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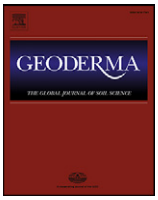

# The effects of land use and landscape on soil nitrate availability in Southern Italy (Molise region)

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## ABSTRACT

The aim of this study was to verify the significance of land use on nitrate availability ($NO_3$–N) at landscape scale in two different sites by using multivariate geostatistical methods. $NO_3$–N and several other soil properties of Nitrate Vulnerable Zone (NVZ) monitoring network of 71 and 63 top-soils, respectively were measured in Venafro and Campomarino areas of Southern Italy (Molise region). Data analysis was performed firstly with classical descriptive statistics assuming spatial independence of samples; secondly, geostatistical analysis was performed in order to investigate spatial dependence and estimate map soil indices. The result of the distribution of $NO_3$–N contents indicates the existence of many hot spots (high kurtosis) with high $NO_3$–N concentration in both the study areas. Higher $NO_3$–N levels in Venafro were distributed in the central zone that appeared to be correlated with animal manure applied to the fields in the summer strongly associated to high values of soil organic matter (SOM) and total nitrogen (Ntot). In Campomarino, the highest $NO_3$–N concentrations occurred in random spots that appeared lesser correlated with high SOM content and low C/N ratio. Factor co-kriging analysis was applied separately to the two data sets to synthesize the complex multivariate variation of the two areas in a restricted number of zones so they could be ranked as at different risks of $NO_3$–N leaching. The loading values of the factors indicate that Venafro SOM and clay and, to a lesser extent, Ntot and C/N are the variables that mainly affect the first factor at shorter range. On the other hand, cation exchangeable capacity (CEC) and, to a less extent, silt, SOM, C/N and fine sand content weighed more, but negatively, on the first factor at longer range. For Campomarino, clay content and available water capacity (AWC) and, to a lesser extent, $NO_3$–N, weighed more and positively on the first factor at shorter range. The first factor at longer range was quite exclusively dominated by elevation and partially and negatively by pH and $CaCO_3$. Soil factor map appears more variable in both the NVZ areas, characterized by many spots indicative of intensive land use and management. The highest $NO_3$–N levels were found in intensive land use and in dairy farming located for the most part in Venafro catchment. The maps of the two factors at small scale for Campomarino appear to be quite erratic owing to the small size of the farms with different cropping systems differently managed. The results, of the present research, provide data useful to support land use planning and soil management, to mitigate soil nitrate leaching. Reduction in soil $NO_3$–N could be achieved by enhancing useful recommendations in N fertilization and animal manure application to farmers.

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## 1. Introduction

Nitrogen is an essential key nutrient needed to increase and maintain worldwide agricultural production. However, over-application of nitrogen fertilizer can contribute to environmental impacts in Europe and in other worldwide regions (Follett and Delgado, 2002). Contamination by nitrate loss by agriculture soils is mainly due to its use in inorganic fertilizers (Stewart et al., 1968) which also results in nitrification processes of reduced forms of fertilizer N (Schepers et al., 1991). Nitrate leaching in intensive agricultural land varies substantially in time and space and is mainly affected by management practices such as fertilizer application, irrigation and planting patterns (Marriott et al., 1997; Sylvester-Bradley et al., 2001; Ju et al., 2006). In addition, differences in N uptake capacity of crops, fertilizer management, and irrigation in different cropping systems may lead to different patterns of nitrate leaching in the soil profile (Power and Schepers, 1989; Rock et al., 2011). The surplus nitrate, derived from large utilization of nitrogenous fertilizers in intensive agriculture, can percolate in relatively large amounts in the aquifer below (WHO, 2004). Over 85 percentage of the agricultural land area in Europe (about 90 million ha) has nitrate levels above the threshold limit (25 mg $L^{-1}$) caused by leaching of nitrate ($NO_3^-$) and approximately 22% (21 million ha) has exceeded the maximum admissible concentration (50 mg $L^{-1}$) for agricultural areas

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**Table 1a**
Characteristics of land use and parent material and the soil samples.

| N. of sample | Location | Altitude (m a.s.l.) | Parent material | Land use | Land use code |
|---|---|---|---|---|---|
| 33 | Campomarino | 46 | Calcarenitic sandstone, limestone, argilleous, siltstone | Fruit tree, olive grove, vineyard (wine) | FOV |
| 11 | Campomarino | 44 | Sandstone | Orticolture | OR |
| 27 | Campomarino | 46 | Limestone, argilleous | Wheat (grain) | W |
| 9 | Venafro | 189 | Alluvial deposit | Olive grove | FOV |
| 36 | Venafro | 173 | Fluvial deposit | Corn (grain) | C |
| 18 | Venafro | 179 | Fluvial deposit, lacustrine deposit | Wheat (grain), | W |

(Addiscott, 2005; Velthof et al., 2009). The principal N input surplus in soil is derived from manures, fertilizers, sewage sludges and crop residues in agricultural areas (EEA, 1995). N fertilizer can be applied as urea or ammonia, as well as nitrate, but the ammonia forms are generally converted rapidly to nitrate in aerobic soils. The proportions of soil nitrogen loss vary between 30% and 60%, and the main N loss is leached below the root zone (Knudsen et al., 2006; Kros et al., 2011). In addition, the excess of nitrate in soil, mainly in dairy and poultry farms, is frequently assumed to be responsible for increased nitrous oxide emissions ($NH_3$, NO or $N_2O$), which contribute to global warming and the destruction of stratospheric ozone (Ambus, 1998; Destouni and Darracq, 2009; Milne et al, 2011).

In 1991, European member states unanimously adopted the Nitrates Directive (EEC, 1991), aimed at reducing and preventing water pollution caused by nitrate runoff from agricultural sources: fertilizers, feedlots, dairy and poultry farms, sewage systems and septic drainage tanks. The Directive also defines Nitrate Vulnerable Zones (NVZs) as the areas of land draining into waters affected by nitrate pollution. In these areas farmers are required to comply with the measures laid out in Action Programmes designed to reduce the amount of nitrogen fertilizer applied. Best management practices (BMP) for intensive, irrigated cropping systems in Italy are based on controlled nitrogen (N) applications with limitation in NVZs (Gardner and Vogel, 2005; Arauzo and Valladolid, 2013). An understanding of spatial–temporal variability of soil and associated crop yield can provide a framework to assess and model the main processes affecting soil nitrate leaching in NVZs. Several studies have investigated the spatial variation of available nitrate ($NO_3$–N) at plot (Cambardella and Karlen, 1999; Ferguson et al., 2002) and field scales (Van Meirvenne and Hofman, 1989; Wadea et al., 2001). Soil physical and chemical properties can vary spatially due to changes in soil parent material and soil position in the landscape (Webster, 1985; Papritz and Webster, 1995). Spatial variation of some of soil chemical properties related to nitrate leaching is not generally well known, whereas these spatial variations should be taken into account in nitrate pollution modeling (Eghball et al., 2003; Pringlea et al., 2008). Examples of the factors whose spatial influences remain relatively constant over time are topography, hydrogeology and soil landscape (Burgess and Webster, 1980; Sogbedji et al., 2001; Thorburn et al. 2013).

On the other hand, agronomic practices and some soil properties must also be considered when changes in the spatial distributions are studied over a short period of time (e.g. one year). Evaluation of soil nitrate availability is a useful tool to support sustainable land planning in order to avoid N supply exceeding crop demand. The knowledge of spatial distributions of nitrate at a landscape scale requires proper tools to investigate which factors significantly affect such distributions and understand the changing scenarios for future agricultural developments (Cambardella and Karlen, 1999; McBratney and Pringle, 1999; Lilburne and Webb, 2002). Regression is one of the most common ways to describe the relationship between nitrate and other soil properties and nominal factors. Ordinary least squares (OLS) regression, the most common statistical procedure used for prediction, assumes normality and independence of errors. However, residuals generally tend to be spatially autocorrelated. Ignoring spatial dependence might significantly impact estimation variances and increase the probability to make type I errors, i.e. to reject the null hypothesis more often than it should. This could lead to critical interpretation errors and consequently lead to incorrect management decisions. Spatial models, based on mixed effect model theory (Stein, 1999; Lark, 2009), which incorporate spatial variability, will then help improve the understanding of the factors that affect nitrate distribution. Therefore, the objectives of this study were: 1) to verify the significance of land use and parent material on $NO_3$–N availability at landscape scale in two different sites by using mixed effect theory; and 2) to relate available nitrate ($NO_3$–N) with specific explanatory soil variables at landscape scale using multivariate geostatistical methods.

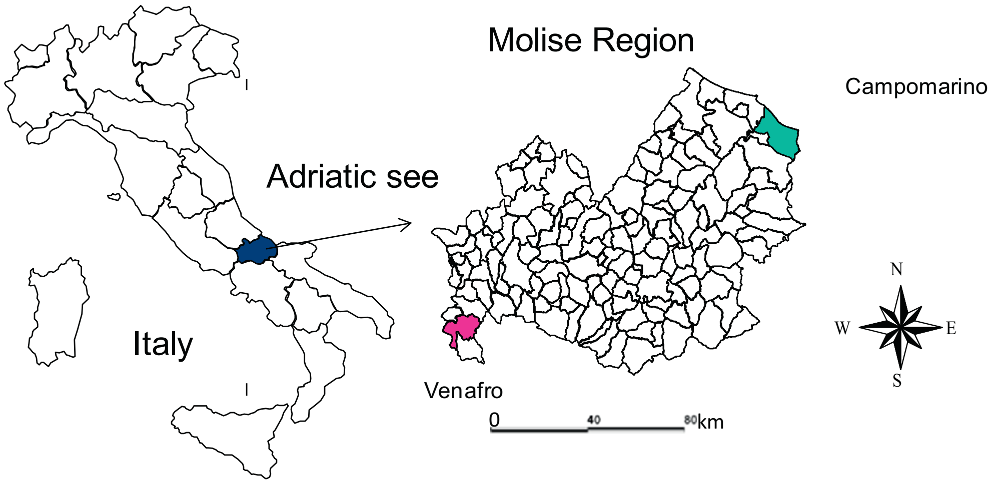

**Fig. 1.** Location of the two agricultural study areas of Venafro and Campomarino (Molise Region, South Italy).

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