Assessment and modelling of spatial variability of the soil factors potentially affecting groundwater nitrate contamination in two agricultural areas of Molise Region (Southern Italy)

Colombo[1] C., Palumbo[1] G.,
[1] Dipartimento di Scienze Animali, Vegetali e dell'Ambiente, Università del Molise,
Via De Sancits s/n 86100, Campobasso (CB) Italy colombo@unimol.it

Sollitto[2] D., Castrignanò[2] A.
[2] Consiglio per la Ricerca e la Sperimentazione in Agricoltura (CRA)
Unità di Ricerca per i Sistemi Colturali degli Ambienti Caldo-Aridi
Via Celso Ulpiani, 5 70125 Bari (BA) Italy

Abstract: In this study spatial variability was used to analyze soil factors influencing the occurrence of high nitrate concentrations in agricultural soils in the Molise region of Southern Italy. The proposed methodology applied to two agricultural areas combines measurements of soil nitrate concentrations carried out by a monitoring network of 164 top-soils. A multivariate approach based on multivariate geostatistics and GIS was used to model spatial variability of the soil variables. The maps of each individual soil variable and regionalised factor show the areas of the landscape that might cause nitrate loss from agriculture soils. The results can be used to support sustainable land use planning in order to mitigate soil nitrate leaching.

Keywords: nitrate contamination, soil variability, multivariate approach, geostatistics.

1. Introduction

Evaluation of nitrate loss from agricultural soils is a useful tool to support sustainable land use planning. An understanding of the spatial-temporal variability of important soil properties and associated nitrate contamination can provide a framework for assessing and modelling of the main processes occurring in the soil. Many factors may affect the spatial distribution of nitrate in the soil and the consequent nitrate pollution of groundwater. Important factors include topography, hydrogeology, climate, pedology, land use, and the type of crop (Power and Schepers, 1989). All of these factors need to be accounted for when analyzing spatial distribution of nitrate in soil. On the other hand, the spatial patterns of these factors do not change over short periods of time and, therefore, are not the major contributors to changes in spatial distribution of nitrate from year to year (Marriott et al., 1997). The aim of our research is to analyze nitrate concentrations in agricultural soils with respect to specific explanatory soil variables, using GIS and geostatistical methods to delineate areas at different risk of soil nitrate leaching as a result of soil management.

2. Materials and methods

The study sites were Campomarino and Venafro, two agriculturally fertile areas in the region of Molise (southern Italy). The land use consists mostly of olive orchards, vineyards, fruit orchards, maize, and horticultural crops. The town of Venafro is located near an important agricultural plain, identified as a nitrate vulnerable zone by the European Community according to the EU Nitrate Directive (91/976/EC). Campomarino is a small farming town in lower Molise. Molise has a typical Mediterranean climate, with mean annual rainfall varying from 600 mm to 1500 mm, and mean annual temperature ranging from 10 to 16° C. Surface soil samples (Ap horizons) were collected to a depth of 0.40 m. A total of 71 samples were collected in Venafro and 63 samples were collected in Campomarino. The variables analysed were: pH, texture, available water capacity (AWC), cation exchangeable capacity (CEC), electrical conductivity (EC), $CaCO_3$ content, total organic carbon (TOC), and total nitrogen (Ntot) according to the standard Soil Methods of Analysis. Nitrate-N was extracted from the field-moist soil samples with 0.1 M KCl solution at a soil:solution ratio of 1:2 and determined colorimetrically.

Statistical data analysis was done in two steps. First, classical descriptive statistics were determined, and then geostatistical analysis was performed to investigate spatial dependence, to map soil variables, and to delineate homogeneous areas.

Even if ordinary cokriging does not require the data to follow a normal distribution, variogram modelling is sensitive to strong departures from normality because a few exceptionally large values may contribute to many very large squared differences. To produce the map of the variables we used multi-Gaussian cokriging (Wackernagel, 2003). The multivariate spatial data were analysed by cokriging and Factor coKriging Analysis (FCKA). The theory underlying FCKA has been described in many papers (Castrignanò et al., 2000; Wackernagel, 2003). The approach consists of decomposing the set of original second-order random stationary variables into a set of reciprocally orthogonal regionalized factors, related to N_S spatial scales. The three basic steps of FKA are the following:

1) modelling the coregionalization of the set of variables using the so called Linear Model of Coregionalization (LMC) and interpolating the variables by cokriging;

2) analysing the correlation structure between the variables by applying Principal Component Analysis (PCA) at each spatial scale;

3) cokriging a set of specific factors at each characteristic spatial scale and mapping them.

All statistical and geostatistical analyses were done by using the software package ISATIS®, release 11.0.

3. Results

The spatial maps of the eight raw variables from the Venafro site, obtained by cokriging on a 10 m x 10 m square grid cell, display distinct spatial patterns and also reveal some degree of spatial association among the different textural attributes. The surveyed area can be roughly divided into two main zones of approximately equal extent along the NW-SE direction. The southern part is characterised by higher clay contents, while the northern part is coarser textured. The spatial maps of the ten raw variables from Campomarino, obtained by cokriging on a 10m x 10m square cell-grid, were better structured spatially, probably due to the impact of topography and soil parent material. As regards the textural properties, the higher contents of sand occur along the sea coast up to a distance of 2500 m inland, whereas clay is more concentrated at the south-east and south-west corners. The maps of Ntot and TOC show a wide area characterized by higher values in the south-eastern part where the soils are manly finer textured. The map of N-NO_3 are more variable, probably due to the impact of agricultural management. There is a wide central inner area characterized by higher values, which means that this area is potentially at risk of contamination (in Figure 1 only some maps are shown).

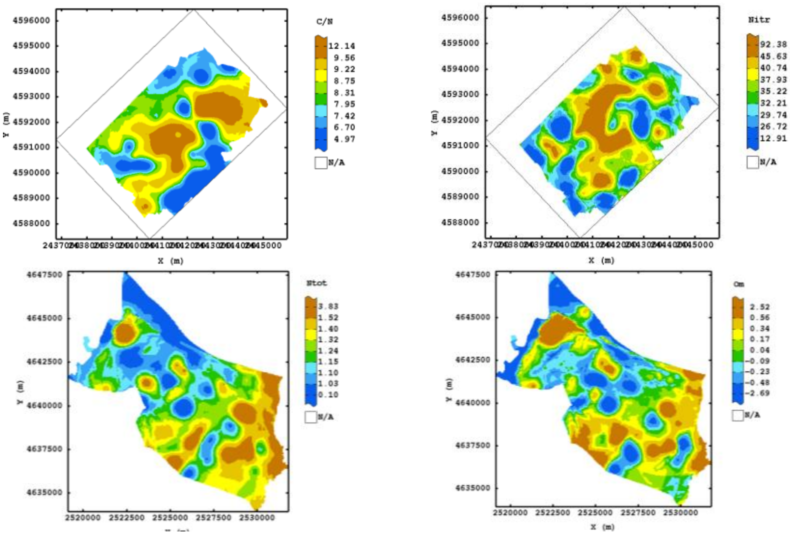
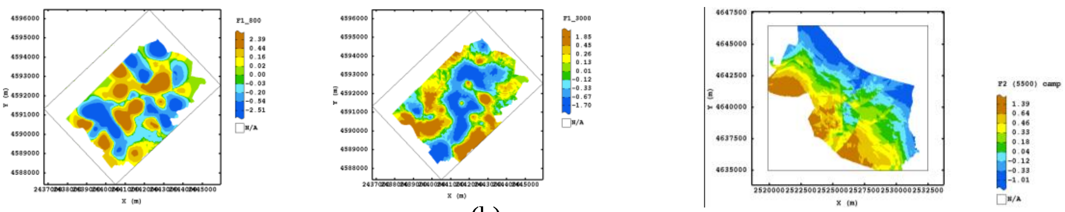


Figure 1. Spatial distribution of C/N ratio and N-NO_3 (Nitr) in Venafro soil (top) and Ntot and TOC (OM) in Campomarino soil.

To synthesize the complex, multivariate variation of the two areas in a small number of zones, to be ranked as to different risks of contamination, the factor cokriging analysis was applied separately to the two data sets from Venafro and Campomarino. The main component of variation for Venafro occurs within a range of 800 m, whereas for Campomarino the spatial variation is dominated by the structured components at both short (1000 m) and long (5500 m) ranges. In the following analysis we have retained only the eigenvectors producing eigenvalues greater than one and omitted the ones corresponding to nugget effect because the latter are mostly affected by measurement errors. Therefore, we focus for Venafro on the first factors at shorter (800 m) and longer scale (3000 m) which account for about 61% and 56%, respectively, of the variation at the corresponding spatial scales. For Campomarino the first two factors at shorter range (1000 m) and the first factor at longer range (5500 m) account for 45%, 25% and 78%, respectively, of the related spatial scale variation. The loading values for the factors (data not reported) indicate that for Venafro the TOC and clay content and, to a lesser extent, Ntot and C/N, as the most influencing first factor at shorter range. On the other hand, CSC and, to a lesser extent, silt content, TOC, C/N, and fine sand weigh more, but negatively, on the first factor at longer range. As for Campomarino, clay content and, to a lesser extent, N-NO_3 weigh more and positively on the first factor at shorter range, whereas TOC and Ntot weigh more on the second factor. The first factor at longer range is quite exclusively dominated by elevation and partially and negatively by pH and $CaCO_3$. Figures 2 a-b show the maps of the two factors for Venafro. The one at short scale looks more variable, characterised by many spots of about 800 m wide with contrasting values of Ntot probably due to differences in land use and management. The soil factor at longer range is more related to CSC and partly to TOC and Ntot contents and looks better structured spatially.



(a) (b) (c)

Figure 2. Maps of the first regionalized factors at shorter and longer range (a-b) of Venafro and of the first regionalized factor at longer range (c) of Campomarino.

The map of the first factor at longer range (Fig. 2c) reproduces the topographic patterns faithfully and shows also a wide area characterized by higher values of $CaCO_3$ and pH at the north-west corner of the area.

4. Concluding remarks

In this study a multivariate geostatistical approach on different soil parameters was used to delineate the zones which might cause contamination by nitrate loss from agriculture soils. The resulting zones were also used to characterise spatial variability in physical and chemical soil properties that may potentially have an impact on soil nitrate contamination. In order to give useful site-specific recommendations to farmers for N fertilization, finer sampling is necessary.

References

Castrignanò A., Giugliarini L., Risaliti R., Martinelli N. (2000) Study of spatial relationships among some soil physico-chemical properties of a field in central Italy using multivariate Geostatistics. *Geoderma*, 97, 39-60.

Marriott C.A., Hudson G., Hamilton D., Neilson R., Boag B., Handley L.L., Wishart J., Scrimgeour C.M., Robinson D. (1997) Spatial variability of soil total C and N and their stable isotopes in an upland Scottish grassland. *Plant Soil*, 196, 151–162.

Power J. F., Schepers J. S. (1989) Nitrate Contamination of Groundwater in North America. Agriculture. *Ecosystems and Environment*, 26, 165–187.

Wackernagel H., (2003) *Multivariate Geostatistics: An Introduction with Application*. Springer Ed., New York, 387.

Webster R. (1985) Quantitative spatial analysis of soil in the field. *Advances in Soil Science*, vol. 3. Springer, New York, 1–70.