Assessment of spatial and temporal within-field soil variability by using geostatistical techniques[1]

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Abstract:
The main objective of this study was to analyze, with geostatistical techniques, the soil variability for some soil parameters on a 12-ha field cropped with durum wheat in Foggia (Southern Italy). Soil samples were collected at 100 georeferenced locations in 2005 and 2007. The application of multivariate geostatistical technique, called factorial co-kriging, allowed the delineation of the field into 3 main clusters. Contingency tables, k statistics and Q-Q plots were applied to assess the temporal variation.
The results showed a significant increase in soil organic matter and a decrease in P content up to 40 cm depth during the trial period.

Keywords: Soil variation; Multivariate geostatistics; Organic matter; Phosphorous.

1. Introduction

Soils commonly exhibit within-field spatial variability of some inherent properties such as texture, depth of topsoil and organic C content, resulting from complex geological and pedological processes acting over different spatial and temporal scales. Therefore, soil variables are expected to be correlated in a scale-dependent way (Castrignanò et al., 2000). Moreover, meteorological conditions and anthropogenic activities, such as tillage and fertilization, may cause spatial and temporal variation in soil (Basso et al., 2009).
The main objectives of this work were to characterize the soil variation of a field in southern Italy and test whether the soil management has affected chemical fertility significantly. We deemed a geostatistical analysis of coregionalization to be more revealing than a univariate approach, and we studied the scale-dependent correlation

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structure of some soil properties, focusing on the delineation of the field into homogeneous areas.

2. Materials and Methods

The research was carried out in a 12-ha field cropped with durum wheat (*Triticum durum* Desf.) at the Experimental Farm of the CRA - Cereal Research Centre (Foggia, 41° 27' N, 15° 36' E, south-eastern Italy), during November 2005 – July 2008 period. The soil is silty-clay Vertisol of alluvial origin, classified as Fine, Mesic, Typic Chromoxerert by Soil Taxonomy-USDA. The climatic conditions were characteristic of a Mediterranean environment, with a drier season between May and September and cold likely returning in the spring months (March-April).
One hundred georeferenced locations were selected so to evenly cover the field. Soil samples were collected at these locations, before sowing and fertilization, to 0-40 cm in 2005 and to 0-20 and 20-40 cm in 2007, and analyzed for sand, silt and clay contents (%), organic matter (%, OM), available P (mg kg^{-1}, expressed as P_2O_5), according to the standard methods of soil analysis (Pagliai, 1997; Violante, 2000).
The multivariate spatial and temporal data set was jointly analyzed by cokriging to produce thematic maps and by the Factor Co-kriging Analysis, developed by Matheron (1982), to delineate homogeneous areas. The geostatistical analyses were performed with ISATIS (Geovariances, 2010). Contingency tables and k statistics were calculated to assess the spatial association of the P maps and the ones of OM at the two dates. Q-Q plots were used to test the temporal trend. The approach was implemented with the FREQ procedure of the SAS/STAT software package (SAS/STAT Software Release 9.2, 2010).

3. Results

The exploratory analysis of the data revealed considerable spatial variation in soil properties at each sampling date and most variables were significantly correlated, which justified the choice of a multivariate approach. A linear model of coregionalization (LMC) was fitted to all both direct and cross-variograms, including the following basic spatial structures: a nugget effect and two exponential models with a range of 100 and 300 m.
Figures 1(a-d) display the co-kriged maps of the available P and the OM contents at the two sampling dates. The P maps were characterized by great erraticity, with several hot spots evenly spread over the field. However, it is possible to notice a tendency to higher values on north-western border of the field at both dates. On the contrary, the OM maps seem better spatially structured and can be roughly split into three main zones: a southern part with generally higher contents, a central area with lower ones, and a more variable northern area. All maps showed a general consistency over time. However, to make less subjective the results of a visual inspection, the contingency tables for P and OM were calculated using a common classification in three isofrequency classes. The overall accuracy was 58 and 59% for P and OM, respectively. The results showed that the structures of spatial dependence for P and OM remained stationary over about 58% of the field, due to inherent soil variation, but also other dynamic factors affected their spatial distributions, more related to meteorological conditions and crop management. The Bowker's test of symmetry verified the significance of P and OM variation over

time and the simple kappa coefficient values were 0.38 and 0.39 for P and OM, respectively.

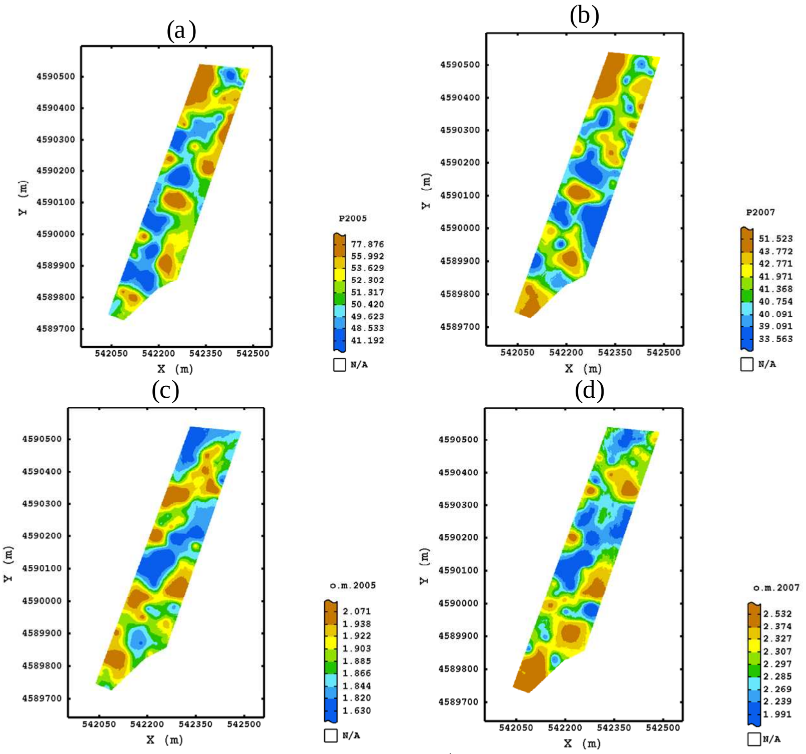

Figure 1: (a,b) Maps of available P (mg kg^{-1} P_2O_5) and (c,d) of organic matter (%) contents at the two dates

Actually, the spatial association between the two maps of either P or OM was not very high, confirming the dynamic character of soil fertility. However, the Q-Q plots (Figure 2) revealed a significant increase in organic matter and a significant decrease in P content during the trial period. Although a two-year trial period is not enough to draw general conclusions on observed P and OM trends, crop residue management very probably had a positive impact on increasing soil fertility.

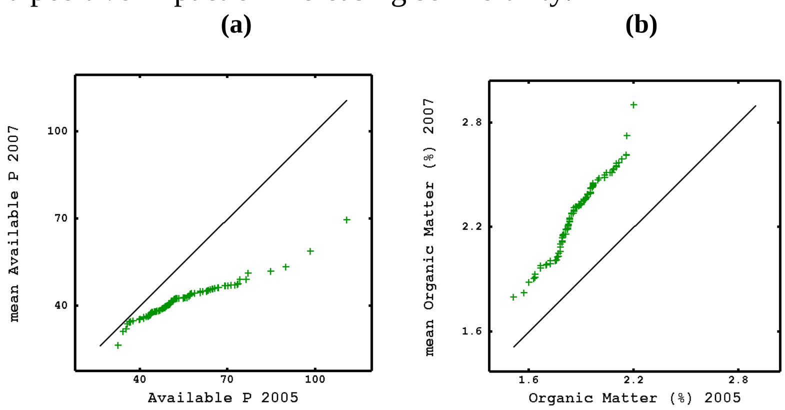

Figure 2: Q-Q plots of the variables P and OM for 2005 and 2007

As far as factor analysis, we retained only the first factor at longer range (=300 m; F1) with eigenvalue greater than 1, because it could produce a delineation of the field into

areas of size manageable by farmer. F1 was negatively correlated (data not shown) with OM and fine sand contents in both years and positively with clay contents and coarser sand content in both years, which also means that the main structures of spatial dependence are permanent over time.
The map of the first factor (Figure 3), displayed using three isofrequency classes, showed a wide central area with lower content of OM to 0-40 cm depth and higher contents of clay and coarser sand, whereas the northern and southern areas were characterized by higher content of finer sand and lower organic fertility. F1 could then be used as an indicator of soil organic fertility and soil texture.

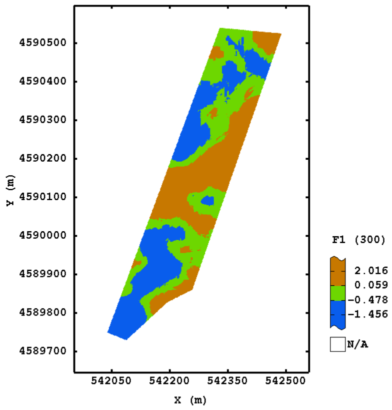

Figure 3: Map of the regionalized factor F1 produced using the Factorial co-Kriging procedure

4. Concluding remarks

Multivariate geostatistical analysis has produced the partition of an agricultural field into three homogeneous areas with different organic fertility and particle size distribution, which could be managed differentially. The results are encouraging and the approach might be used to test the effects of soil management over time.

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