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Evaluation of soil degradation produced by rice crop systems in a Vertisol, using a soil quality index

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ABSTRACT

One of the priorities of land planners is the development of methodologies that allow the detection of negative impacts on soils. The objective of this work was to evaluate the impact of rice production systems that use irrigation with groundwater on soil at the field scale, using a soil quality index. Six soil quality indicators (SQI) corresponding to different soil properties were measured: aggregate stability, water percolation, soil organic matter (OM), exchangeable sodium content (ESC), pH, and electrical conductivity in saturated paste extract. Data was collected in 75 sampling sites, setting reference values and threshold values for each SQI. The indicators were standardized and 5 soil quality categories were defined: very low, low, moderate, high and very high. The impact of rice crop on soil quality was analyzed in 6 field plots with different crop rotations using this SQIn. A negative effect on soils structure was observed with the introduction of rice in the crop rotation. This effect was attributed to a decrease in OM and an increase of ESC resulting from the use of water for irrigation rich in sodium bicarbonate. Soil management should promote activities that help to increase organic matter in the soil, and to reduce the amount of Na in the exchangeable complex. The use of a SQIn can provide an early assessment of soil degradation processes and help land managers to implement soil conservation practices.

1. Introduction

The province of Entre Ríos is the second largest rice-production province in Argentina, accounting for 30.7% of the total area of the country cultivated with rice during the growing season 2012/13. In this province, rice cultivation is carried out under flood irrigation, following contour lines and maintaining a water layer of 5–12 cm above the soil surface during the growing period, which varies between 90 and 100 consecutive days. The water used for irrigation is normally pumped from wells, and contains relatively high sodium bicarbonate concentrations.

Most of the rice-cultivated soils are Vertisols (Argiacuolic and Argiudolic Peluderts) and Mollisols with vertic properties (Vertic Argiudolls). Under natural conditions, these soils show high structural stability due to the nature of soil colloids, a low amount of Na in the exchangeable complex, and high organic matter content. However, the intense tillage that rice crop requires accelerates the mineralization of organic matter, and the irrigation with water containing sodium bicarbonate increases exchangeable sodium content (ESC). Both phenomena lead to a progressive degradation of soil structure, and their effect is more acute as the contribution of rice to the crop rotation increases (Wilson, 2003). Reversing the collapse of soil pore system is difficult and costly, especially when this process is at an advanced stage of development.

De Datta and Hundal (1984) observed that a continuous cultivation with irrigated rice results in soil structural degradation, creating non-favorable physical conditions for the following crops. For this reason, and due to the importance of rice crops in Entre Ríos, it is crucial to develop standard methodologies to detect negative effects of rice cultivation on soil structure at early stages, in order to adopt conservation measures that stop or reverse soil degradation.

Soil quality is a useful concept when assessing the sustainability of agricultural activities (Doran et al., 1996) and indicates soil capability to sustain plant and animal productivity, to maintain or improve water and air quality, and to protect human health (Karlen et al., 1998). Although soil quality cannot be measured directly, it can be inferred using soil quality indicators (SQI). The SQI are soil variables with the following characteristics: i) a good correlation with ecosystem processes; ii) integration of soil physical, chemical and biological properties; iii) good sensitivity to human-induced changes in the soil (Doran and Parkin, 1994); iv) simplicity of measurement and interpretation (Viglizzo, 1996); and v) reproducibility (Gregorich et al., 1994).

Abbreviations: MDS, minimum dataset; SQI, soil quality indicator; SQIn, soil quality index; TH, threshold; RV, reference value; Bl, baseline.

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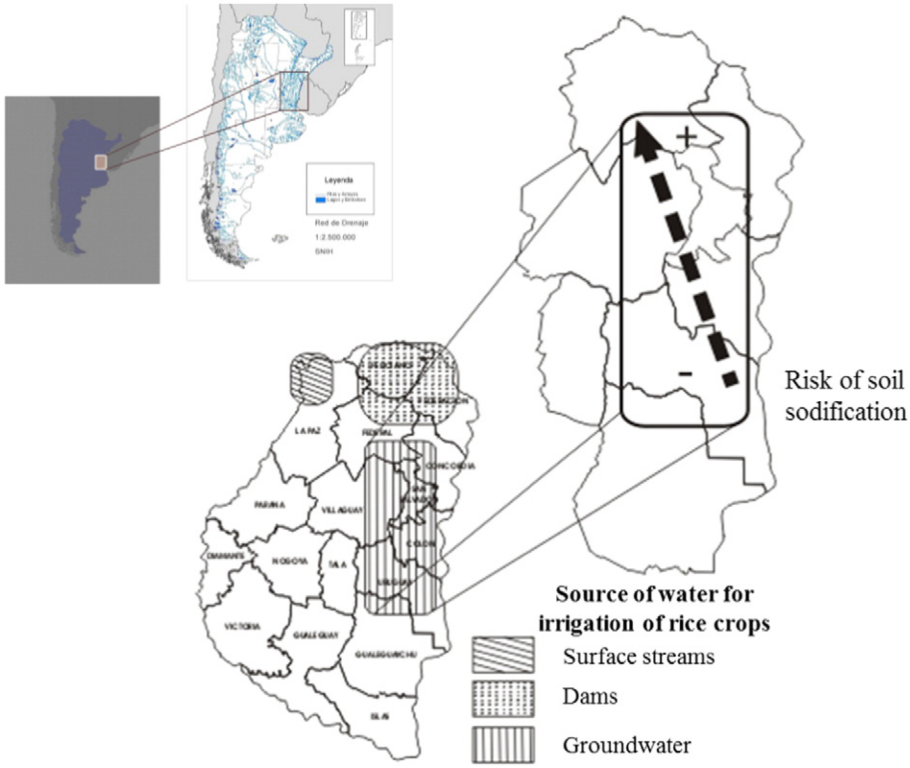

Fig. 1. Location of Entre Ríos in Argentina, main areas of rice production in this province, and type of water used for irrigation.

Some authors state that SQIs cannot be an *ad-hoc* group of soil properties defined for each situation in particular, but they should be fixed to allow comparisons between soil conditions at different work scales (Dumansky et al., 1998). However, other authors consider that the selection of indicators should reflect the main restrictions of each system for a given situation, and therefore SQIs can be different for each specific case. Consequently, indicators can be defined for different cases and scales (Askari and Holden, 2014; Brejda et al., 2000; Astier et al., 2002; Segnestam, 2002; Wilson, 2008). For practical purposes, the definition of a potential Minimum Dataset (MDS) is recommended, consisting on the smallest group of SQIs that provide sufficient numerical data to assess the capacity of a soil to carry out its function (Doran and Parkin, 1994; Larson and Pierce, 1994). Although a MDS may not be enough to quantify soil quality, since a proper definition of soil quality requires understanding the dynamics of soil processes, it can be very useful to identify degradation or recovery processes (Orellana et al., 1997). Finally, the integration of SQIs in soil quality indexes (SQIn) summarizes the multiple dimensions of soil quality in a practical and simple manner (Acton and Padbury, 1993).

Two different methodologies to measure and assess changes in soil quality have been proposed: one based on monitoring trends, and the other one consisting on setting reference values for each SQI (Seybold et al., 1999). Regardless of the adopted approach, the identification of positive or negative impacts of an activity on soil quality requires the definition of a baseline (Bl) for each SQI, representing the SQI values prior to the start of the activity. Finally, threshold values (TH) should be defined, as the minimum or maximum values of a SQI that should not be trespassed (Patrick et al., 2013; Segnestam, 2002). Threshold values can be designated using different criteria: regulatory values, scientifically-based values, spatial (synchronic comparisons) or temporal (diachronic comparisons) measurements, expert-knowledge based values, or institutional and social groups' opinions (Tolon Becerra and Ramirez Roman, 2000).

The objective of the present study is to evaluate the impact of rice production systems that use irrigation with groundwater on soil at the field scale, using a soil quality index.

2. Material and methods

2.1. Study area

The study area was located in the traditional rice farming area of Entre Ríos, Argentina (Fig. 1). The area has a humid-temperate climate, with average annual rainfall and temperature of 1000 mm and 16.6 °C, respectively. Typical soils of the area are Vertisols (Argiacuolic and Argiudolic Peluderts) and Mollisols with vertic properties (Vertic Argiudolls). These soils have a significant amount of swelling clays, mainly montmorillonite, and the sub-surface horizons are very dense, with low hydraulic conductivity. The agricultural activities have been intensified throughout the last years, and rice cultivation has been steadily introduced as a part of the crop rotations. Rice cultivation is usually conducted under flood irrigation, using groundwater rich in sodium bicarbonate whose application to the soil increases the risk of sodification (Fig. 1 and Table 1).

Soil quality evaluation was conducted in 6 plots located in the Department of Villaguay (Entre Ríos) that were cultivated using traditional crop rotations including rice. The crop rotations in those plots differed in the percentage of rice that was included in the crop rotation, which relates to the number of years from the 10 prior to soil sampling when the plot was cultivated with rice (Table 2). Flood irrigation requires leveling

Table 1
Groundwater quality in the rice area of Entre Rios province. n = 229 (extracted from Decombar (2005) in Wilson (2008).

	pH	EC[a] μS cm^{-1}	Ca^{2+} mmol$_c$ l^{-1}	Mg^{2+}	Na^{+}	$CO_3^{2=}$	$HCO_3^{=}$	SAR	SAR_{adj}
Maximum	8.27	1200	2.56	1.60	7.23	6.14	18.16	9.98	18.17
Minimum	6.97	235	0.16	0.40	2.23	0.43	1.97	1.96	4.06
Average	7.58	694	0.94	0.96	5.49	1.95	5.74	5.85	11.49
Standard deviation	0.18	136	0.47	0.20	1.01	0.76	1.62	1.53	2.77

[a] EC = electrical conductivity; SAR = sodium adsorption ratio; SAR_{adj} = adjusted SAR.