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Spatial Variability of Selected Soil Properties in an Olive Orchard in Tarom Region, Zanjan Province, Iran

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Abstract

An experiment was carried out in order to study the spatial variability of soil fertility variables in an irrigated mature olive tree (*Olea europea cv. `Zard'*) orchard. The orchard is located in the Tarom area of Zanjan Province (48° 56′ to 50° 5′ E and 36° 47′ to 37° 36′ N) and is under olive with trees planted 7×7 m. Soil parameters - including K, P, Na, Cl, EC and OM - were determined in soil samples from 0-60 cm depth in late February 2011. A regular 98×98 m sampling grid was established and the intersection points were georeferenced. The data were analyzed using both classical statistics and geostatistical methods. Maps were created as a basis for orchard soil site-specific management. Interpolations were realized according to thresholds and standard deviation of every parameter. Estimates were used to draw variation maps of each soil fertility component based on Kriging method. High geo-distribution variation was detected. The results showed that an important area is menaced by K deficiency. Indeed, in this area soil K was revealed to be under the 70 ppm threshold level. The geostatistical analysis indicated different spatial distribution models and spatial dependence levels for the soil properties. Sodium and OM were strongly distributed in patches. Phosphorous was moderately spatial dependent, and K did not follow a spatial correlated distribution.

Keywords: Spatial Variability, Geostatistical, Soil fertility, Olive tree.

تغییرپذیری مکانی متغییرهای حاصلخیزی خاک در یک باغ زیتون در منطقه طارم استان زنجان، ایران

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چکیده

تغییرپذیری مکانی متغییرهای حاصلخیزی خاک در یک باغ زیتون تحت آبیاری، با درختان رقم زرد، مورد مطالعه قرار گرفت. این باغ در منطقه طارم استان زنجان با مختصات جغرافیایی ۴۸ درجه و ۵۶ دقیقه طول شرقی و ۳۶ درجه و ۴۷ دقیقه عرض شمالی واقع شده و فاصله درختان از هم ۷×۷ متر است. متغیرهای پتاسیم، فسفر، سدیم، کلر، هدایت الکتریکی و ماده آلی در نمونه‌های خاک، از عمق ۶۰-۰ سانتی متر در اویل اسفند ماه ۱۳۸۹ تعیین شد. برای نمونه برداری، یک شبکه منظم شطرنجی به ابعاد ۹۸×۹۸ متر ایجاد شد. نمونه برداری در نقاط تقاطع این شبکه انجام شد و مختصات جغرافیایی نقاط مورد نظر با استفاده از دستگاه سامانه مکان یاب جغرافیایی دستی، تعیین شد. داده ها با استفاده از روش آمار کلاسیک و زمین آمار مورد تجزیه و تحلیل قرار گرفت. نقشه‌هایی با هدف مدیریت ویژه خاک باغ ایجاد شد. درون یابی‌ها با توجه به آستانه و انحراف استاندارد هر متغییر بدست آمد. از محاسبات به منظور ترسیم نقشه‌های تغییرات هر جزء حاصلخیزی خاک بر اساس روش کریجینگ استفاده شد. تغییرات توزیع زمینی بالایی مشاهده شد. نتایج نشان داد که کمبود پتاسیم تهدیدی در منطقه مورد مطالعه است. در واقع، محتوای پتاسیم خاک منطقه مورد مطالعه، سطح آستانه زیر ۷۰ پی‌پی‌ام را نشان داد. تجزیه‌های زمین آماری مدل‌های متفاوتی از توزیع مکانی و سطوح وابستگی مکانی برای متغییرهای خاک نشان داد. سدیم و ماده آلی خاک در بخش‌های مطالعه شده از توزیع بالایی برخوردار بود. وابستگی مکانی فسفر در حد متوسط بود، و پتاسیم از یک توزیع همبسته مکانی پیروی نمی‌کند.

کلمات کلیدی: تغییرپذیری مکانی، زمین آمار، حاصلخیزی خاک، درخت زیتون.

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Introduction

Olive has been cultivated for several thousand years in the world and, recently, olive culture has been expanded to many regions of Iran (Sadeghi, 2002). With the progress made in olive growing during the past two decades, especially on sloping land, cultivation of this crop has been increased to 13000 ha in the Tarom region. The cultivar `Zard' is the main cultivar of olive in this region.

A research study was carried out to determine soil spatial variability and strategies for fertilization in an olive orchard which has 84 trees in Turkey; the soil analyses were realized by using samples taken from grids (Belliturk *et al.*, 2010). Olive is generally grown in well-drained sandy loam, sandy, lime and stony soils; poorly drained soils cause olive root rot. In addition, growing olive in heavy soils is also not successful. Nutrient deficiency in olive trees is a common issue as they are usually grown on hillsides (Damavandi, 2005). Lack of care in taking precautions is a further reason for problems in cultivation (Belliturk *et al.*, 2010). In Iran, the tree is usually grown under poor soil conditions not suitable for field crops and three-quarters of the areas in Iran under olive cultivation are located in hillsides. Soil fertility is often considered invariable at the small scale, such as the olive orchard level. Generally, geomorphic processes associated with erosion and sedimentation cause substantial changes in soil properties, especially along slopes. The application of new crop management techniques, such as precision farming (fertilization) in which inputs are limited to patches where they are needed (Lopez- Granados *et al.*, 2002), may require to be fine-tuned to local variable conditions. However, fertilizers and other crop inputs have been applied to olive orchards without considering the spatial variability, especially of soil fertility, within orchards. Such agricultural management approaches not only increases management costs but may also be harmful to the environment as they may easily lead to the excessive application of chemicals. On the other side, low application of inputs may lead to unsatisfactory and lower than potential yields (Bouma, 1997).

The status of olive orchard productivity throughout the world also appears to be unsatisfactory. About 70% of the olive orchards in the world are managed traditionally and have marginal productivity due to the lack of appropriate management. The new intensive orchards (about 30% of the total) have suitable productivity but are often associated with higher environmental impacts (Michelakis, 2002; Touzani, 1998, 1999). Olive cultivation has been developed during the past two decades in Iran, especially in sloping and marginal lands. This has caused the cultivation area to increase from 30000 ha to approximately 103000 ha (Anonymous, 2011). The Tarom region in Zanjan province is one of the most important regions for olive production in Iran.

In order to characterize soil fertility, we need to rely on those soil characteristics that influence soil behaviour and nutrient availability and are more stable throughout the seasons. Georeferenced soil sampling and laboratory analysis permit us to quantify the variability of soil properties (Adamchuk *et al.*, 2007) and, together with interpolation methods, are used to describe their spatial variation (Pozdnyakova *et al.*, 2005). These techniques are mathematical formulations of the variation of soil properties that serve to minimize prediction error for the observed variables and provide confidence in predictions for the un-sampled locations (Corstanje *et al.*, 2006).

Determining which soil properties to use in defining separate units of relative uniformity is a complex process due to interactions among the various factors that affect crop development. Soil organic matter content is often considered an important factor for its effect on soil physical, chemical, and biological processes (Wu *et al.*, 2008; Adekayode *et al.*, 2009). Other soil properties found to have a strong influence on grapevine development and production were cation exchange capacity (Ping *et al.*, 2008), clay fraction and soil depth (Bodin and Morlat, 2006). It is also feasible to use a mathematical combination of the values of a set of soil properties to build a single continuous variable (Ortega and Santibañez, 2007).

Soil organic matter enhances both olive tree productivity and soil structure, and helps the soil maintain several nutrients in forms available for the roots. Soil water retention capacity is enhanced by the presence of humus and, thus, the tree can better resist water shortage during the dry season (Zucconi *et al.*, 2001). As a result, one can assure the sustainability and the autonomy of olive farming by preserving soil richness in organic matter. Olive trees are reported to grow fairly well on soils containing more than 1% of organic matter (Soyergin *et al.*, 2002), although a threshold of 1.5% is considered to be low under other conditions (Freeman and Carlson, 1994). The amount of soluble phosphate in the soil solution is rather low in comparison to the two engaged forms; i.e. available and unavailable fractions (Richter, 1995). The available fraction is simply adsorbed on the surface of argillaceous minerals, carbonates and apatite and is in balance with dissolved phosphates. This balance is influenced by several factors such as pH, production after organic matter mineralization, and adsorption on the organic molecules. Several researchers have tried to determine the limiting and optimal values of the soil available P concentration. The optimal P range is between 20 and 280 ppm, according to the soil type (Hartmann *et al.*, 1966; Gonzalez and Troncoso, 1972; Llamas, 1984). Potassium is very mobile in soil and is rapidly leached out of sandy soils. The optimal value for soil potassium is between 40 and 400 ppm (Hartmann *et al.*, 1966). However, the minimal threshold for available K in the soil is correlated to clay. These thresholds vary between 80 ppm when clay is less than 15% and 150 ppm under other conditions (Gargouri and Mhiri, 2002).

Taheri *et al.* (2007) found in their study that the most important edaphic problems with the olive orchards of Tarom are organic matter and potassium deficiency. In saline soils, low soil water potential, along with the adverse effects of ions such as chloride, bicarbonate, boron, and especially Na, increase the ratio of Na/Ca, and Na/K in plants and cause an imbalance in nutrient concentration (Cl/NO_3 and Mg/Ca). These are the main factors that reduce plant growth. Under saline conditions, Na and Cl concentrations are usually more than the concentration of other macro- and micro-nutrients which result in nutrient imbalances in soil (Homaei, 2002).

In this study, the spatial variation of soil fertility has been studied. Geostatistics is concerned with detecting, estimating and mapping the spatial variation trends of regional variables, and is centred on the modelling and interpretation of the semivariogram. This method distinguishes variation in measurement separated by the known distance. Semivariogram models provide necessary information about Kriging, which is a method for interpolating data at unsampled points (Lopez-Granados *et al.*, 2002 and 2004). This method has been shown to be a useful method for exploring the structure of the spatial variation of soil quality (Webster and Oliver, 1992; McBratney and Pringle, 1999; Bocchi *et al.*, 2000; Lopez-Granados *et al.*, 2002, 2004). The majority of soil spatial variability studies have been conducted in temperate countries, while little information is available for soils under arid and semiarid Mediterranean conditions (Lopez- Granados *et al.*, 2002, 2004).

The aim of this work, therefore, was to determine if there were any within-field variations and to draw a spatial variability map of the principal soil fertility properties in an irrigated olive orchard located in the Tarom region of Zanjan Province in Iran.

Materials and methods

Location and sampling

The experimental field was located in a 320 hectare irrigated olive orchard located in Tarom region, of Zanjan Province in Iran (between 48° 56′ and 50° 5′ E; and 36° 47′ and 37° 36′ N). The orchard is covered with 15 year-old olive trees *cv* \`Zard'. The trees have been planted at a density of 204 trees/ha (*7×7* m) and the soil is sandy. For soil sampling, *98×98* m grid patterns were established and each intersection point (node) represented a sampling point; a total of 41 sampling points were identified. Soil samples were taken at 0-60 cm depth in mid-July 2011. Four 500g soil cores were taken within a 2 m radius of each grid point and one more core was taken right at the intersection point. The position of each node was georeferenced using a commercial GPS (Garmin Oregon 300, 5 m resolution). These 5 samples were mixed thoroughly to provide a bulked sample and to ensure that it was representative. Soil samples were air-dried overnight and passed through a 2 mm sieve. OM (Organic Matter) was determined by dichromate oxidation using the Walkley and Black method (Pauwel *et al.*, 1992). The Olsen method was used to determine the concentration of available phosphorous (P, ppm). Available K and Na were determined using a flam photometer after extraction by ammonium acetate (Pauwels *et al.*, 1992). Soil EC (Electrical Conductivity) was measured on the soil extract of saturated soil. The data were analyzed using both classical statistics and geostatistical methods.

Statistical analysis

Data were analyzed statistically by SAS 9.1 (SAS Institute, 1992). Classical statistics such as mean, maximum, minimum, standard deviation and the skewness of data distribution were determined. The classical statistics of the soil data suggested that they were all normally distributed and therefore, no transformation was used for geostatistical analysis. Also, a correlation matrix was calculated for all variables.

Geostatistical analysis

A semivariogram model was established for each soil parameter using the following model (Lopez-Granados, 2002, 2004):

$$\gamma(h) = \frac{1}{2N\,(h)} \sum_{i=1}^{N(h)} [z\,(x_i + h) - z\,(x_i)]^{\,2}$$

where γ (h) is the experimental semivariogram value at distance interval h; N(h) is the number of sample value pairs within the distance interval h; z(xi) and z (xi + h) are sample values at two points separated by the distance interval h. All pairs of points separated by distance h (lag h) were used to calculate the experimental semivariogram. The lag *h* was 200 m. Several semivariogram functions were evaluated to choose the best fit with the data. Semivariograms were calculated isotropically. Semivariogram models were fitted by the least squares procedure using ArcGIS software. No nested semivariogram structures were used since adequate fits were obtained using simple structure, spherical, exponential and pure nugget models. The properties of the model - nugget semivariance, range, and sill or total semivariance - were determined. Nugget semivariance is the variance at zero distance; sill is the lag distance between measurements at which one value for a soil property does not influence neighbouring values; and range is the distance at which values of soil properties become spatially independent of the neighbouring values. The ratio between nugget semivariance and total semivariance or sill was used to define different classes of spatial dependence for soil properties (López-Granados *et al.*, 2002). If the ratio was ≤25%, the soil properties were considered to be strongly spatially dependent, or strongly distributed in patches; if the ratio was between 26 and 75%, the soil properties was considered to be moderately spatially dependent; if the ratio was greater than 75%, the soil properties was considered weakly spatially dependent; and if the ratio was 100%, or the slope of the semivariogram was close to zero, the soil properties was considered as not being spatially correlated (pure nugget). Differences between estimated and experimental values were summarized using cross- validation statistics, i.e. MSE (Mean Squared Error). Once cross-validated, the properties of the semivariogram models described above were used to map every soil property for each year by Kriging. Ordinary point Kriging was performed on a regular grid of 24 m and it produced unbiased estimates of soil parameter values at non-sampled points (López-Granados *et al.*, 2002, Godwin and Miller, 2003). Maps were generated using ArcGIS 9.3.

Results

The statistics analysis showed high variation within the orchard and medium coefficients of variation (CV; from 20 to 30%) for P, K, Na, EC, and OM, and 49% for Cl were found. (Table 1).

Pearson's correlation coefficients for soil properties showed highly significant positive correlations between EC, Na and Cl. No significant correlation was found for other soil properties (Table 2).

The geostatistical analysis indicated different spatial distribution models and spatial dependence levels for the soil properties (Table 3): Na and OM were strongly distributed in patches; P was moderately spatial dependent; and K did not follow a spatially correlated distribution. Exponential, spherical, Gaussian, and pure nugget models were fitted to the soil characteristics, finding that K followed the pure nugget model (Table 3) while P, OM and Na followed the spherical spatial distribution model (Table 3). Range values varied from 171.32 m for P to 381.79m for Na.

Gradients appear in the spatial distribution of both Na and OM conversely; the spatial distribution of P was similar to a spot one. The K in the soil varied between 60 and 140 ppm (Fig. 1).

Table 1. Descriptive statistics of soil properties in the 0 -60 cm depth.

Parameter	Min.	Max.	Mean	SD	CV (%)	Skew
K (ppm)	27.000	137.100	83.258	25.37	30.47	1.989
P (ppm)	4.155	10.325	7.225	1.76	24.36	-0.219
Na (ppm)	32.464	103.820	70,248	14.22	20.24	0.399
Cl (meq/100g)	0.820	4.245	1.832	0.90	49.12	3.813
EC (µS/cm)	336.430	756.100	477.120	119.81	25.11	1.108
O.M. (%)	0.244	0989	0.511	0.15	29.35	0.196

Table 2. Pearson's correlation coefficients between soil properties.

		K	P	Na	Cl	EC	O.M.
K		1					
P		0.183	1				
Na		0.186	-0.017	1			
Cl		0.203	-0.142	0.579**	1		
EC		0.173	0.074	0.638**	0.653**	1	
OM		-0.112	0.356	0.292	-0.033	0.278	1

**Significant correlation at the level of 0.01.

Table 3. Geostatistical analysis of the soil properties.

Variable	Nugget/Semivariance Ratio[1] (%)	Sill	Range (m)	Spatial dependence/model[2]	MSE[3]
K	500	500	0	Pure nugget	15770.5
P	0.82	2.16	171.32	**M**, spherical	0.74
Na	0.846	4.3	365.84	**S**, spherical	3.5
OM	0.0012	0.0029	381.79	**S**, spherical	0.00038

1: Percentage of the sill due to the nugget; 2: Spatial distribution (S, strong spatial dependence; M, moderate spatial dependence; Pure nugget: no spatial dependence), and spatial distribution model; 3: MSE: mean squared error expressed as percentage of the sample variance.

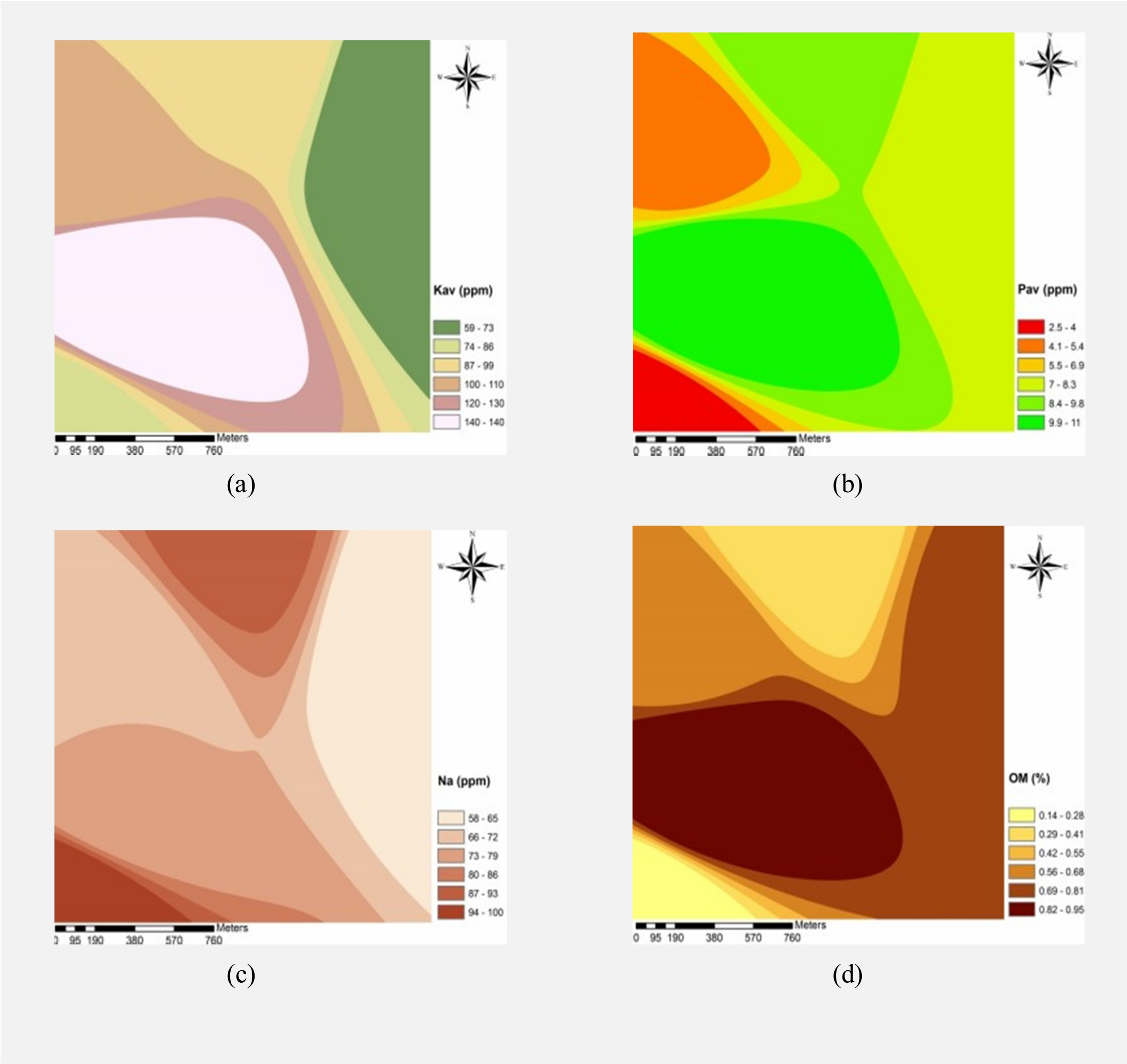

Figure 1. Estimated spatial distribution of (a) K, (b) P, (c) Na and (d) OM.

Discussion

The spatial variation observed in soil properties was not unexpected as it is usually the result of variability in soil properties and management practices. Classical statistics did not show a strong distribution of soil properties and provided values that had medium and large CV in the case of all soil properties (Cambrella and Karlen, 1999; Lopez-Granados *et al.*, 2002). The large nugget semivariance and the non-spatial dependence of K suggest that, apparently, the lag *h* did not characterize the spatial variation and additional samplings of this variable at shorter lag distances and in greater numbers might be needed to detect spatial dependence. Cambrella and Karlen (1999) reported that exchangeable K exhibited three spatial patterns: strong dependence at topsoil (0-0.05 m depth), moderate dependence from a depth of 0.05 to 0.2 m, and no spatial correlation in the lower layer (0.2 – 0.3 m). These results are similar to the results of the present study. Lopez-Granados *et al.* (2002) found a strong spatial dependence for K up to a depth 0.35 m in southern Spain. This phenomenon might be explained by the high mobility of K in sandy soils where cation exchange capacity is low and the risk of nutrient leaching is great due to the heavy rains characteristic of the Mediterranean climate. When the distribution of soil traits is spatially correlated, the average extent of these patches is given by the range of the semivariogram. The various soil properties studied showed high differences between ranges. Our finding is also supported by several other studies (Robertson *et al.*, 1997; Cambarrdella *et al.*, 1994; Lopez-Granados *et al.*, 2002, 2004; Gargouri *et al.*, 2006). A larger range indicates that the observed values of the soil variables are influenced by other values of these variables over greater distances (Lopez-Granados *et al.*, 2002, 2004). Organic matter had a range of more than 300 m indicating that its value has influenced neighbouring values of OM over greater distances than other soil variables. On the other hand, 40% of the whole surface had low K close to the deficiency threshold of 80 ppm (Gargouri and Mhiri, 2002). This situation may lead to the appearance of K deficiency during high demand. The Na concentration is high (more than 90 ppm). On the other hand, 55% of the whole surface had low P close to the deficiency threshold of 8.4 ppm (Gargouri *et al.*, 2006, Gargouri and Mhiri, 2002), with spots having a very low content, i.e. less than 4 ppm. This situation highlights the requirement of K and P fertilization (Gargouri *et al.*, 2006).

Conclusion

The present study provided a first look at using geostatistics and mapping to understand the relationships between some soil fertility components and olive tree nutrition, and should be considered as an initial attempt to better understand their combined influence on olive tree nutrition and production in Iran. However, more work still remains to be done in order to verify this approach and to make it applicable to developing a global comprehensive soil fertility index with ultimate goal of integrating important soil fertility components.

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