SOIL QUALITY ASSESSMENT OF URUGUAYAN AGRICULTURAL SOILS

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Abstract

The process of agricultural intensification in Uruguay brought up questions about the impacts on the soil. In order to analyze the soil quality status in the *departamentos* of Soriano and Río Negro, we sampled 108 fields to determine soil organic carbon (SOC) and potentially mineralizable nitrogen (PMN). Average losses were 20% in SOC and 42% in PMN in the 0-15cm sampling depth. About one third of the sampled fields had losses between 30 and 60% in SOC and between 35 and 80% in PMN. Losses in SOC and PMN varied among edaphic environments. Results about the effects of soil use and management on SOC and PMN are not conclusive. This paper concludes with reference values for SOC and PMN for the different edaphic environments studied.

Keywords: agriculture, soil organic carbon, mineralizable nitrogen, soil quality.

Introduction

During the last ten years, Uruguay underwent a process of agriculture intensification. One important component of this process is the cereal and oilseed production. Some characteristics of this intensification are: increased number of crops per unit surface per year; increased yields in most crops; change from a crop-pasture rotation system to a continuous-crop system; dominance of land lending regime for most cropping area; dominating presence of soybeans; expansion of the cropping area; and generalized adoption of no-tillage (DIEA, 2010 and 2011).

This process of agriculture intensification rose important questions about the environmental impacts, especially on the soil. Recent quantitative information on soil quality based on commercial fields was almost unavailable. A research project was carried out with the following objectives: a) to quantitatively determine the current status of agricultural soils, b) to obtain reference values as an objective guide for proper diagnosis of agricultural soils, c) to identify soil use and management practices that affect soil quality, and d) to develop, -as a result, a first approximation of a quality control system along with recommendations for soil use and management. In this paper, information is presented and discussed specifically on soil organic carbon (SOC) and potentially mineralizable nitrogen (PMN) for the above-mentioned objectives. Preliminary results of this work were presented by Molfino (2010) and Morón and Quincke (2010).

Material and methods

The field work was carried out in 2009 and 2010, respectively in the *departamentos* (i.e. counties or districts) of Soriano and Río Negro, which are located in the southwest of the country and represent the main crop production region of Uruguay.
Principal target soils were selected and defined using the following sources:
Landsat satellite images, processed with the geographic information system of the *Dirección de Recursos Naturales Renovables* of the *Ministerio de Ganadería Agricultura y Pesca* (i.e. office of Natural Resources under the State Department of Agriculture), in order to delimit areas with highest agricultural activity (fallow and crops).
Carta de Reconocimiento de Suelos del Uruguay (CRSU) (i.e. soil classification map) at the scale 1:1,000,000 (Dirección de Suelos y Fertilizantes – MAP, 1979).
Cartografía CONEAT (Ministerio Agricultura y Pesca, 1979).
Digital soil map for Río Negro and Soriano, at the scale 1:200,000 (Dirección de Suelos y Aguas – MGAP, 1993).

Based on these information sources, six edaphic environments (AE, from *Ambiente Edáfico*) were defined

(Table 1). Edaphic environments are soil associations that are homogenous with respect to originating material, landscape and general characteristics. Therefore, it can be assumed that plant responses will be similar among soils that belong to the same AE.
In order to select specific farms and fields for soil sampling, soil use and management classes were defined with local agronomist from both Río Negro and Soriano, as follows:

Río Negro:
Continuous cropping under no-till with occasional tillage: more than 5 years under no-till, no burning residues, yet with occasional tillage every 4 or 5 years.
Continuous cropping under no-till with no occasional tillage: more than 5 years under no-till, no burning residues and no occasional tillage.
Crop-pasture rotation under no-till: more than 8 years under no-till, no burning residues and no occasional tillage. Sampled in years 2 to 5 after the perennial pasture.

Soriano:
Crop-pasture rotation with conventional tillage: at least one tillage operation (disc, chisel plow, etc) per year. Sampled in years 2 to 5 after the perennial pasture.
Continuous cropping under no-till: more than 8 years of no-till, no burning of residues and no occasional tillage.
Crop-pasture rotation under no-till: more than 8 years of no-till, no burning of residues and no occasional tillage. Sampled in years 2 to 5 after the perennial pasture.

Two sampling sites were established in each field: on one hand a “reference” or undisturbed soil which was generally located beneath an old fence. On the other hand the soil of the field *per se*. Special attention was paid when defining the location of the reference sampling site in order to ensure minimal alterations from its virgin condition. For each field sampled, a form was completed in order to collect information regarding relevant aspects of soil use and management history, as well as to record a detailed description of the soil.

At each sampling site (reference and field) three composite samples were obtained (each with at least 20 soil cores) at two sampling depths: 0-7.5 and 7.5-15cm. Samples were collected from May to October 2009 and 2010. For the present work, information is presented for analytical determinations of soil organic carbon (SOC) and potentially mineralizable nitrogen (PMN). SOC was determined with a combustion at 900°C and detection of CO_2 with infrared, using a LECO Truspec equipment. Values obtained were corrected with a factor of 0.81 (Morón, 2009) in order to report values equivalent to the traditional wet oxidation methodology (Tinsley, 1967). PMN was determined with an anaerobic incubation of 7 days at 40°C using samples that were sieved at field moisture (Morón and Sawchik, 2002). Soil texture was determined with the method after Bouyoucos (1962). Information for the 0-15cm sampling depth comes form averaging the results of the 2 actual sampling depths (0-7.5 and 7.5-15cm).

The experimental design is an incomplete factorial with following factors (and levels in parenthesis): Loc (2; Río Negro, Soriano); AE (6; A, B1, B2, B3, C, D); Ubi (2; field, reference); Depth (2; 0-7.5, 7.5-15). Analysis of variance and quartile distributions were performed using SAS (1996). The statistical significance is abbreviated as follows: * 10%, ** 5% *** 1% and ns = not significant. Q1 and Q3 correspond to the first and third quartiles, respectively.

Results and discussion

Six different AEs were defined according to the above mentioned criteria (Table 1). AEs B1 and B2 were sampled only in Soriano, and B3 only in Río Negro. A total of 108 fields were selected, of which 48 were located in Soriano (Table 2) and 60 in Río Negro (Table 3). Even though the sampling design was originally balanced, the final selection of fields had an appreciable unbalance with regards to both, AE and use and management. A noteworthy case is for use and management A in Soriano (the crop-pasture rotation with conventional tillage), which was sampled in only one edaphic environment. This used to be the dominant crop production system until the early 2000s, but only a very low area remained at the time of this study.

Table 1 Characteristics of edaphic environments (AE) selected for the *departamentos* Río Negro and Soriano.

AE	Geological material	Departmento	Uruguay soils	USDA Soils	CRSU Unit	CONEAT
A	Quaternary thick sediments	Soriano y Río Negro	Brunosoles vérticos, Vertisoles	Paquic vertic Argiudols, Hapluderts	La Carolina, Risso, Libertad, Bellaco	10.1/3/5/6/8/12 10.2
B 1	Deep sediments on Fray Bentos	Soriano	Brunosoles Típicos, Brunosoles Háplicos	Paquic Argiudols Hapludols	Bequeló (zona Cololó)	11.4/5/6
B 2	Sediments with influence of Fray Bentos	Soriano	Brunosoles Típicos	Argiudols	Cañada Nieto	11.7/8
B 3	Sediments on Fray Bentos	Río Negro	Brunosoles	Argiudols	Young	11.5/6
C	Fray Bentos (CO_3Ca)	Soriano y Río Negro	Brunosoles Háplicos	Hapludols	Fray Bentos	11.1/2
D	Sandy Sediments with influence Cretaceous	Soriano y Río Negro	Brunosoles (Sub eutricos) Lúvicos, Argisoles	Argiudols	Cuchilla Corralito, Chapicuy, Algorta (Tres Bocas)	9.2/3/5/6, 09

Table 2 Distribution of fields selected according to edaphic environments and soil use and management in the *departamento* of Soriano (N=48).

Soil Use and Management	A	B	C	Sub-total
Edaphic Environment				
A		4	7	11
B1		6	6	12
B2	3	2	5	10
C		4	2	6
D		5	4	9
Sub-total	3	21	24	

Table 3 Distribution of fields selected according to edaphic environments and soil use and management in the *departamento* of Río Negro (N=60).

Soil Use and Management	1	2	3	Sub-total
Edaphic Environment				
A	1	17		18
B3	4	5	8	17
C	3	9	3	15
D	5	1	4	10
Sub-total	13	32	15	

Analysis of variance for SOC and PMN are presented in tables 4 and 5. For both variables, significant effects were found due to *departamentos*, edaphic environments, and sampling depth. Also, soils under crop production (i.e the field soils) are different from their respective reference soils, for both SOC and PMN (tables 4 and 5, figures 1 and 2). On average, SOC in field soils decreased 20.2% from the respective reference soils. For Soriano and Río Negro, this SOC loss was 17.6% and 21.6%, respectively. For PMN, this loss from the reference soils averaged 43.2% and 38.3% for Soriano and Río Negro. The higher sensibility of PMN compared to SOC was reported previously by Morón and Sawchik (2002). While SOC comprises all organic pools, PMN represents only a fraction of the biologically more active nitrogen.

Table 4 Summary of the analysis of variance for soil organic carbon.

Source of variation	Degrees of freedom	F	P>F
Departamento (Loc)	1	93.4	< 0.0001
Environment Edaphic (AE)	5	38.6	< 0.0001
Location (Ubi)	1	73.9	< 0.0001
Depth (Prof)	1	60.1	< 0.0001
AE x Ubi	5	2.4	0.0354
AE x Prof	5	0.2	0.9680
Ubi x Prof	1	3.2	0.0767
Error	410		

Previous studies that used the same methodology as the present work were performed for the main dairy production areas (Colonia, San José and Florida) covering 166 paddocks. In this study, Morón et al. (2011) reported an average decrease of 20.4% in SOC, while in PMN the average loss from reference soils was 26.2%, considerably lower than the average of 41.5% loss reported here. These differences could be explained in part by a higher nitrogen input from biological fixation of leguminous species in dairy systems. Also, N exports are likely higher in grain production systems than extraction as milk and animal tissue.

Table 5. Summary of the analysis of variance for potentially mineralizable nitrogen.

Source of variation.	Degrees of freedom	F	P>F
Departamento (Loc)	1	99.4	< 0.0001
Environment Edaphic (AE)	5	10.8	< 0.0001
Location (Ubi)	1	84.7	< 0.0001
Depth (Prof)	1	106.7	< 0.0001
AE x Ubi	5	1.7	0.1387
AE x Prof	5	0.6	0.6688
Ubi x Prof	1	3.1	0.0803
Error	410		

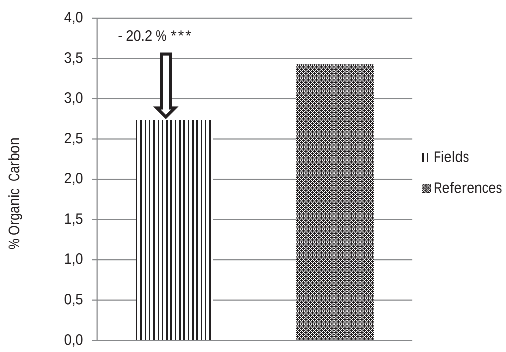

Figure 1. Average values of soil organic C in 108 agricultural fields and respective reference values at 0-15 cm in the *departamentos* of Soriano and Río Negro.

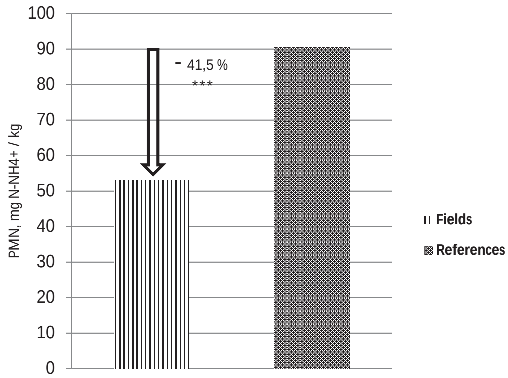

Figure 2. Average values of PMN in 108 agricultural fields and respective reference values at 0-15 cm in the *departamentos* of Soriano and Río Negro.

The average reduction of 20.2% in SOC reported here could be regarded as moderate in light of other results (Flach et al,1997; Morón, 2003). The distribution of losses and gains of SOC and PMN in field soils of grain production systems is presented in figures 3 and 4.

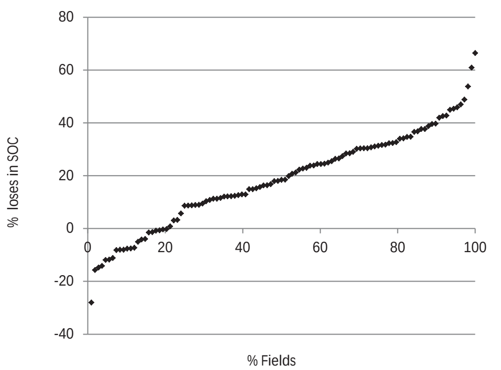

Figure 3. Distribution of gains and losses of soil organic carbon (SOC) in 108 agricultural fields compared with respetive reference soils at 15 cm depth in Soriano and Río Negro.

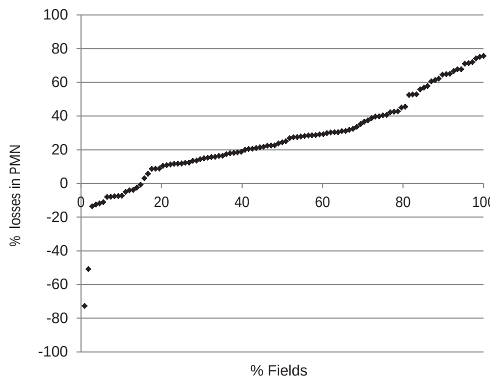

Figure 4. Distribution of gains and losses of potentially mineralizable nitrogen (PMN) in 108 agricultural fields ompared with respetive reference soils at 0-15 cm depth in Soriano and Río Negro.

Both figures show relevant contrasts. On one hand, approximately 20% of field soils had SOC gains (0 to 20 %) compared to the reference soils (figure 3). On the other hand, approximately 30% of fields had losses in SOC (30 to 60%). With regards to PMN (figure 4), 12% of fields had increases in PMN (0 to 14%), while about 30% of the fields had losses in PMN (between 35% and 80%).

When considering absolute losses in both SOC and PMN, these are higher in the 0-7.5 cm than in the 7.5-15 cm sampling depth. However, relative losses compared to reference soils are not always higher for the 0-7.5cm depth (figures 5 and 6).

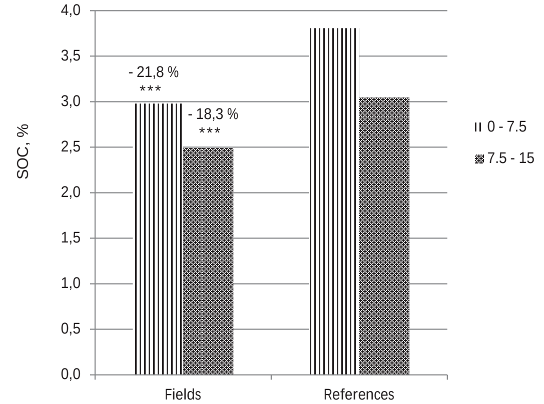

Figure 5. Average values of soil organic carbon (SOC) in 108 agricultural fields and respective reference values at two depths in Soriano and Rio Negro.

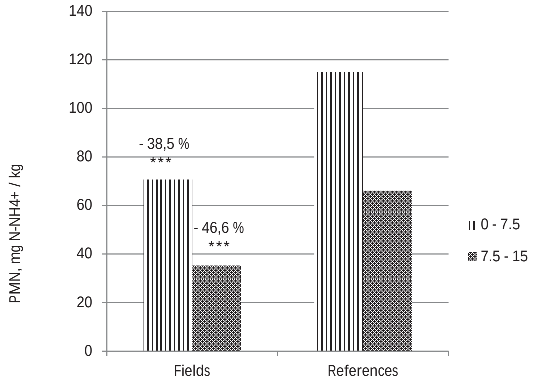

Figure 6. Average values of potentially mineralizable nitrogen (PMN) in 108 agricultural fields and respective reference values at two depths in Soriano and Rio Negro.

Relative losses in SOC and PMN for different AEs are presented in figures 7 and 8. For both indicators, highest losses occurred in AE B3, while smallest losses were observed in B1. Soils belonging to B3 correspond to the mapping unit Young (DSF/MAP, 1976), which typically has steep slopes that may favor erosion.

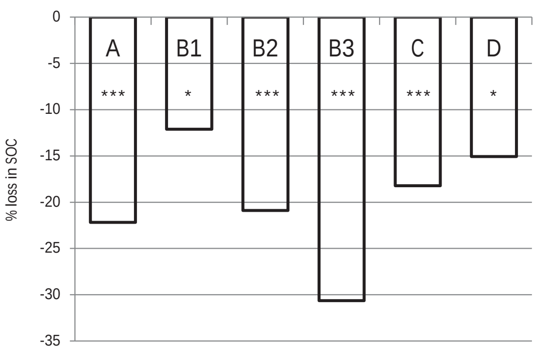

Figure 7. Average percentage loss of soil organic carbon (SOC) in 108 fields of different edaphic environments at depth of 0-15 cm in Soriano and Río Negro.

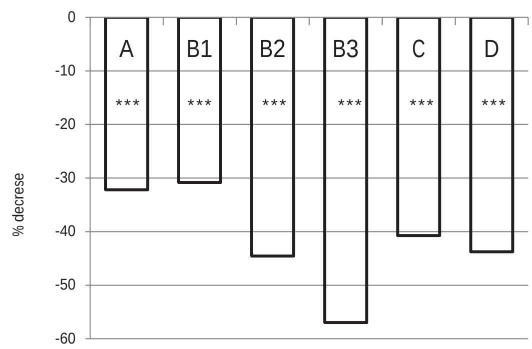

Figure 8. Average percentage loss of potentially mineralizable nitrogen (PMN) in 108 fields in different edaphic environments at depth of 0-15 cm in Soriano and Río Negro.

Effects of soil use and management for SOC and PMN are summarized in tables 6 and 7 for Río Negro and Soriano, respectively. In Río Negro, SOC detected no differences among management systems. However, management systems were statistically different in PMN. The system with highest PMN was “Continuous cropping under no-till with occasional tillage” and averaged 82.1 mg $N\text{-}NH^{+}_{4}$/kg, while “Continuous cropping under no-till” and “Crop-pasture rotation under no-till” averaged 68.4 and 70.2 mg $N\text{-}NH^{+}_{4}$/kg, respectively.

Table 6 Statistical significance between different soil use and management categories for soil organic carbon (COS) and potentially mineralizable nitrogen (PMN) in the *departamento* of Río Negro at 0-15 cm depth.

	1		2		3	
	COS	PMN	COS	PMN	COS	PMN
1	-----	-----	ns	**	ns	*
2			-----	-----	ns	*
3					------	------

Table 7 Statistical significance between different soil use and management categories for soil organic carbon (COS) and potentially mineralizable nitrogen (PMN) in the *departamento* of Soriano at 0-15 cm depth.

	A		B		C	
	COS	PMN	COS	PMN	COS	PMN
A	-----	-----	ns	*	**	*
B			-----	-----	ns	**
C					------	------

At present we have no satisfactory explanation for these results. The characterization of fields in soil use and management systems has the limitation that only information of last 8-10 years is considered, but not the soil use applied in previous decades. Although we anticipated this limitation when designing and planning this study, we considered that this issue had not a practical solution. Obtaining reliable information on soil use and management for a larger time window (i.e. decades) would have been complicated and could have been cause for excluding most sampling sites from the study.

In Soriano (table 7), SOC was higher in the system “Crop-pasture rotation under no-till” than in “Crop-pasture rotation with conventional tillage” (2.39 *vs* 2.02%, respectively). However, PMN had the opposite response for these two systems (37.0 *vs* 42.4 respectively). A possible explanation is that no-till systems accumulate higher amounts of crop residues. These have usually high C:N ratios, which could reduce net mineralization of N during the incubation and thereby result in lower PMN values.

Table 8 Average values for soil organic carbon (COC), potentially mineralizable nitrogen (PMN) and clay content of the reference soils in Río Negro and Soriano at 0-15 cm depth.

	SOC, %	PMN, mg $N\text{-}NH_4^+$/kg	% Clay
Río Negro	4.04	121.8	29
Soriano	2.81	60.9	24

Moreover, the system “Crop-pasture rotation under no-till” had significantly higher PMN than “Continuous cropping under no-till” (37.0 vs 28.7 mg $N\text{-}NH_4^+$/kg). This is the positive effect of including pastures in a crop rotation, which is detected with PMN but not with SOC.

When comparing *departamentos*, reference soils of Río Negro are higher in SOC, PMN and clay content than reference soils of Soriano (table 8). This appears to occur in the three edaphic environments that were sampled in both *departamentos* (A, C, D). Because of this, Río Negro and Soriano were considered separately for establishing reference soil quality indicators.

Table 9 Reference ranges for soil organic carbon (SOC, in %) for different edaphic environments in Río Negro and Soriano at 0-15 cm depth.

Edaphic Environments	Q1	Q3
A (R. Negro)	3.48	4.67
A (Soriano)	2.46	3.72
B1 (Soriano)	2.80	3.70
B2 (Soriano)	2.18	3.24
B3 (R. Negro)	3.71	4.67
C (R. Negro)	3.84	5.33
C (Soriano)	2.64	3.57
D (R. Negro)	2.10	3.71
D (Soriano)	1.28	1.65

Table 10 Reference ranges for potentially mineralizable nitrogen (PMN, in mg $N\text{-}NH^{+}_{4}$/kg) for different edaphic environments in Río Negro and Soriano at 0-15 cm depth.

Edaphic Environments	Q1	Q3
A (R. Negro)	101.5	167.5
A (Soriano)	42.2	119.8
B1 (Soriano)	47.0	99.0
B2 (Soriano)	44.5	87.2
B3 (R. Negro)	79.0	163.5
C (R. Negro)	90.5	128.2
C (Soriano)	35.0	90.2
D (R. Negro)	42.2	119.8
D (Soriano)	26.3	37.2

Table 11 Reference ranges for clay content (in %) for different edaphic environments in Río Negro and Soriano at 0-15 cm depth.

Edaphic Environments	Q1	Q3
A (R. Negro)	28.7	39.8
A (Soriano)	25.8	32.2
B1 (Soriano)	22.8	29.4
B2 (Soriano)	19.3	25.3
B3 (R. Negro)	23.3	29.0
C (R. Negro)	22.3	35.7
C (Soriano)	20.2	22.2
D (R. Negro)	17.2	30.5
D (Soriano)	12.2	18.0

Table 12 Reference ranges for sand content (in %) for different edaphic environments in Río Negro and Soriano at 0-15 cm depth.

Edaphic Environments	Q1	Q3
A (R. Negro)	25.7	45.5
A (Soriano)	31.8	38.0
B1 (Soriano)	35.6	45.7
B2 (Soriano)	34.7	52.7
B3 (R. Negro)	46.7	56.2
C (R. Negro)	34.5	48.3
C (Soriano)	46.5	54.7
D (R. Negro)	42.7	69.7
D (Soriano)	70.3	77.2

Table 13 Reference ranges for silt content (in %) for different edaphic environments in Río Negro and Soriano at 0-15 cm depth.

Edaphic Environments	Q1	Q3
A (R. Negro)	25.5	34.0
A (Soriano)	30.5	37.7
B1 (Soriano)	28.8	33.6
B2 (Soriano)	28.3	41.8
B3 (R. Negro)	20.3	24.3
C (R. Negro)	24.5	32.7
C (Soriano)	24.3	29.3
D (R. Negro)	15.0	29.2
D (Soriano)	9.0	18.2

Tables 9 and 10 present ranges for SOC and PMN as a guide for interpretation as soil quality indicators. These ranges encompass 50% of central values, and are determined by Q1 (first quartile) and Q3 (third quartile). It can be observed that separating by *departamentos* in AEs A, C and D was justified. If these interpretation tables will be used in order to infer the soil quality status of a given field, attention has to be paid in using the same type of sampling as well as same analytical procedures. In addition, it is useful to consider the texture ranges for the different AEs (tables 11, 12 and 13).

Final considerations

In the main *departamentos* of crop production (Río Negro and Soriano) a moderate (20%) loss in soil organic carbon was found, although about one third of the fields had medium to high losses (30 to 60%). The average loss in potentially mineralizable nitrogen is more than twice as much, and also about one third of fields had medium to high losses (35 to 80%). When comparing these results with results from dairy production areas, losses in SOC are similar on a relative basis , but losses in PMN are higher in crop production areas. Recording soil use and management in categories should be improved in order to obtain more coherent results with regards to the effects on SOC and PMN. The reference values for SOC and PMN established in this paper may be useful if field and laboratory methodologies are carefully observed.

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