3D soil compaction mapping with a three-coefficient polynomial

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Abstract

Soil property mapping is commonly done in two dimensions, and variation by depth is ignored. The only way to consider the vertical variation is mapping in 3D. In this paper, we present a method based on polynomial depth functions. The objective is determining the effectiveness of a simple polynomial to predict cone-index data by depth over a field. In order to study the performances of the proposed method we compared our results with 3D ordinary kriging using cross validation, excluding a percentage of samples and repredicting their values. Results show that the proposed method performs better that 3D kriging.

Keywords: depth function, 3D mapping, kriging, soil compaction, digital soil mapping

Introduction

The study of soil properties does not generally involve the vertical dimension into the mapping process, causing loss of important information about their spatial distribution, which are preserved with 3D mapping. The common methods for 3D soil mapping involve geostatistical interpolation (Bonomi, 2009; Bonomi et al., 2007; Castrignanò et al., 2002) and the use of depth functions (Minasny et al., 2006; Kempen et al., 2011; Malone et al., 2009; Meersmans et al., 2009). An equation, which describes the changes in soil properties with depth, is fitted through horizons data in order to increase the vertical resolution of each sample. Common methods involve fitting of exponential decay functions or splines through soil data. In this paper we propose an improved method of 3D soil compaction mapping, based on the depth function approach, using 2D kriging of the polynomial coefficients.

Study site and Sampling Methods

The study site is the CULS (Czech University of Life Sciences) Farm at Lany (21 ha) located in the Czech Republic, in central Bohemia, 40Km W of Prague. The soil type, according to the WRB classification, is a haCM Haplic Cambisol with a loamy texture (36% Sand, 43% Silt, 21% Clay on average).The Lany dataset consist of 57 penetrometer samples. The instrument sampled a thickness of 0.04m, starting from the surface to a depth of -0.52m. Every sample is located at an average distance of 55m on a regular grid.

Results

Polynomial Depth Function

Most of the cone-index data present a simple pattern. In general, the samples could be subdivided into two layers. The first begin at -0.08m and end at -0.28m and has cone-index values varying from 0.7 to a maximum of 17MPa. The second layer has values varying from 15 to 35MPa, starting at -0.28m to the maximum sampling depth. The transition layer coincides with a localized increase of resistance values, probably caused by a plough layer. Because the pattern was simple, we decided *a priori* to use a three-coefficient polynomial, to avoid over fitting (Erh, 1972). We screened hundreds of equations and the simplest and most accurate equation to describe this patter was the following:

$$y_{(i,j)} = \beta_0 x_{(i,j)}^{6} + \beta_1 x_{(i,j)}^{3} + \beta_2 \qquad (1)$$

For every point of depth $x_{(i,j)}$, the value of the soil compaction, $y_{(i,j)}$, could be calculated with a polynomial in which β_0, β_1 and β_2 are the coefficients of the equation, fitted with a least squares estimation. Its accuracy was confirmed by a goodness of fit analysis, between observed values and predicted with the polynomial. The R^2 of the depth function in 0.82, while the root mean squared deviation (RMSD) is 0.22.

Validation

In order to validate the developed procedure, we decided to compare the proposed mapping method with 3D geostatistical interpolation, because it was already used in soil compaction mapping (Castrignano et al., 2002). To compare the two predictions we used cross validation. We excluded a varying percentage of the samples, and repredict them using the remaining observations, repeating the process 500 times. For assessing the prediction accuracy we calculate the RMSD between observed and predicted data, the results are shown in Fig.1.

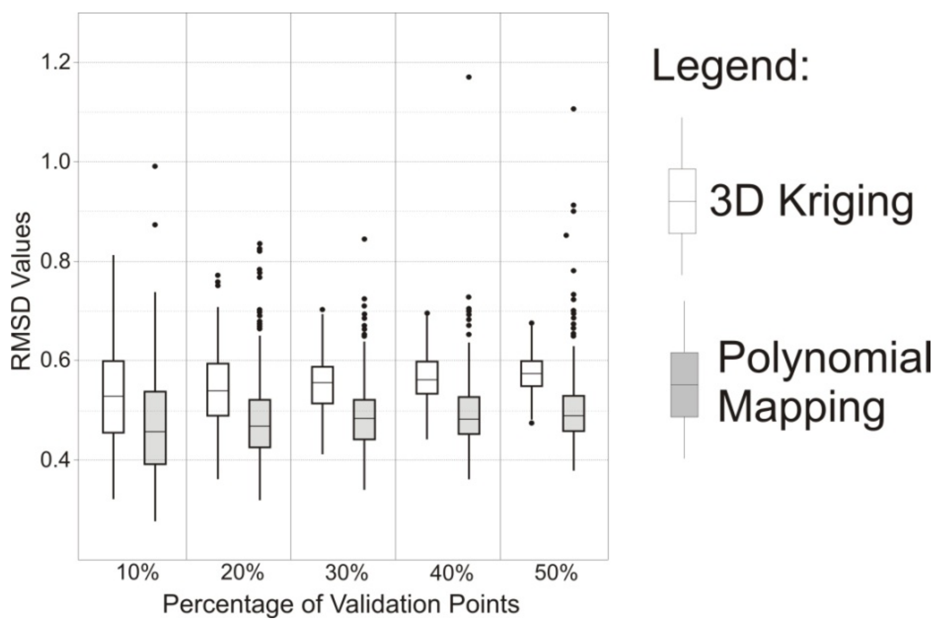

Fig. 1: Validation results. The box-cox plot represents the average RMSD value for each validation percentage.

Discussion

From the results of this study we can say that for the Lany Field is possible to describe the variation of cone-index values along the depth profile with a simple polynomial. The goodness of fit analysis shows that a three-coefficient polynomial can predict the soil property along the profile, with an adequate level of accuracy. In order to evaluate the mapping potential of the depth function, we compared the proposed mapping method with a three-dimensional geostatistical interpolation. The proposed mapping method, on the other hand, relies on a 2D ordinary kriging interpolation of the three coefficients. We presented the results of the mapping in two ways; first, a numerical validation performed by randomly subsetting the dataset and re-predicting a percentage of samples (Fig 1); second, a graphical output in which the two 3D maps are presented as bi-dimensional slices at three different depths (Fig. 2). The numerical validation shows clearly that the proposed mapping method obtained better results in predicting the soil property of interest in the study field. Moreover, from the validation is possible to conclude that even with 50% exclusion the precision of the map, created with the proposed mapping method, is only slightly affected (with a mean RMSD lower than the value of 3D kriging with 10% exclusion).

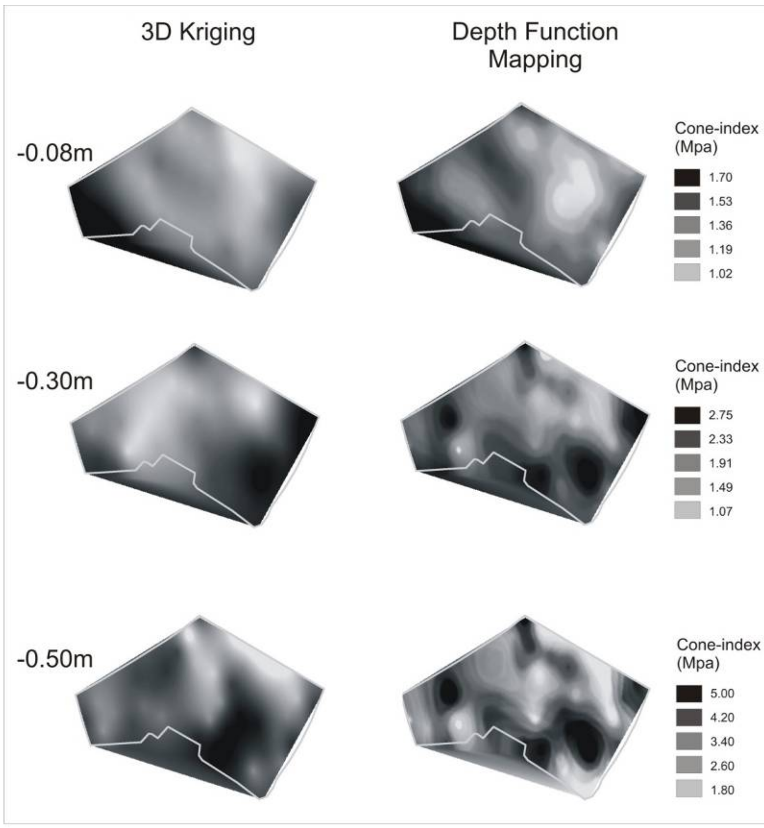

Fig. 2: Graphical comparison between the map created with 3D Kriging, on the left, and the map created with the proposed mapping method, on the right.

Conclusions

The polynomial presented here has a prediction power superior to 3D kriging interpolator.
This method can theoretically be used to increase the precision of the prediction with a relative small number of samples.
This study presents an example of soil mapping with a limited dataset and its successful application to 3D mapping. Although this study was limited to a field with particular soil properties in theory the approach could be applied in a larger area, if a general soil pattern is recognizable.

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