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State-space approach to evaluate effects of land levelling on the spatial relationships of soil properties of a lowland area

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ABSTRACT

Land levelling is an agricultural practice to correct soil surface irregularities turning the area more efficient for management of agronomic inputs. The technique has been adopted mainly in lowland areas used for flood irrigation of rice. As a result sub-surface soil layers may be exposed with possible impact on crop production by changing soil properties. This study aimed to evaluate the effects of land levelling on the spatial relationships of soil properties. Relations among them were quantified using a state-space approach in different scenarios constructed from data sets in a 1 ha lowland area sampled as a grid. The grid consisted of 100 sampling points (10 m × 10 m), with samples collected from the 0–0.20 m soil layer, before and after levelling, totalizing 200 samples. Soil water contents at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}) were taken as response variables due to their importance on rice water management. Sand, silt and clay contents, soil microporosity (Micro) and bulk density (BD), cation exchange capacity (CEC), organic carbon content (Corg), and the depth of the top of the B horizon in relation to soil surface (DTB) were used as co-variables through an evaluation of their spatial auto- and cross-correlation behaviors with θ_{FC} and θ_{PWP}. Eight data-array scenarios were tested. Results showed that levelling induced negative effects on soil quality since this procedure decreased θ_{FC} and θ_{PWP}, Corg, and CEC as well as increased BD. Using the state-space approach, we concluded that its performance in estimating θ_{FC} and θ_{PWP} was affected by the scenarios after levelling, the best performance being for the vertical scenarios. DTB and CEC contributed to the estimation of both soil water contents for all scenarios after levelling. The main problem associated to the levelling is the cutting of shallow soils which decreases their capacity to store water and to exchange cations in the effective arable depth which will be explored by the crop root system. As DTB is directly related to the spatial distribution of taxonomic soil profile properties, the state-space approach, which considers sampling location coordinates, may be a potential on-site-specific tool aiming at the recuperation of degraded soils through amendments since it opens the possibility for farmers to manage a crop field based on local environmental properties, with their spatial association and localized variation being a function of the distance between their measurements.

1. Introduction

Land levelling is a widely used practice for increasing the efficiency of agricultural production. This practice is frequently

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applied to lowland areas predominantly used for flooded rice cultivation. The main benefits that justify this procedure are related to a more uniform application of the water depth, more adequate drainage conditions, more efficient management practices, a better nutrient availability, and a greater cultivation area index, i.e., the relation between the effectively cultivated area and the total area, as compared to the rice field before levelling (Parfitt et al., 2004; Ramos and Martínez-Casasnovas, 2010; Sharifi et al., 2014). Levelling also allows the adoption of crop rotation schemes between irrigated lowland rice cultivation and upland cropping (Walker et al., 2003; Gastal et al., 2004; Brye et al., 2004, 2005, 2006).

Due to soil movement while lower parts of a field being filled and higher parts being cut, previous sub-surface soil layers may be exposed to the surface. This can be detrimental for crop growth, since it can change the physical environment in which the plant develops (Walker et al., 2003). Therefore, studies have been carried out with the intent of quantifying the effect of land levelling on physico-hydric, chemical and biological soil attributes. These studies have also evaluated the possible impact of levelling on the relationships among soil attributes, and on the structure of their spatial variability through geostatistical tools. Brye et al. (2003) and Brye (2006) concluded that land levelling changed the relation between some physical and biological soil attributes of the surface 0–0.20 m soil layer, which was evaluated through linear regressions. These procedures did not consider the spatial coordinates of the attributes in the field, which can lead to errors in the interpretation of the results (Nielsen and Alemi, 1989).

The state-space approach evaluates the relations among variables measured in the field, considering the position coordinates (Nielsen and Wendroth, 2003; Timm et al., 2003a). This approach has been widely and successfully applied in agronomy, mainly when compared to classical models of multiple regression (Timm et al., 2004; Jia et al., 2011; Oliveira et al., 2011; Liu et al., 2012). Although the state-space approach was originally developed for data collected along spatial transects or as time series, studies were also carried out using grids of experimental data (Stevenson et al., 2001; Liu et al., 2012; She et al., 2014).

In southern Brazil and many parts of the world, the rice crop has been cultivated under levelling and flooded conditions (Brye et al., 2006; Reichert et al., 2008). Nowadays, in southern Brazil the use of sprinkler irrigation in rice production under lowland areas has been increased due to the decrease of water availability in this region. Despite, few studies have been focused on soil water conditions for rice production, more specifically on the impact of levelling on the management of water available for rice growth. Therefore, to quantify the spatial changes in the topsoil as a result of levelling operations, i.e., cutting, filling, smoothing and shaping its surface related to field capacity and permanent wilting point and soil physico-chemical variables related to water management and crop nutrition is crucial to improve farm management for rice or other crop production (soybean, sorghum, etc.) in lowland areas. Therefore, this study aimed to: (i) evaluate the impacts of land levelling on soil water content variables at field capacity and permanent wilting point, and on some selected soil physico-chemical properties using data collected in a grid on a levelled lowland area in southern Brazil, and (ii) use the state-space approach for evaluating the effects of land levelling on the spatial relationships between these soil properties in eight (four horizontal and four vertical) different scenarios based on data sets sampled in the grid pattern.

2. Material and methods

2.1. Experimental area

The site consisted of 1.0 ha field located in the municipality of Capão do Leão, Rio Grande do Sul state, Brazil (31° 40′ 12.75″ S; 52° 27′ 59″ W) on which a 100 point grid of 10 × 10 m was established (Fig. 1). According to Köppen's classification, the climate is of the Cfa type, subtropical, sea influenced, sub-humid summer with the rest of the year humid or super-humid (Moreno, 1961). The two soils of the lowland basin were classified as: a Typic Albaqualf in the relatively higher elevations of the land and an Umbric Epiaqualf in the lower portions (Soil Survey Staff, 2010). Before levelling the area was cultivated for two years with flooded rice and grain sorghum (*Sorghum vulgare*).

2.2. Land levelling and soil sampling

The land levelling was performed at the beginning of 2008 based on the elevation map (an accuracy measurement of ±0.5 cm) of a total area of about 2.5 ha, calculating cuts and fills through the minimum squares method to a slope of 0.15% imposed on our study area of 1.0 ha, approximately in the east–west direction (Fig. 2). A soil volume of 519 m^3 ha^{-1} was transported by a laser ray controlled scraper from about half of the higher to the lower portion of the field, with a maximum cut height of 0.21 m and a maximum fill height of 0.17 m (Fig. 2b). The period between samplings before and after levelling was about three months.

Before and after levelling soil samples were collected at each of the 100 points of the grid, from the 0–0.20 m layer. Disturbed samples were collected with a screw auger at the 0–0.20 m soil layer (approximately 1.0 kg of soil) and used for determinations of

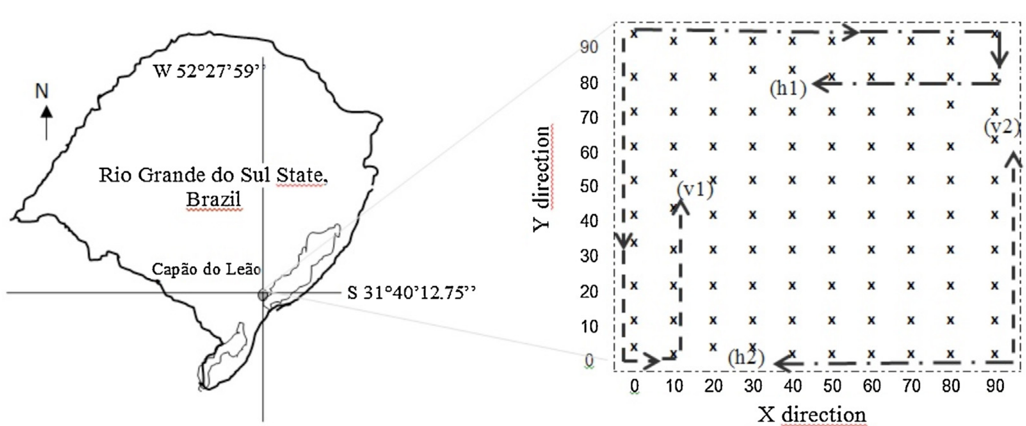

Fig. 1. Site location on the map of the Rio Grande do Sul state, Brazil, illustration of the 100 point experimental grid, and the evaluated scenarios before and after levelling. v1 and v2 are vertical scenarios and h1 and h2 are horizontal scenarios.