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Multivariate and geostatistical analyses to evaluate lowland soil levelling effects on physico-chemical properties

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ABSTRACT

Levelling is used in rice fields to correct land irregularities for management practice improvement. Effects of levelling have been evaluated using univariate tools from classical statistics and geostatistics, which disregard possible effects on interrelations among soil properties. This study aimed to: (i) evaluate the effect of levelling on soil physico-chemical properties using classical statistics and geostatistical tools, (ii) group soil properties in homogeneous sets using multivariate cluster analysis, (iii) reduce the dimensionality of sets by principal component analysis, and (iv) characterize and map spatial distributions of principal components to compare them with individual maps to elaborate maps of homogeneous management zones. On a 1.0 ha field in Southern Brazil a grid of 10×10 m points was used to sample the 0–0.20 m soil layer, before and after levelling. All data sets were submitted to descriptive statistics and the Kolmogorov–Smirnov (K–S) test, as well as to geostatistical analysis. Maps were constructed using ordinary kriging or the inverse square distance interpolation. Groups were formed by cluster analysis. To reduce their dimensionality principal component analysis and geostatistics were used to evaluate spatial dependencies of the main principal components. Maps of the main principal components and of each soil property were visually compared to verify if they had similar patterns of spatial variability. Levelling caused an increase of the spatial range for the majority of the properties as well as an improvement of the goodness of fit of the semivariogram models. Variability structures of the majority of the properties were best modeled by Gaussian and spherical models. Levelling also caused changes in the variance and covariance structures of all properties as detected by cluster multivariate analysis. Soil bulk density and organic matter represented the sets that were most affected by land levelling, so that their maps are considered useful and accessible tools for farmers in future operations of land recuperation.

1. Introduction

Land levelling is a widely used agricultural practice in cultivated rice fields of the Southern Brazil, mainly in the states of Rio Grande do Sul (RS) and Santa Catarina (SC) (Parfitt et al., 2009), as well as in the United States (Brye et al., 2006) and Iran (Sharifi et al., 2014). Levelling is also used in areas cultivated with other crops in Spain (Martínez-Casasnovas & Ramos, 2009) and India (Kuotsu et al., 2014). The main benefits that justify levelling operations are well known and related to a more uniform unpressurized surface water

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application, of the more adequate drainage conditions, more efficient application of management practices and the possibility of a better nutrient availability (Parfitt et al., 2004; Aquino et al., 2015). Levelling also allows the adoption of rotation schemes between irrigated lowland rice cultivation and upland cropping rotation (rice and soybean, rice and corn, rice and sorghum, etc.). On the other hand, studies have also pointed to some disadvantages mainly due to severe soil surface disturbance causing a significant decrease of the A horizon thickness with possible exposure of subsoil layers (Brye et al., 2003; Ramos and Martínez-Casasnovas, 2010). Levelling operations may also cause effects on the magnitude, variance and spatial variability of soil properties. Most studies have assessed the effects of levelling on soil properties using univariate statistical approaches by applying descriptive statistics, geostatistics, multiple linear regressions, etc. (Brye et al., 2004, 2005, 2006; Ramos et al., 2007; Parfitt et al., 2013, 2014; Kuotsu et al., 2014; Ogunwole et al., 2014; Sharifi et al., 2014).

Soils are highly variable partially due to the combined effects of physical, chemical and biological processes that operate with different intensities and scales (Goovaerts, 1998). In this sense, statistical and mathematical methods could be applied to resolve the complexity and uncertainty inherent in the soil system. Therefore, using soil data and their analysis is important in field assessment because uncertainty and imprecision often occur in data sets (McBratney et al., 2000). The use of univariate (descriptive statistics, geostatistics, multiple linear regressions, etc.) and multivariate (cluster analysis, principal component analysis, etc.) statistical approaches can be a potential and useful tool to assess the effects of land levelling. For instance, in an area of 24,000 ha in northern Iran which has mainly been cultivated with irrigated rice, Davatgar et al. (2012) established an experimental grid consisting of 303 points. At each point they measured several soil physico-chemical properties and applied multivariate and geostatistical tools (principal component and fuzzy-cluster analyses). They defined and delineated homogeneous soil management zones in terms of soil fertility aiming to provide a basis for variable rate application of plant nutrients (precision agriculture concept). They concluded that the combined use of cluster and geostatistical analyses allowed the definition of four outlined zones providing an opportunity for farmers to adopt a specific management for soil nutrients. In Chile, Ortega and Santibáñez (2007) used cluster and principal component analyses as well as the coefficient of variation method aiming to find the most efficient method to delineate management zones for corn (*Zea mays* L.). They concluded that the three zoning methods were similar and adequate to delineate homogeneous zones in terms of soil fertility.

The spatial variability of soil properties is influenced by intrinsic factors (soil material, climate, topography, relief and time) and extrinsic factors (agricultural management practices, such as land levelling, fertilization and irrigation). Few studies have been carried out to assess the possible effects of levelling operations (extrinsic) on soil properties near the surface using multivariate approaches. Thus, this study aimed to: (i) evaluate the effect of land levelling on thirty soil physico-chemical properties of the 0–0.20 m layer of a lowland soil of Southern Brazil using classical statistics and geostatistics; (ii) group these soil properties before and after levelling into homogeneous groups using multivariate cluster analysis; (iii) reduce the dimensionality of each group of variables using principal component analysis; and (iv) characterize and map the spatial distribution of the principal components to compare them with individual maps of each soil property to elaborate a unique and representative map of homogeneous management zones for future operations of land recuperation.

2. Material and methods

2.1. Study area and the land levelling procedure

The study was carried out on an area of 1.0 ha of the lowland experimental station of "*Embrapa Clima Temperado*" located in the county of Capão do Leão, state of Rio Grande do Sul, Brazil (31°49′13″S, 52°27′59″W). An experimental grid of 10 × 10 m was established totaling 100 georeferenced points (Fig. 1). According to Köppen's classification, the regional climate is of the Cfa type, subtropical, sea influenced, sub-humid summer with the rest of year being humid or super-humid (Moreno, 1961). The two types of soils of the lowland area were classified as Typic Albaqualf in the relatively higher elevations and an Umbric Epiaqualf in the lower portions (Soil Survey Staff, 2010). Before levelling the area was cultivated twice with flooded rice and once with sorghum (*Sorghum vulgare*) under conventional tillage management

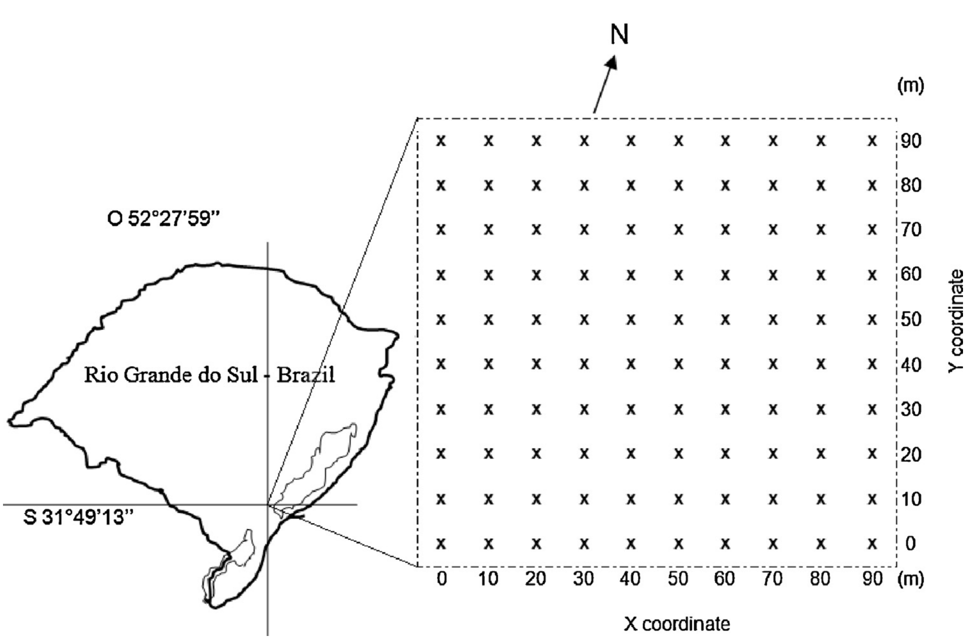

Fig. 1. Study area location and the illustration of the experimental grid with 100 georeferenced points.