SOIL QUALITY INDICATORS IN A LONG-TERM CROP-PASTURE ROTATION EXPERIMENT IN URUGUAY

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ABSTRACT

The search of soil quality indicators that provide differences due to changes in soil use and management is needed. Fertilizer use, soil erosion and cropping system type have determined important changes on soil quality of Uruguayan soils. The objective of this research was to evaluate the sensitivity of several soil quality indicators closely related to soil organic matter in a long term crop-pasture rotation experiment. The experiment was established on a Molissol soil in 1963 at INIA La Estanzuela Experimental Station located in Uruguay. The site had thirty to forty years of continuous agriculture before 1963. For this particular research four treatments were selected: CS-1, continuous cropping (wheat, barley, sorghum and sunflower) without fertilizers; CS-2 is similar to S1 but with fertilizers; CS-5, crop-pasture rotation with a mixture of legumes and grasses with fertilizers; CS-7 continuous cropping with a biannual legume and fertilizers. All the treatments are under conventional tillage. In the fall of 1999, composite soil samples were taken in each treatment and replication at two depths: 0-7.5 cm and 7.5-15 cm. Traditional soil quality indicators used were total organic carbon and total nitrogen. The new indicators evaluated were: a) Carbon (C) in particulate organic matter from 53 to 212 mm (C-POM 53) and from 212 to 2000 mm (C-POM 212) obtained after soil dispersion and sieving; b) C in the light fraction obtained by dispersion and density separation (C-LF); c) Nitrogen (N) in particulate organic matter from 53 to 212 mm (N-POM 53) and from 212 to 2000 mm (N-POM 212); and d) N supplying capability of soil determined by anaerobic incubation (PMN). Major differences were observed for both traditional and new soil quality indicators between CS-1 and crop-pasture rotations (CS-5 and CS-7). In average and at the 0-7.5 cm depth, total organic carbon and total N in CS-5 and CS-7 were 55 and 62 % higher than CS-1. The new soil quality indicators showed a higher sensitivity to detect treatment differences. PMN was 4 to more than 6 times greater under crop-pasture treatments compared to CS-1. C-POM 212 and N-POM 212 were 3 and 4 times greater while C-LF was 3 times greater in CS-5 and CS-7 compared to CS-1. Considering both depths PMN was the most sensitive indicator evaluated.

Key words: soil quality, indicators, organic matter, crop rotations.

INTRODUCTION

The use of conventional agriculture generally lead to soil degradation and consequently a decrease in productivity (Johnston, 1991; Lal, 2000). Until the late fifties continuous cropping under conventional tillage was the predominant production system in Uruguay. No techniques to control erosion neither fertilizer applications lead to soil degradation. This is a result of negative carbon (C) and nitrogen (N) balances and their deleterious effects on soil physical, chemical and biological properties. Under Uruguayan conditions, the negative effect of continuous cropping under conventional tillage has been alleviated with the adoption of crop and pasture rotations

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and the use of fertilizers. This is the predominant production system in the country. Díaz Rossello (1992a;1992b), reported the effect of these soil management practices on soil chemical properties for a long-term crop rotation experiment established in Uruguay in 1963. Results showed that several years and replications are required to detect the effect of these practices on soil organic C and total N. These results agree with those reported by Rasmussen and Collins (1991) for temperate regions in the USA.

There is an increasing interest to define the soil quality concept as well as selecting indicators suitable for a more rational soil management (Doran & Parkin, 1994; Bezdicek *et al.*, 1996; Cameron *et al.*, 1998). The objective of this research was to compare the sensitivity of different soil quality indicators to detect changes due to different soil management treatments for a long-term crop rotation experiment located in Uruguay. These indicators are directly or indirectly related with soil organic matter.

MATERIALS AND METHODS

Four treatments were selected from a long-term experiment established in 1963 in La Estanzuela Experimental Station located in Uruguay (34º S, 57º W), on a silty clay loam Mollisol.Treatments selected were: a) cropping system 1 (CS-1): continuous crops (wheat, barley, sunflower, sorghum) without fertilizers; b) CS – 2: continuous crops (same crop sequence as CS-1) with N and P fertilizers;c) CS-5: a 6-year sequence fertilized with N and phosphorus (P), with 50 % of the time under crops (same as CS-1 and CS-2) and the other half of the time under a grass-legume pasture; d) CS-7: a 3-year sequence fertilized with N and P with 67 % of the time under crops and 33 % under red clover. Conventional tillage was used throughout the experiment. Treatments are arranged in a randomized complete block design with three replications. Plot size is 25 by 200 m.

In July of 1999 composite soil samples were collected from each experimental unit. Samples were taken at two depths (0 - 7.5 and 7.5 – 15 cm) and composed of 20 subsamples. Samples were then taken to the laboratory, wet sieved (2-mm) and stored at 4° C until analysis. Classical soil quality indicators determined were: total organic C (TOC) using $K_2Cr_2O_7$ and heat as described by Tinsley (1967) and total N (TN) measured after sulfuric digestion, distillation with microKjeldahl and titration (Bremner, 1965). The new soil quality indicators evaluated were: a) C in particulate organic matter from 53 to 212 mm (C-POM 53) and from 212 to 2000 mm (C-POM 212) obtained after soil dispersion and sieving; b) C in the light fraction (LF) obtained by dispersion and density separation; c) N in particulate organic matter from 53 to 212 mm (N-POM 53) and from 212 to 2000 mm (N-POM 212); and d) N supplying capability of soil determined by anaerobic incubation (PMN).

C and N in particulate organic matter (POM) were determined following a modification of the method described by Cambardella and Elliott (1992). An equivalent of 3.33 and 6.66 g of oven dry soil were taken from wet sieved 2-mm soil samples and placed in 100 ml plastic flasks. 10 and 20 ml of sodium hexametaphosphate (5 %) were added for C-POM and N-POM determination respectively. The suspension was then placed in a shaker for 16 hours and sieved through a two-sieve nest (212 and 53 microns-opening sieves). Organic and inorganic material retained in each sieve was washed thoroughly with deionized water and transferred to 250 ml erlenmeyers flasks for C-POM determinations. The material was then oven dried at 80° C and C was then determined following the procedure described previously. Two C fractions were then generated: C-POM 212 and C-POM 53. The C fraction smaller than 53 microns (C-MAOM), associated with the mineral fraction, was calculated as the difference between TOC and the sum of C-POM 212 and C-POM 53. Similar procedure was followed to determine N fractions resulting in N-POM 212, N-POM 53 and N-MAOM. For N-POM determination the material retained in each sieve was transferred to 100 ml Tecator digestion tubes. A catalytic mixture and sulfuric acid were then added and oven dried at 90° C for 24 hours and then to 100° C until the solution reached a 4 cm height from the base of the tube. Next each digestion tube was homogenized (vortex) and the N was determined according to methodology mentioned previously. Light-fraction C (C-LF) was determined following the procedure described by Strickland and Sollins (1987) and Janzen et al (1992) with modifications. This consists in a densimetric separation with a NaI solution with a density of 1.7 g /cm^3 An equivalent of 5 g of oven dry soil was placed in 100 ml glass tubes 20 ml of NaI (1.7 g/cm^3) were added and homogeneization was carried out during 30 seconds. Next it was left in rest by 24 hours. The supernatant containing LF was transferred (vacuum pump) to erlenmeyer flasks, and filtered through Whatman 1 filter paper. The supernatant was then rinsed three times with 35 ml of 0.01 M $CaCl_2$. The same procedure was repited using distilled water. Preliminary experiments showed the need to add 3 more rinses with 50 ml distilled water. LF retained in filter paper was then transferred (distilled water) to a 250 ml erlenmeyer, oven dried at 80º C to evaporate water and organic C was then determined following the procedure described previously. Nitrogen mineralization potential (PMN) was determined by incubation under waterlogged conditions at 40° C and 7 days on wet sieved soil samples following the methodology recommended by Bundy and Meisinger (1994). An equivalent of 5 g of oven dry soil was placed in a 25 ml glass tube with 12.5 ml of distilled water. Glass tubes were then sealed and incubated at 40°C during seven days. At the terminus of the incubation solution was transferred to 125 ml plastic flasks and then 12.5 ml of 4 M KCl were added. The supernatant was then filtered through Whatman 1 filter paper and ammonium was determined using colorimetric analysis with sodium salicillate according to Mulvaney (1996). Non incubated soil was used to determine initial ammonium content. PMN was calculated as the difference between the ammonium at the end of the incubation and the initial ammonium value.The percentage of N mineralized (Nmin) was calculated as PMN/10/TN.

Analysis of variance was performed with SAS (SAS Institute, 1996) to assess the treatment effects for each depth separately. Analyses were carried out for TOC, TN, C-POM 212, C-POM 53, C-MAOM, N-POM 212, N-POM 53, N-MAOM, C-LF, PMN and Nmin. Regression and linear correlation analysis were also performed with PMN as a dependent variable.

The sensitivity comparison analysis of the different soil quality indicators was performed assuming as criteria that a higher relative change implies a higher sensitivity. To achieve this the soil indicators were compared only between treatments were significant differences were detected using LSD at the 0.05 probability level.

RESULTS AND DISCUSSION

Mean values for each variable are given in Tables 1 and 2. For both depths (0-7.5 and 7.5-15 cm), treatments effects were significant at a 0.05 probability level for all variables measured. Only for C-LF and at the 0-7.5 cm depth, treatment effects were significant at P= 0.06.

Crop rotations including pastures (CS-5 and CS-7) showed higher TOC and TN contents. At the 0-7.5 cm depth the lowest observed TOC value was in CS-1, 14.9 g/kg while the highest was 23.1 g/kg in CS-5, 55 % higher than CS-1. Similar results were observed with TN. These data show the effect of 36 years of contrasting management practices. CS-5 show higher inputs of C than CS-1 due to higher grain yields and therefore higher amounts of residue and the presence of grass-legume pastures . CS-5 presents also N inputs through biological nitrogen fixation and N fertilizer. Losses of TOC and TN through erosion are also lower in CS-5 compared to CS-1 due to shorter periods of bare fallow. At the 7.5 – 15 cm depth, treatment effects were similar for both TOC and TN.

Treatments also significantly affected active fractions of soil organic matter, C-POM 212 and C-POM 53. At both depths, treatments including pastures (CS-5 and CS-7) presented significantly higher values of C-POM 212 and C-POM 53 than CS-1 and CS-2. The relative magnitude of these differences was more important than the observed with

Table 1. Mean values of measured variables at the 0-7.5 cm depth.

	TOC g / kg	TN g / kg	C-POM 212 g / kg	C-POM 53 g / kg	C-MAOM g / kg	N-POM 212 g / kg	N-POM 53 g / kg	N-MAOM g / kg	C-LF g / kg	PMN mg / kg	Nmin %
CS-1 0-7.5	14.9 b	1.3 b	0.6 b	0.5 b	13.7 b	0.03 b	0.03 b	1.2 b	0.4 b	9 b	0.7 c
CS-2 0-7.5	16.4 b	1.4 b	0.8 b	0.8 b	14.9 b	0.04 b	0.05 b	1.4 b	0.7 ab	19 b	1.3 bc
CS-5 0-7.5	23.1 a	2.1 a	2.0 a	1.6 a	19.5 a	0.12 a	0.10 a	1.9 a	1.3 a	60 a	2.8 a
CS-7 0-7.5	21.5 a	2.1 a	2.2 a	1.5 a	17.8 a	0.14 a	0.12 a	1.8 a	1.3 a	44 a	2.1ab

Values in the same column followed by the same letter are not significantly different at P= 0.05 according to LSD.

Table 2. Mean values of measured variables at 7.5-15 cm depth.

	TOC g / kg	TN g / kg	C-POM 212 g / kg	C-POM 53 g / kg	C-MAOM g / kg	N-POM 212 g / kg	N-POM 53 g / kg	N-MAOM g / kg	C-LF g / kg	PMN mg / kg	Nmin %
CS-1 7.5-15	13.8 b	1.3 b	0.4 b	0.5 b	13.0 b	0.02 c	0.03 b	1.2 b	0.2 c	6 c	0.5 b
CS-2 7.5-15	15.6 b	1.4 b	0.5 b	0.7 b	14.4 b	0.03 bc	0.04 b	1.3 b	0.3 b	11 b	0.8 b
CS-5 7.5-15	20.3 a	2.0 a	0.9 a	1.3 a	18.2 a	0.05 a	0.09 a	1.8 a	0.4 ab	24 a	1.2 a
CS-7 7.5-15	19.2 a	1.9 a	0.8 a	1.0 a	17.9 a	0.04 ab	0.08 a	1.8 a	0.4 a	25 a	1.4 a

* Values in the same column followed by the same letter are not significantly different at P = 0.05 according to LSD.

TOC and TN. This suggests that C-POM would be a suitable indicator to detect differences in soil quality. At the 0-7.5 cm depth the sum of both fractions (C-POM 212 and C-POM 53) was 327 % higher in CS-5 compared to CS-1. Figures 1 and 2 show the TOC distribution under the different cropping systems evaluated. Treatments including pastures presented a higher C-POM relative content than CS-1 and CS-2 specially at the 0-7.5 cm depth. Treatments including pastures showed a pronounced stratification especially in C-POM 212. C-MAOM is less affected by treatments and accounts for the highest percentage of TOC. The main tendencies observed with TOC are explained mainly by C-MAOM.

C-LF using another methodology, also measures an active fraction of soil organic matter. C-LF absolute values were lower

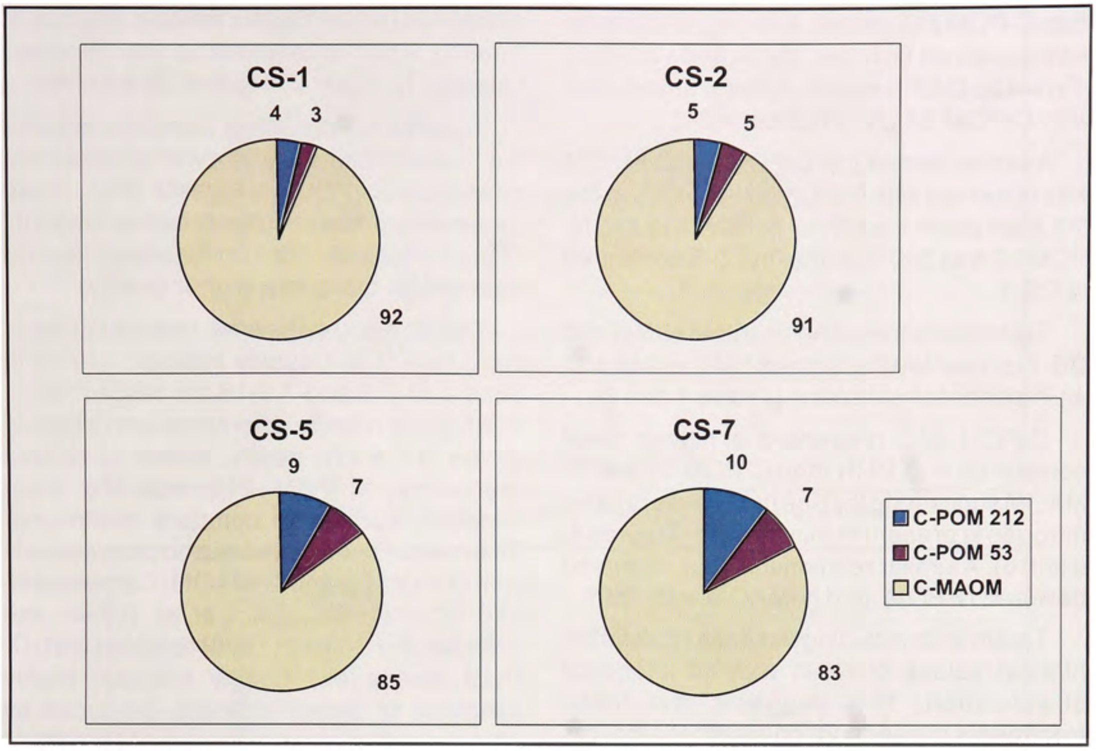

Figure 1. Relative distribution of organic C forms across treatments at the 0-7.5 cm depth.

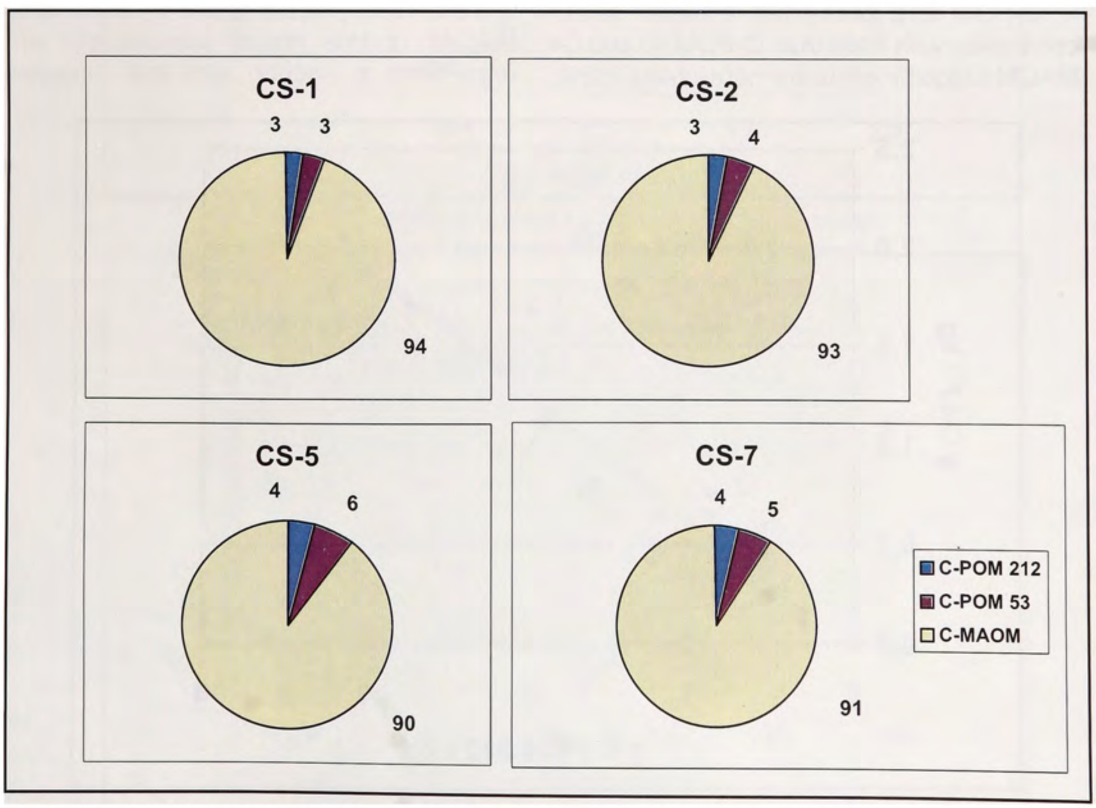

Figure 2. Relative distribution of organic C forms across treatments at the 7.5-15 cm depth.

than C-POM 212 values. A strong relationship was observed between these two variables (Figure 3). C-LF presents a poorer association with C-POM 53 ($R^2 = 0.50$; n = 24).

A similar behavior of C-POM and C-MAOM was observed with N-POM y N-MAOM. At the 0-7.5 cm depth the sum of N-POM 212 and N-POM 53 was 360 % higher in CS-5 compared to CS-1.

Treatments including pastures (CS-5 and CS-7) presented the highest PMN values with an important stratification (Tables 1 and 2).

C-POM 212 presented a higher lineal correlation with PMN than C-POM 53 and C-MAOM suggesting that the more labile organic nitrogen is present in this fraction (Figures 4, 5 and 6). A similar relationship was observed between N-POM and N-MAOM with PMN.

Treatments including pastures showed the highest values of Nmin with an important stratification. This suggests that these treatments present not only higher amounts of organic matter than continuous cropping treatments, but also a higher quality.

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Tables 3 and 4 show the relative values of the different soil quality indicators for both depths (0-7.5 and 7.5-15 cm respectively). The highest relative differences are observed at the 0-7.5 cm depth. Within C related indicators, C-POM 212 was the most sensitive fraction to compare treatments. This relative change decreased progressively with C-POM 53 and C-MAOM. Cambardella and Elliot (1992), Elliot *et al.* (1994) and Wander and Bollero (1999) reported that C-POM was a soil quality indicator highly sensitive to detect changes produced by different soil use and management practices in different regions of the US. The traditional determination of TOC shows a poor sensitivity to treatments (Tables 3 and 4), because C-MAOM is the major constituent and represents a fraction with low biological

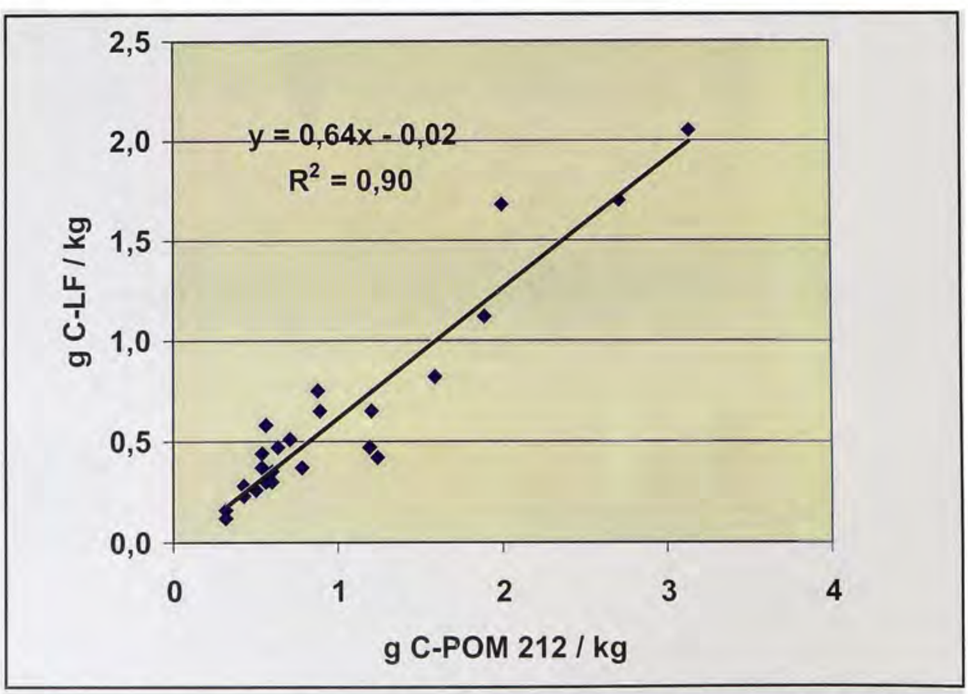

Figure 3. Relationship between C-LF and C-POM 212 for both depths evaluated.

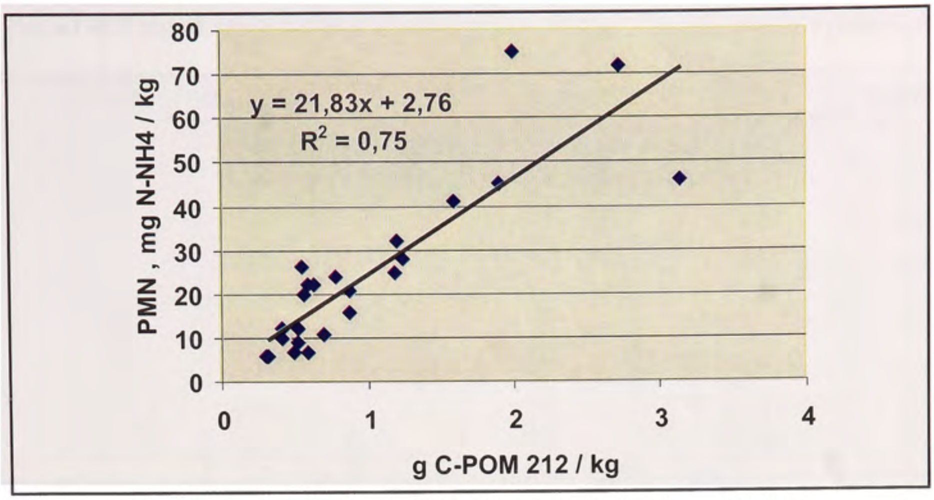

Figure 4. PMN vs C-POM 212 for both depths evaluated.

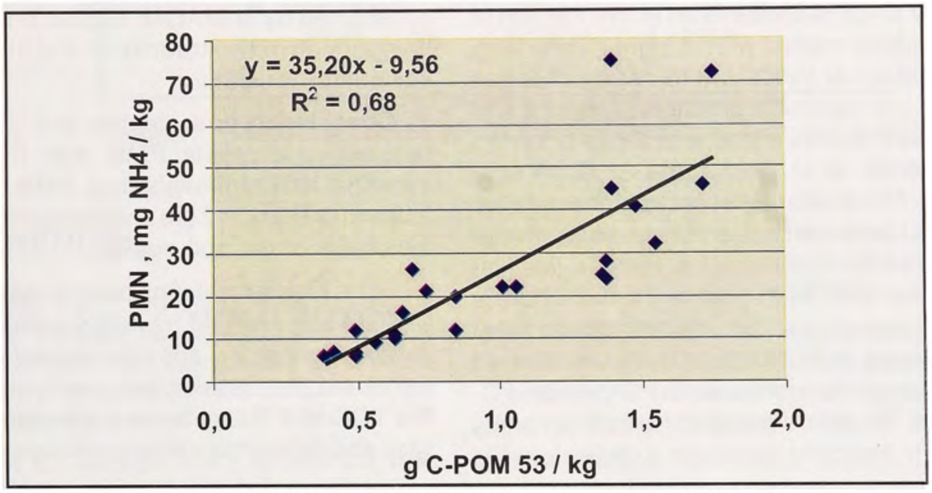

Figure 5. PMN vs C-POM 53 for both depths evaluated.

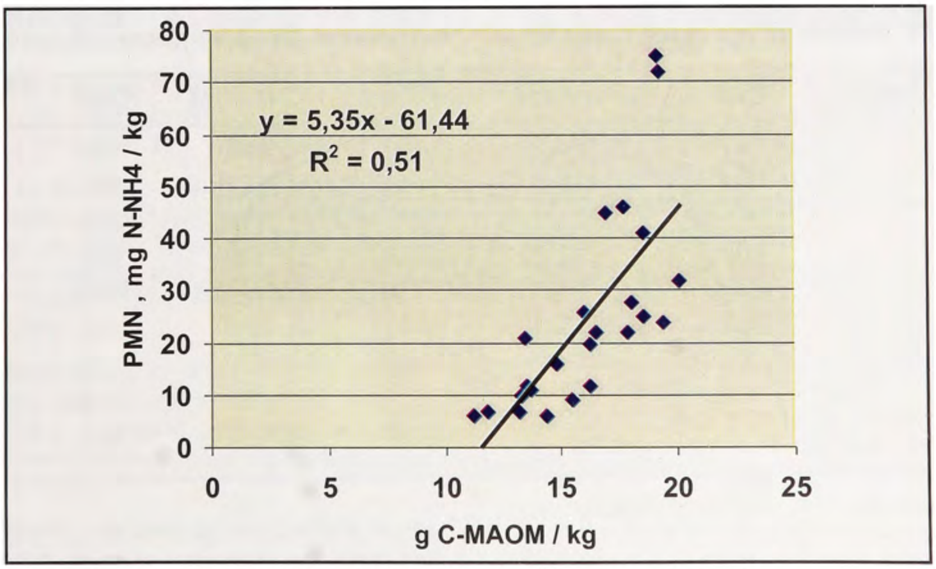

Figure 6. PMN vs C-MAOM for both depths evaluated.

Table 3. Relative values of soil C and N quality indicators at 0-7.5 cm depth (CS-1=100).

Treatment	TOC	C-POM 212	C-POM 53	C-MAOM	C-LF	
CS-1	100	100	100	100	100	
CS-2	110	127	139	108	152	
CS-5	155	324	290	142	309	
CS-7	144	363	284	129	305	
	TN	N-POM 212	N-POM 53	N-MAOM	PMN	Nmin
CS-1	100	100	100	100	100	100
CS-2	114	146	163	111	211	187
CS-5	167	431	315	155	663	397
CS-7	167	518	348	148	489	293

activity. C-LF represents an active fraction of soil organic matter with a higher sensitivity than classical indicators to detect changes due to management practices(Tables 3 and 4). These results agree with those obtained by Bremer *et al.* (1994) and Studdert et al (1997). N indicators presented higher relative values between treatments than those observed for C indicators. PMN in the first term and N-POM 212 were the N indicators more sensitive to detect treatment differences. N-POM 53 and N-MAOM showed a similar performance as C-POM 53 and C-MAOM. TN does not appear to be a sensitive enough indicator because a major part is constituted by N-MAOM. Figure 7 shows a comparison of two traditional and three new soil quality indicators

Considering both depths and contrasts between treatments PMN was the most sensitive indicator evaluated. PMN, N-POM 212 and C-POM 212 are shown as promissory indicators of the soil quality.

From an interpretation point of view, PMN, C-POM and N-POM have a meaning more indepently that the soil type considered. As a contrast, the classical soil quality indicators like TOC and TN are more dependent on soil type and reference value considered.

Table 4. Relative values of soil C and N quality indicators at 7.5-15 cm depth (CS-1=100).

Treatment	TOC	C-POM 212	C-POM 53	C-MAOM	C-LF	
CS-1	100	100	100	100	100	
CS-2	113	122	144	111	165	
CS-5	147	227	273	140	213	
CS-7	139	216	228	138	222	
	TN	N-POM 212	N-POM 53	N-MAOM	PMN	Nmin
CS-1	100	100	100	100	100	100
CS-2	111	165	142	109	179	161
CS-5	156	293	277	151	374	239
CS-7	149	267	252	144	400	269

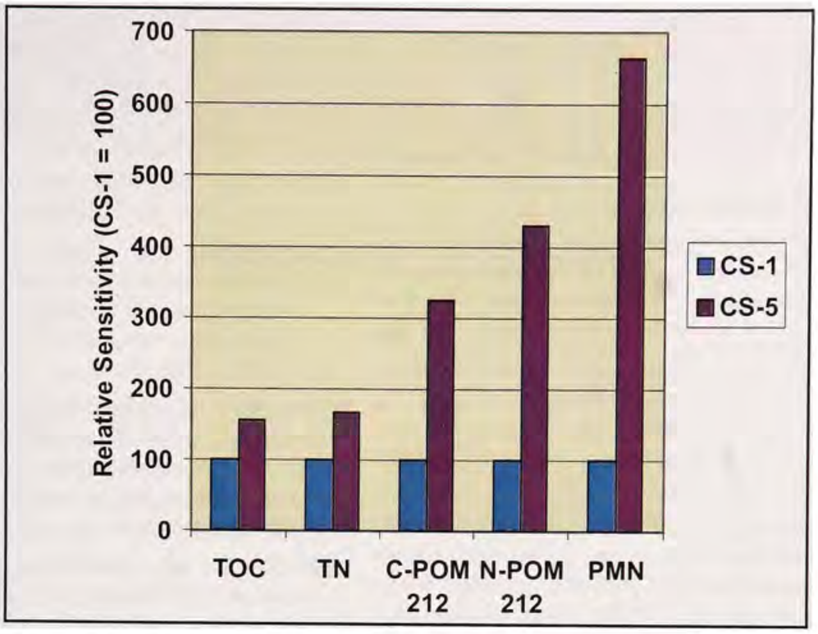

Figure 7. Relative sensitivity of two classical and three new soil quality indicators at the 0-7.5 cm depth.

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