Soil quality assessment of rice production systems in South of Brazil

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Abstract
Soil quality, as a measure of the soil capacity to function, can be quantified by indicators based on physical, chemical and biological properties. Maintaining soil quality at a desirable level in the rice cropping system is a very complex issue due to the nature of the production systems used. In the state of Rio Grande do Sul, Brazil, rice production is one of the most important agricultural activities in the region. The study presented here was conducted with the following objectives: (i) to identify soil quality factors present from a set of soil indicators, (ii) to identify which selected indicators within these factors could discriminate between management systems or soil classes, (iii) to establish a minimum data set (MDS). Soil quality assessment was based on multivariate statistical analysis using the SPSS program. For this study, 29 soil biological, chemical and physical indicators were evaluated to characterize aspects of regional soil quality. Data were collected from rice fields located in the Camaquã region of Rio Grande do Sul that were under the three main soil management systems for rice. Different factors were found as the most important to discriminate either management systems or soil classes. The most powerful soil attributes retained into MDS for distinguishing differences in soil quality of rice production under different management systems and soil classes were copper, potassium, earthworm number, microbial quotient, manganese, organic matter, magnesium, iron, water stable aggregates, soil respiration, mineralizable N.
Keywords: Soil quality; indicators; minimum data set; rice; Brazil.

1. Introduction

In the state of Rio Grande do Sul, Brazil rice production is one of the most important regional activities. This production is located mainly in the southern lowlands where approximately 5,5 million tons of rice per year is produced, equivalent to 52% of total Brazilian rice production (Azambuja et al., 2004). The inherent high fertility level of that region, mainly in Camaquã, brought since 1960's the expansion of rice cropping, increasing consequently the intensity of land use (Westphal, 1998; Cunha et al., 2001). Soils have an inherent quality as related to their physical, chemical and biological properties within the constraints set by climate and ecosystems but the ultimate determinant of soil quality is the land manager (Doran, 2002). The concern here is that the land use patterns of Camaquã region may not be sustainable because of their effects on soil quality. The definition of soil quality is "the fitness of a specific kind of soil, to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Maintaining soil quality at desirable levels is a very complex issue and it is more challenging in rice cropping systems due to the climatic, soil, plant, and human factors and their interactions and mainly because its required puddling practices (Chaudhury et al., 2005). As a complex functional state soil quality cannot be measured directly (Brejda et al., 2000a). The capacity of soil to function can be reflected by measured soil physical, chemical and biological properties, also known as soil quality indicators (Shukla et al., 2005). Several MDS of soil attributes have been proposed at the plot and field scale (Doran & Parkin, 1996), at a regional scale (Brejda et al., 2000a; Brejda et al., 2000b) and national scale (Sparling & Schipper, 2002, 2004; Sparling et al., 2004). According to Schipper & Sparling, (2000) currently, there is neither consensus on a definitive data set for soil-quality monitoring, nor consensus on how the indicators should be interpreted. Research has shown that multivariate statistical analyses are useful techniques which provide soil quality indicator identifications and/or interpretation for simultaneously analyzing correlated indicators (Wander & Bolero, 1999; Brejda et al. 2000a; Brejda et al. 2000b; Schipper & Sparling, 2000; Chaudhury et al., 2005; Govaerts et al., 2005; Shukla et al., 2005). This study was a first step toward identifying the MDS which could be meaningfully applied to monitor soil quality of rice fields in the south of Brazil. The hypothesis is that, because the inherent differences in soil clay content in the Camaquã region, the intensive anthropic activities (management systems) cannot be the only factor that discriminate indicators to establish a MDS. Therefore, the present study was conducted with the following objectives: (i) to identify soil quality factors present from a set of soil indicators, (ii) to identify which selected indicators within these factors could discriminate between management systems or soil classes, (iii) to establish a MDS. Twenty-nine soil biological, chemical and physical indicators were evaluated to characterize aspects of regional soil quality.

2. Material and Methods

2.1. Area description and soil sampling

Camaquã is located in the south of Brazil, in the Rio Grande do Sul state situated in the latitude between 30º48'and 31º32' S and longitude between 51º47' and 52º19'W. This area is characterized by mean annual rainfall of 1213 mm, average temperature of 18.8ºC. Albaqualfs and Gleysols are the two soil great groups found in this region. The main difference between them is clay content (Cunha et al., 2001). This region covers the three rice management systems most used in the state: conventional, pre-germinated and semi-direct (differing in terms of degree of intensity of soil management and water uses). Twenty one rice fields on different soil great groups and rice management systems were selected. At each site, five replicate plots, 2 by 2 m, were chosen within a square of 3 ha. In total 105 representative points were sampled. From within each plot, 20 samples were taken from 0-10 cm depth using a hand spiral and tube auger. Individual cores from each plot were bulked and mixed before analysis for chemical and biological characteristics. For physical analyses, three undisturbed soil cores were obtained from each plot.

2.2. Analysis

Samples collected for biological analysis were analyzed for microbial biomass (Islam & Weil, 1998), soil respiration (Heinemeyer et al., 1989), potentially mineralizable N (Bundy & Meisinger, 1994), ß-glucosidase, acid phosphatase, alkaline phosphatase (Tabatabai, 1994). Earthworms were sampled using the standard method of the Tropical Soil Biology and Fertility Programme (Anderson & Ingram, 1993). Chemical analysis was done using the methodology described by Tedesco et al., (1995). These samples were analyzed for organic matter, total N, pH, Al, H+Al, Al sat., exchangeable cations (Ca, Mg, K), P, micronutrients (Fe, Zn, Cu, Mn) and cation exchange capacity. Bulk density, texture, water stable aggregates, microporosity, and water release by drainage on pressure plates at 340 and 1500 kPa were the physical analyses measured according to physical methods described by Gee et al., (2002). The results from texture analysis were used to divide the soil into 4 classes according to clay content (Class 1= clay < 20%, Class 2= 20>clay<42%, Class 3= 42>clay<60% and Class 4= clay >60). Some of the indicators which have also been suggested as useful for soil-quality monitoring (Doran & Parkin, 1994; Schipper & Sparling, 2000) were derived from the data set such as available water, macroporosity, mean weight diameter, microbial quotient. Besides that, rice grain was manually cut from each plot in each site. The grain was separated from the straw, weighed and moisture content determined. The final yield was calculated based on

13% of moisture. All indicators were sampled during the 2004 crop cycle or following fallow period.

2.3. Statistical approach

The rationale for the statistical methodology used in this paper is described by Hair et al., (1998).

2.3.1. Factor Analysis

Factor analysis was used to group 29 soil quality indicators into statistical factors based on their correlation structure using SPSS. The objective to use this analysis is to reduce the entire data for subsequent analysis with other techniques, in this case, discriminant analysis. Only the factors having eigenvalues greater than 1 were considered significant. Factor loadings greater than 0.40 were selected. Principal component analysis (PCA) was used as the method of factor extraction and factors were subjected to Varimax rotation.

2.3.2. Discriminant Analysis

Discriminant analysis was used to select the statistical factor(s) that were most discriminating between the different management systems and soil classes. Following selection of the most discriminant factor(s), soil quality indicators that comprised these factors were also subjected to discriminant analysis. Discriminant loadings were used to tell how closely a variable is related to each function. Variables exhibiting a loading of 0,30 or higher were considered sufficiently substantive to enter in the function.

3. Results and Discussion

3.1. Grouping soil quality indicators in factors

The 29 soil quality indicators considered in factor analysis were grouped into five factors that accounted for 78.20% of the total variance for the entire data set (Table 1). The first five factors had eigenvalues greater than one (Table 1) and were retained for interpretation. Communalities estimate the portion of variance in each soil indicator explained by the factors. Communalities for the soil indicators indicate the five factors explained >95% of the variance in OM and Ca, >90% of variance in BD, TN, CEC, Mic., Al and >80% of variance in H+Al, Alk. Ph., ß-Glic., Mg, SB, Cu, Zn, Al sat., pH (Table 2). However, the five factors explained <60% of the variance in AW, EN and Mac.(Table 2).

The fist factor explained 43.80% of variance (Table 1). This factor was termed the “soil organic matter factor” because it had high positive loading (>0.95) from OM (0.98) and TN (0.95), and high negative loading from BD (-0.95) (Table 2). It also had positive loading from Ca, CEC, Mic, H+Al, Ac. Ph., Alk. Ph., ß-Glic, SR, Mg, Fe, MN, SB, WSA, MWD and Al (>0.50). The second factor explained 9.68% of variance (Table 1) and was termed the “soil micronutrients and aggregate factor” because it had high positive loading from Cu (0.77), Zn (0.64), MWD (0.62), K (0.44) and WSA (0.43) and high negative loading with AW (-0.62) and EN (-0.45) (Table 2). The third factor was termed the “soil acidity factor”. It explained 9.57% of variance (Table 1) and had high positive loading from pH (0.74) and high negative loading from Al sat. (-0.87) and Al (-0.77) (Table 2). The fourth factor explained 9.01% of variance with high positive loading from Mn (0.75) and K (0.60), then it was termed the “soil nutrient factor”. It had also high negative loading from Mic. q (-0.86) (Table 2). The fifth factor was termed the “soil P factor” because it had the largest positive loading from P (0.79) and negative loading from Mac. (-0.72). It also had a moderate positive loading from pH (0.47) (Table2). This factor explained only 6.14% of variance (Table 1)

3.2. Selecting soil quality indicators

3.2.1. Management Systems

Based upon the value of the discriminant coefficients, “soil micronutrients and aggregate” and “soil nutrients” factors were the most powerful in discriminating among three rice management systems for the function 1 (Eq. (1))

Y_1 = +0,551(Soil micronutrients and aggregate) +0,345(Soil nutrients) -0,273(Soil Organic Matter) -0,109(Soil Acidity) -0,090(Soil P) (1)

Discriminant analysis of the measured soil attributes constituting those factors were analyzed separately. The most dominant measured soil attributes for the "soil micronutrients and aggregate factor" were copper, potassium and earthworm number (Eq. (2))

Y_2=0,638(Cu)+0,390(K)-0,323(EN)-0,266(AW)+0,248(Zn)+0,232(MWD)+0,053(WSA) (2)

Microbial quotient, potassium and manganese were the most dominant measured soil attribute for the "soil nutrients factor" (Eq. (3))

Y_3 = -0,422(Mic.q)+0,412(K)+0,980(Mn) (3)

These results indicate that the physical attributes could not be considered useful indicators for detecting changes in soil quality under different rice management systems. Similar results, from New Zealand, were found by (Schipper & Sparling, 2000)) who pointed out that soil biological and chemical indicators generally showed greater response to multiple land use than did the soil physical indicators. From the soil chemical attributes, Cu, K and Mn were the most important for discriminating management systems, whereas, EN and Mic. q were the most dominant soil biological attributes. According to (Schipper & Sparling, 2000) for rationalizing a minimum data set it is important to consider if some indicators show strong correlation with other it may not be necessary to measure all of them. Because, none attributes showed high correlation between them no one was dropped out of MDS.

3.2.2. Soil Classes

The "soil organic matter factor" was the most powerful in discriminating among soil classes (Eq. (4)).

Y_4 = 0,558(Soil Organic Matter)-0,001(Soil micronutrients and aggregate)+0,130(Soil acidity)+0,175(Soil nutrient)-0,016(Soil P) (4)

As BD, TN, Ca, CEC were highly correlated to OM and had similar factor loadings (Table 2), those four attributes were dropped out of the further analysis to avoid multicollinearity.

Discriminant analysis of the measured soil attributes that comprise 'soil organic matter factor" was analyzed. The most dominant measured soil attributes for that factor are shown in Eq. (5).

Y_5=0,741(Mic.)+0,625(ß.Gluc.)+0,589(OM)+0,535(Ac.Ph.)+0,508(Mg)+0,507(Fe)+0,456(H+Al)+0,444(WSA)+0,427(MWD)+0,406(Alk.Ph)+0,313(SR)+0,300(MN)+0,209(MB)+0,254(Al) (5)

Microporosity dominated the relationship with a high discriminant coefficient. However, none of the others clearly showed to be the following attribute to discriminate soil classes. Because Mic. was highly correlated with OM and OM was also highly correlated with all enzymes studied and H+Al, then the correlation suggests that the more simple and inexpensive measure of OM could serve as a satisfactory surrogate for those correlated attributes to be retained under MDS. WSA was the only physical attribute of soil that was retained under MDS because its high correlation with MWD. Therefore, the soil attributes selected for including into MDS in order to discriminate soil classes were OM, Mg, Fe, WSA, SR, MN.

4. Conclusion

The statistical procedure selected indicators to assess the soil quality from large data set. Different factors discriminated management systems and soil classes. "soil micronutrients and aggregate" and "soil nutrients" were the most important factors to discriminate management systems and "soil organic matter" was the most significant factor to discriminate soil classes. The most powerful soil attributes retained into MDS for distinguishing differences in soil quality of rice production under different management systems and soil classes were Cu, K, EN, Mic.q, Mg, OM, Mg, Fe, WSA, SR, MN.

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Table 1. Eigenvalue, partial and cumulative % of variance explained by factor analysis

Factors	Eigenvalues	% of Variance	Cumulative %
1	12,70	43,80	43,80
2	2,81	9,68	53,48
3	2,78	9,57	63,05
4	2,61	9,01	72,06
5	1,78	6,14	78,20

Table 2. Factor loadings and communalities of five factors model of physical, chemical, and biological soil quality indicators from rice fields of Camaquã region

Soil quality indicators		Factors					Communalities
		1	2	3	4	5	
Organic matter (%)	OM	**0.978**	-0.035	-0.024	0.076	0.011	0.964
Bulk Density (g cm^{-3})	BD	**-0.955**	-0.119	0.033	-0.125	-0.029	0.943
Total N (%)	TN	**0.952**	-0.062	-0.159	-0.058	0.043	0.940
Calcium (cmolc (dm^3)$^{-1}$)	Ca	**0.950**	0.114	0.206	0.054	0.031	0.962
Cation-exchange capacity (cmolc/dm^3)	CEC	**0.949**	0.031	-0.097	0.153	0.007	0.935
Microporosity (%)	Mic.	**0.932**	0.128	0.044	0.154	0.187	0.946
H + Al (cmolc (dm^3)$^{-1}$)	H+Al	**0.867**	-0.037	-0.298	0.155	-0.019	0.867
Alkaline Phosphatase (μg p-nitrofenol gsoil^{-1})	Alk. Ph.	**0.861**	0.060	-0.104	-0.167	-0.226	0.834
ß-Glucosidase (μg p-nitrofenol gsoil^{-1})	ß-Gluc.	**0.847**	0.252	-0.099	0.005	-0.108	0.802
Acid Phosphatase (μg p-nitrofenol gsoil^{-1})	Ac. Ph.	**0.828**	0.114	0.180	0.163	-0.034	0.759
Soil Respiration (μmol CO2/h/gsoil)	SR	**0.784**	-0.078	0.185	-0.069	0.200	0.700
Magnesium (cmolc (dm^3)$^{-1}$)	Mg	**0.769**	0.157	0.328	0.325	0.079	0.836
Iron (mg dm^{-3})	Fe	**0.745**	0.319	0.188	0.162	0.061	0.722
Mineralizable N (mg gsoilN-NH4-1)	MN	**0.709**	0.081	0.288	-0.162	0.143	0.639
Soil Biomass (CTMB (μg gsoil^{-1}))	SB	**0.694**	0.084	-0.055	-0.601	0.032	0.855
Water stable aggregates (%)	WSA	**0.694**	**0.431**	-0.036	0.093	0.025	0.678
Mean Weight Diameter (mm)	MWD	**0.626**	**0.624**	0.028	0.024	0.093	0.791
Copper (mg dm^{-3})	Cu	-0.212	**0.771**	0.212	0.368	-0.094	0.828
Zinc (mg dm^{-3})	Zn	0.368	**0.642**	0.394	0.240	0.262	0.829
Available Water (%)	AW	-0.260	**-0.616**	0.229	-0.007	-0.133	0.518
Earthworm number (ind.m^{-2})	EN	0.021	**-0.451**	0.086	0.048	0.231	0.267
Aluminium saturation (%)	Al sat.	-0.311	-0.052	**-0.872**	-0.132	-0.065	0.881
Aluminium(cmolc (dm^3)$^{-1}$)	Al	**0.561**	0.068	**-0.762**	-0.038	0.082	0.908
pH (H_20)	pH	0.020	-0.082	**0.739**	-0.223	**0.474**	0.827
Microbial quotient (%)	Mic.q	-0.150	0.086	0.035	**-0.864**	0.032	0.779
Manganesium (mg (dm^3)$^{-1}$)	Mn	0.145	0.337	-0.079	**0.747**	-0.081	0.706
Potassium (mg (dm^3)$^{-1}$)	K	0.146	**0.437**	0.264	**0.596**	0.245	0.698
Phosphorus (mg (dm^3)$^{-1}$)	P	0.114	-0.163	0.248	0.024	**0.789**	0.725
Macroporosity (%)	Mac.	0.054	-0.107	0.038	0.025	**-0.723**	0.539