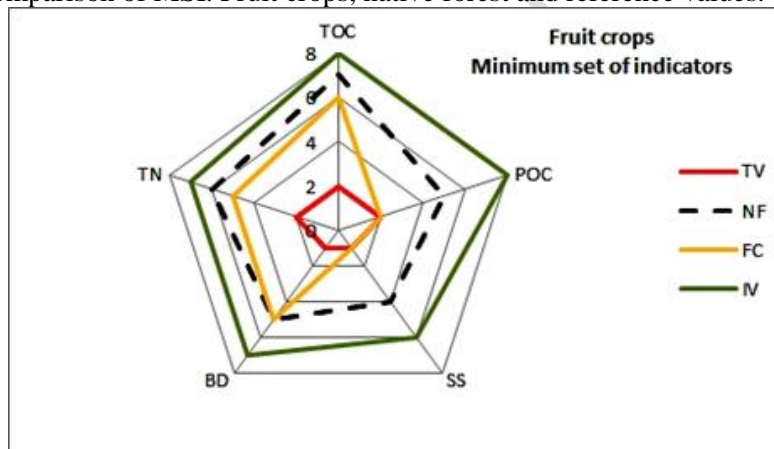
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190 **Figure 4.** Comparison of MSI. Extensive livestock in pasture implanted, native forest and  
 191 reference values.  
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193 TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD:  
 194 bulk density; TN: total nitrogen; TV: threshold values; NF: native forest; P: pasture; IV:  
 195 initial values.  
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197 **Figure 5.** Comparison of MSI. Fruit crops, native forest and reference values.  
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199 TOC: total organic carbon; POC: particulate organic carbon; SS: structural stability; BD:  
 200 bulk density; TN: total nitrogen; TV: threshold values; NF: native forest; FC: fruit crops; IV:  
 201 initial values.  
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#### 203 4. DISCUSSION

204  
 205 A first analysis of Table 2 data indicates that continuous agriculture is the cause of  
 206 the greatest loss of soil quality. In a similar way, although to a lesser extent, the fruit  
 207 crops also produced negative effects in all the parameters evaluated. The extensive  
 208 livestock with implanted pasture caused an increase in the total carbon content, total  
 209 nitrogen and stability of the aggregates, with respect to the average values of these  
 210 parameters in the native degraded forest. The lowest values of standard deviation  
 211 were registered in almost all cases under fruit crops (Table 2), possibly due to the  
 212 uniformity in the management of this productive system.



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

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

234 After 25 years of continuous agriculture, in conventional sowing, the deterioration of  
235 soil quality has increased, as shown in the graph of the MSI, Figure 3. Cantú et al.  
236 [9]; Piccolo et al. [20]; Ferreras et al. [5]; Moges et al. [21]; among others, have  
237 evaluated the organic carbon content as an indicator in different soils and regions. In  
238 the study area, the continuous realization of conventional tillage in CA use has  
239 favoured the mineralization of organic matter, which would justify the decrease of  
240 29% in the content of TOC with respect to NF. This loss is somewhat lower than that  
241 reported by Moges et al. [21], for subtropical soils of Ethiopia and similar to that  
242 reported by Ferreras et al. [5] in Argiudolls in the provinces of Santa Fe and  
243 Córdoba, Argentina. Figure 3 shows that the values of POC and SS have exceeded  
244 the threshold values. The POC has decreased 74% with respect to the NF, and 87%  
245 with respect to the pristine native forest; thus also the SS has been reduced 63% with  
246 respect to NF degraded, and 70% with respect to the pristine forest. TOC, TN and  
247 BD also point to a loss of soil quality; however they are still in the range of values in  
248 which the degradation process could be reversed. The implementation of direct  
249 sowing and the use of crops to maximize the amount of surface residues are frequent  
250 practices in order to increase the organic carbon content in the soil [22]. Céspedes et  
251 al. [23], working in a drier area of the Chaco region, reported that the highest  
252 contributions of surface carbon were produced by meadows, and by the forest in the  
253 first 15 cm of the soil. The rotation of crops allows to improve the soil carbon  
254 balance [24]; rotations that include pastures and service crops should be applied  
255 immediately in this situation of use.

256 The MSI in the fruit crops, (Figure 5) indicates a loss of soil quality. The decrease  
257 with respect to NF in the POC content is highlighted, 48%, and 47% of SS; in both  
258 indicators reaching values close to the thresholds. Ferreras et al. [5] and de  
259 Figueiredo et al. [24], agree in pointing to the particulate fraction of organic carbon  
260 as the one where the greatest changes occur in the face of different managements.  
261 After the clearing and preparation of the soil for the implantation of the fruit tree,  
262 soil tillage is generally limited to weed control by means of disc harrowing between  
263 rows during the first years. This would have caused the decrease of 15% of TOC  
264 with respect to NF; the TN has accompanied this trend. Although there were  
265 statistical differences in BD values, they do not seem agronomically relevant.  
266 Contrary to other land uses, the implanted pasture, (Figure 4), has achieved an  
267 improvement in the TOC, TN, and SS indicators, recomposing the blank values, NF  
268 degraded, and even exceeding the content of TN to the pristine native forest. The  
269 increase in the content of TN for use P, 30.6% on degraded NF and 9.6% on the  
270 initial values, is related to the quantity, quality and distribution of the organic matter  
271 that the prairies incorporate into the soil every year. The content of TN in NF (2.35  
272  $\text{g.Kg}^{-1}$ ) is coincident with the behavior of TN under scrub vegetation, even in  
273 conditions of lower humidity, reported by Albanesi et al. [25] in Argiustolls and  
274 Haplustolls of the semiarid Chaco region. The IV of TN corresponding to the pristine  
275 situation of the native forest are related to the high contributions by leaf litter of  
276 species such as *Schinopsis balansae*, which are around 11.7  $\text{mg. g}^{-1}$  of N in the  
277 humid Chaco region [19].  
278 The decrease of the content of TN in CA and FC situations would be associated with  
279 the elimination of superficial microbial crusts composed of cryptogams,  
280 cyanobacteria, lichens and microscopic fungi, present in the first centimeters of the  
281 forest floor [25] since they constitute a dynamic source of nitrogen in the Chaco  
282 region.  
283 The POC was a sensitive indicator in all evaluated soil uses confirming its ability to  
284 respond to different management reported by other authors [5, 24]. Duval et al. [26]  
285 confirm that the labile forms of carbon are sensitive to soil management: they  
286 obtained sensitive indicators in short periods of time and direct sowing conditions  
287 when separating the fractions of coarse particulate carbon and fine particulate  
288 carbon.  
289 As the graphical analysis of the MSI indicates (Figure 2) the use of continuous  
290 agriculture with conventional tillage and fruit monoculture has produced the  
291 degradation of soil quality.  
292 Based on the results obtained, it is necessary to reconsider some of the threshold  
293 values used. The required TOC content for the mollic epipedon, 6  $\text{g.kg}^{-1}$  [15], for  
294 example, is a very low threshold if we want to consider that degradation  
295 compromises the resilience of the system.  
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298 **5. CONCLUSION**

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300 The MSI used and its statistical and graphical analysis allowed to evaluate the  
301 quality of Hapludolls and Argiudolls against 25 years of agricultural, fruit and  
302 pastoral use. The continuous agriculture in conventional sowing degraded the  
303 edaphic system with possible affectation of its resilience, associated to the loss of  
304 labile forms of carbon and to the decrease of the structural stability. Fruit crops led to  
305 a decrease in soil quality causing the particulate carbon and the stability of the  
306 aggregates to approach values that compromise their natural recovery. The implanted  
307 pasture favored the improvement in the quality of the soil with respect to the  
308 degraded native forest. Particulate carbon and aggregate stability were the most  
309 sensitive indicators within the MSI.

310

311 **COMPETING INTERESTS**

312

313 Authors have declared that no competing interests exist.

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315 **AUTHORS' CONTRIBUTIONS**

316

317 This work was done in collaboration among the two authors. Both authors read and  
318 approved the final manuscript.

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