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Management systems in irrigated rice affect physical and chemical soil properties

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ABSTRACT

Lowland soils are commonly found in the state of Rio Grande do Sul, Southern of Brazil, where they represent around 20% of the total area. Deficient drainage is the most important natural characteristic of these soils which therefore are mainly in use for irrigated rice (*Oriza sativa*). Degradation in these soils is progressively getting stronger since the intensity of agricultural activities leads to a higher soil density, and a lower water infiltration rate. There is a growing interest by farmers to grow other crops such as soybean in rotation with (flood) irrigated rice but this degradation has become an obstacle to do so. This study was done with the objective to assess the soil physical and chemical quality of the three rice management systems (conventional, semi-direct and pre-germinated) most used in the region of Camaquã municipality, Rio Grande do Sul state, Brazil. Samples were collected from 21 rice farms with 2 different types of lowland soil (Albaqualf and Humaquepts). The soil samples were analysed for physical and chemical properties. Using multivariate analysis of covariance (Mancova), the effects of the natural variability in terms of soil clay content were separated from the management effects. The analysis revealed that soil physical and chemical properties were affected by the management practices adopted by farmers. The results showed that the major effect of the management systems was on a physical property: bulk density. An increase in soil density in the pre-germinated and conventional systems was found to be caused by a significant reduction in the volume occupied by micropores, an indication of structural degradation. The semi-direct management system, associated with less intensive tillage operations retained better soil conditions and a better organic matter status. The chemical properties significantly affected by management (total N, Ca, Mg, Fe, cation exchange capacity (CEC), and potential acidity [PA]) all had their highest values in the semi-direct management system. This study confirmed that the physical soil degradation forms the main obstacle for growing other crops in a rotation with rice.

1. Introduction

In many regions in Brazil human activity has caused environmental problems and unsustainable conditions in agricultural production areas. The lowland soils in the state of Rio Grande do Sul are one example of such a situation, where the problems linked to the nature of the soils are intensified by agricultural activity. The impact of the management systems used in these lowland soils is high and deserves special attention.

Twenty percent of the total area of Rio Grande do Sul state (approximately 5.4 million ha) is under lowland soil. Aqualfs are the most important soil types found, covering 55% of the total lowland area of the state (Pinto et al., 2004). The natural deficient drainage caused by a dense and impervious B horizon makes these soils well suitable to irrigated rice production. With an annual production of approximately 5.5 million tons, equivalent to 52% of total Brazilian rice production, it has been the most important regional agricultural activity (Azambuja et al., 2004), followed closely by soybeans. This production involves puddling and keeping the area flooded for the duration of the rice crop. Rice productivity is decreasing because of infestation of the fields with red and black rice weeds. Crop rotation is a feasible alternative to control this infestation, diversifying agricultural production and improving soil characteristics as well (Lima et al., 2002). However, studies have shown that wet tillage for rice can destroy soil structure (Tripathi et al., 2005) and creates a poor physical condition for the following crop because of its depressing effect on emergence, shoot and root growth (Mohanty et al., 2006).

Degradation of the regional soils is mainly related to high soil density, low porosity, high micro/macro pores ratio, reduced hydraulic conductivity, and low water infiltration rate and it is progressively worsening because of the intensity of tillage applied

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Table 1
Timing of management activities for the three rice management systems and the mean rainfall for the region.

Management system (% of the use of this system in Camaquã, the range of farm size and average rice yield)	May	June	July	August	September	October	November	December	January	February	March	April
Semi-direct (65%, 5–200 ha, 5.7 ton ha^{-1})		Fallow/cattle			Soil preparation[a]		Chemical weed control and sowing[b]				Harvest	
Inundation									XXXXXXXXXXX			
Conventional (25%, 200–500 ha, 8.4 ton ha^{-1})	Fallow/cattle				Soil preparation[a]		Sowing[b]				Harvest	
Inundation									XXXXXXXXXXXXXXX			
Pre-germinated (10%, 2–30 ha, 6.3 ton ha^{-1})	Fallow/cattle			Soil preparation[c]			Sowing[b]				Harvest	
Inundation					XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX							
Mean rainfall (mm)	56	108	92	136	113	125	157	94	172	172	82	120

[a] Plough and harrow.
[b] Drained field is required for sowing operation. Pre-germinated seeds are used in the pre-germinated management system. XXXX: period of inundation.
[c] Plough, harrow and leveler.

in rice production (Pauletto et al., 2004). Accordingly, the level of degradation has become an obstacle for growing deeper rooting crops such as maize, soybeans or sorghum in rotation with flood irrigated rice (Lima et al., 2002).

Different management systems on lowland soils can affect differently the soil properties. Changes in soil characteristics can indicate the ability of soil to function effectively in order to supply water and may reflect limitations to root growth. A number of studies have assessed physical and chemical soil properties in lowland soils, in Brazil (Lima et al., 2002; Pedrotti et al., 2005; Lima et al., 2006; Reichert et al., 2006) and in other countries (Bhagat, 2003; Anders et al., 2005; Mohanty et al., 2007; Mohanty et al., 2004; Lima et al., 2008).

Many soil properties have been proposed (Doran and Parkin, 1994; Schipper and Sparling, 2000; Mohanty et al., 2007) as useful for soil quality monitoring. As the lowland soils assessed here are distinguished basically by texture (different clay content), in this study we measure physical and chemical soil properties that may vary among different soil textures such as porosity, organic matter content, available nutrients, etc.

The majority of these studies were carried out in typical experimental sites with controlled treatments. In contrast, the study presented here is an analysis of soil properties collected from farmers' fields. An additional aspect is that we measured the net effect of the management systems on soil properties, i.e., after removing the effects of the intrinsic soil characteristic represented by the surface clay content.

In this context, it was hypothesized that rice management systems with less intensive tillage practices may lead to better (sustainable) physical and chemical soil conditions. For this, we investigated the soil quality of the three rice management systems, with varying degree of intensity and water use, from farmers' fields in the Camaquã municipality, Rio Grande do Sul state, Brazil.

2. Materials and methods

2.1. Location and soils

Camaquã is located in the Coastal Province of the Rio Grande do Sul state, south of Brazil, latitude between 30°48′ and 31°32′S, longitude between 51°47′ and 52°19′W. Mean annual rainfall is 1213 mm and average temperature is 18.8 °C (Cunha et al., 2001).

Albaqualfs and Humaquepts (Soil Survey Staff, 2006) are the two soil great groups found in this region. The main differences between and within these soils is the inherent clay content found in the topsoil (Cunha et al., 2001).

2.2. Rice production management systems

The growing period of rice in this region is from sowing between late September and early December till harvest in March–April. In the fallow period (between the harvest and soil preparation) the majority of the farmers have cattle in their fields. The three management systems differ with respect to intensity and timing of soil tillage and water use. A calendar of the three systems and the average monthly rainfall is shown in Table 1.

2.2.1. Conventional

Just before the sowing period, the fields for rice are prepared when the soil is not inundated. This is done by deep (15–20 cm) tillage with a disc plough followed by superficial (10–15 cm) operations with a disc harrow with the aim to level the soil and prepare a seedbed of fine aggregates. A conventional sowing machine is used. The fields are inundated after the seedlings have reached a height of approximately 10 cm.

2.2.2. Pre-germinated

The leveled fields areas are inundated in early August before the tillage operations start. In this condition, tillage is done in September and October. Usually, the same disced implements are used as in the conventional system, often complemented with a pass of a special leveller, made by heavy wood, to smoothen and level the puddled surface layer. Seeds are pre-germinated by soaking until the coleoptile is 2–3 mm long. Seeds are broadcast in the shallow (5–10 cm) water layer either by hand or sowing machine, depending on the size of the farm. The water layer allows a more precise levelling of the field and controls weeds.

2.2.3. Semi-direct (no-tillage)

The soil preparation is done in September or October (around 45–60 days before sowing) when the soil is not inundated. This early soil preparation with a disc plough and disc harrow is done to smooth the irregular soil surface left by the last harvest and permits the incorporation of the straw from the previous season and the germination of weeds. In November or December, a herbicide with total action is used to kill these weeds, and rice is sown without seedbed preparation, to avoid regrowth of weeds. Fields are inundated after emergence of the seedlings, as in the case