Assessment of soil fertility variation in an olive orchard and its influence on olive tree nutrition

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Abstract

Soil fertility variation at olive orchard scale was studied in a rainfed olive orchard located on a topographical sequence in the centre of Tunisia (34.37 N 10.16 E). Soil parameters such as pH, organic matter, gypsum, lime, N, P and K contents and soil electrical conductivity were determined in samples obtained at 1m depth and used to characterize soil fertility. Leaf samples from olive trees (cv Chemlali) 80 yrs old and at squared spacing distance (24x24 m apart) were collected in mid-July 2005 to verify plant nutritional status. A regular 200m x 200m sampling grid was established and the intersection points were georeferenced. Each soil fertility component was analyzed statistically and geostatistically. Interpolations were realized according to thresholds and standard deviation of every parameter. Estimates were used to draw variation maps of each soil fertility component (Kriging method). High geodistribution variation was detected. The results showed that an important area is menaced by K deficiency. Indeed, in this area soil K_2O *content revealed to be under the threshold of 80 ppm. Another area, located in the higher part of the topographical sequence resulted to be affected by a high concentration of sulfates, carbonates and sodium. The study of the relationship between soil and plant concentrations for several nutrients did not allow to single out any correlation. Nevertheless, the carbohydrates allocation in the tree was influenced by soil fertility status. The hypothesis that to overlap stress caused by soil limiting conditions the tree concentrate assimilates in the active parts to increase osmotic pressure is discussed. Under these conditions, olive tree may develop a protection system leading to low reserve carbohydrates and yield.*

Keywords: Soil fertility, Olive tree, Mineral nutrition

Introduction

Soil fertility is often considered invariable at small scale such as olive orchard level. Generally, geomorphic processes associated with erosion and sedimentation cause substantial changes in soil properties, especially along slopes. The soils in a toposequence may differ in quality. For instance, soil depth and nutrients availability are limited in the upper part of the slope due to hard erosion. In Andalusia (Spain) a massive calcic horizon was described near the soil surface with the upper boundary of a toposequence (Galvez et al., 2004). The application of new crop management technique, such as precision farming (fertilization) in which inputs are limited to where they are needed (Lopez-Granados, 2002), may require to be fine-tuned to local variable conditions. Olive growing sustainability in the Mediterranean region is highly dependent on sustainability of soil resource management practices. However, fertilizers and other crop inputs have been applied to olive orchards without considering spatial variability of orchard characteristics, notably soil fertility. Such kind of agricultural management, in addition to cause an increase of costs, may be harmful to the environment because may easily lead to excess in the application of chemicals. Conversely, under-application of inputs may lead to unsatisfactory yields, i.e. under the potentiality of the orchard (Bouma, 1997). The general situation of the olive orchards productivity throughout the World seems to be unsatisfactory. About 70% of the olive orchards are traditional and marginal with a medium to very low productivity due, in a significant degree, to the lack of appropriate orchard management. The new intensive orchards (about 30% of the total) present a suitable productivity but are often associated with higher environmental impacts (Michelakis, 2002; Touzani, 1998, 1999). Until few years ago, Tunisian olive orchards yield was limited by lack of water and unsustainable soil management: excessive tillage for weed control and few organic fertilization. Actually, farmers are making important investments to move to modern olive orchards. These orchards are usually drip-irrigated, fertirrigated and planted with quick-growing young olive plantings. However, farmers still manage their fields regardless of the possible existence of differences in soil fertility.

In order to characterize soil fertility we need to rely upon those soil characters influencing soil behavior and water and nutrients availability that prove to be more stable throughout the seasons. The case of $CaCO_3$ content in the soil may better elucidate this. It is well known that the olive-tree tolerates a wide margin of soil pH, but the neutral, slightly alkaline values to alkaline ones, i.e. between 7 and 8.5, assure its best development (Martinez, 1984; Loussert and Brousse, 1978; Chaves, 1975). This condition is realized in soils with high calcium carbonate content, between 10 and 30% (Chaves, 1975). The $CaCO_3$ may reduce the olive tree vigour through its effect on the availability of P, Zn, Cu Mn, Fe and B via different mechanisms (Galvez et al., 2004; Fernandez-Escobar et al., 1993; Benitez et al., 2002). However, excellent yield and vegetative growth can be observed, in both soils with small amount of limestone and where this amount reaches 50%, with a limit of 76% (Llamas, 1984; Chaves, 1975; Belkhodja, 1972). With regards to this wide margin of $CaCO_3$ content tolerated by the olive tree, this parameter seems not to be suitable for soil fertility evaluation. Soil organic matter content enhances both olive tree productivity and soil structure, and helps the soil to maintain several nutrients in available forms for the roots. It limits erosion, nutrient leaching (N), precipitation (P) and inactivation (Fe). The soil water retention capacity is enhanced by the presence of humus and, thus, the tree can better resist to rain shortage during the dry season (Zucconi et al., 2001). Thus, one can assure the sustainability and the autonomy of olive farming by preserving soil richness in organic matter. The olive trees are reported to grow quite well on soils containing more than 1% of organic matter (Soyergin et al., 2002), even if a threshold of 1.5% is considered low in 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: available fraction and unavailable one (Richter, 1995). The available fraction is simply adsorbed on the surface of argillaceous minerals, carbonates and apatite among others and it is in balance with dissolved phosphates. This balance is influenced by several factors like the pH, the production after organic matter mineralization and adsorption on the organic molecules. Several authors tried to determine the limiting and optimal values of the soil available P concentration. Optimal contents of P_2O_5 range between 20 and 280 ppm, according to soil type (Hartmann et al., 1966; Recalde, 1975; Gonzalez and Troncoso, 1972; Llamas, 1984). All these proposed values were based on analytical results obtained by different methods. In previous works carried out in Tunisia we found 8 ppm as critical level (Gargouri and Mhiri, 2002). Potassium is very mobile in the soil and is rapidly leached in sandy ones. The optimal values for potassium soil content are between 40 and 400 ppm (Pansiot and Rebour, 1960; Hartmann et al., 1966; Gonzalez and Troncoso, 1972; Recalde, 1975). However, the minimal threshold for available K content in the soil is correlated to clay content. These thresholds are of 80 ppm when the clay content is less than 15% and 150 ppm in the other case (Gargouri and Mhiri, 2002). The olive tree is able to compensate, partially, the lack of P_2O_5 and K_2O in the soil by the exploitation of a huge soil volume (Loussert and Brousse, 1978). On the other hand, leaf and wood carbohydrates concentration may act as a good indicator of tree nutrition level (Latt et al., 2001). The adequate level of carbohydrates (total sugar) are 4.2 and 3.4 respectively in leaves and wood (Ulger et al., 2004).

In this paper the spatial variation of soil fertility traits on a toposequence has been studied. Geostatistics is concerned with detecting, estimating and mapping the spatial variation trends of regional variables, and is centered on the modeling and interpretation of the semivariogram. This method distinguishes variation in measurement separated by known distance. Semivariogram models provide the necessary information for Kriging, which is a method for interpolating data at unsampled points (Lopez-Granados et al., 2002). They had proven to be useful methods to explore the structure of the spatial variation of soil quality (Lopez-Granados et al., 2002; McBratney and Pringle, 1999; Webster and Oliver, 1992). Most soil spatial variability has been assessed in temperate countries, while few information is available for soils under arid and semiarid Mediterranean conditions (Lopez-Granados et al., 2002). The objectives of this study are to assess and to map spatial variability of principal soil fertility traits in an olive orchard on a toposequence located in the Center of Tunisia under arid conditions.

Material and Methods

Study area, sampling and laboratory analysis

The olive orchard used for this study is located on a toposequence in central Tunisia (Sfax region - 34.37 N 10.16 E). The orchard covers 134 ha and belongs to Chaal farm, the biggest olive farm in Tunisia with more than 17.000 ha. The trees of the cv Chemlali, 80 yrs old, with very low plantation density (24x24 m apart =17 trees/ha), are conducted under rainfed conditions. The soil is sandy (more than 90% of sand). The fertilization plan consists of 3 – 4 Kg of NH_4NO_3 per tree distributed in spring and autumn (1:2). For soil analysis a 200x200 m grid pattern was established; each intersection point (node) represented a sampling point. A total of 27 sampling points were identified. Soil samples were taken at 1 m depth in mid-July 2005. Each soil sample was collected as follows: four 500g soil cores were taken within 2 m radius of each grid point and one more core right at the intersection point. The position of each node was geo-referenced. These 5 samples were mixed thoroughly to provide a bulked sample and to ensure its representativeness. Soil samples were air-dried overnight and passed through a 2 mm sieve. Organic matter content was determined by dichromate oxidation using Walkley and Black method (Pauwel et al., 1992). Total lime content was determined after application of HCl and measurement of CO_2 produced volume. Olsen method was used to determine available phosphorous concentration (P, ppm). Available K and Na were determined using flam photometer after extraction by ammonium acetate (Pauwels et al., 1992). Soil electrical conductivity was measured on the soil extract saturated soil. Leaf and wood samples were taken in July from four trees for each sampling point. Sugar content was determined following sulfuric acid – phenol method (Robyt and White, 1987).

Statistical analysis

Data were analyzed statistically. Classical descriptors were determined, such as mean, maximum, minimum, standard deviation and skewness of data distribution. The descriptive statistics of the soil data suggested that they were all normally distributed (skewness of data between 2.8 and -0.7) and therefore no transformation was used for geostatistical analysis. Also, correlation matrix was calculated for all variables.

Geostatistical analysis

A semivariogram was established for each soil parameter using the following model (Lopez-Granados, 2002, 2003; Journel and Huijbregs, 1978):

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

Where γ(h) is the experimental semivariogram value at distance interval h; N(h) the number of sample value pairs within the distance interval h; z(xi), z (xi + h) 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 square procedure using VARIOWIN software. No nested semivariogram structures were used, as adequate fits were obtained with a simple structure

Spherical, exponential and pure nugget models were fitted to the empirical semivariograms. The parameters 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 leaf nutrient does not influence neighboring values; and range is the distance at which values of leaf nutrient become spatially independent of the neighboring values. The ratio between nugget semivariance and total semivariance or sill was used to define different classes of spatial dependence for leaf nutrients (López-Granados et al., 2002). If ratio was ≤25%, the leaf nutrient was considered to be strongly spatially dependent, or strongly distributed in patches; if ratio was between 26 and 75%, the leaf nutrient was considered to be moderately spatially dependent; if ratio was greater than 75%, the leaf nutrient was considered weakly spatially dependent; if the ratio was 100%, or the slope of the semivariogram was close to zero, the leaf nutrient was considered as not being spatially correlated (pure nugget). Semivariogram models were cross-validated (trial-and-error procedure) by comparing leaf nutrient values estimated from the semivariogram model with actual values. Differences between estimated and experimental values are summarized using the cross-validation statistics, i.e., mean squared error (MSE). Once cross-validated, the parameters of the semivariogram models described above were used to map every leaf nutrient 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 value at unsampled points (López-Granados et al., 2002). Kriging was carried out using Kriging Interpolator 3.2 software, and contour maps were generated using Arcview GIS 3.2.

Results

The summary of descriptive statistics of soil parameters shows high variation within the orchard. Medium coefficients of variation (CV from 16 to 49%) for P, K, Na, electrical conductivity (EC), and organic matter (O.M.), and high CV (> 50%) for Cl and lime were found. Potassium and P minimum values indicate the presence of deficient zones in the toposequence (Table 1).

Table 1. Descriptive statistics of soil parameters in the 0 – 1 m depth layer.

	Min.	*Max.*	*Mean*	*SD*	*CV (%)*	*Skew*
K (ppm)	*36.000*	*149.000*	*73.568*	*24.93*	*33.90*	*1.059*
Na (ppm)	*49.667*	*107.670*	*7.,238*	*15.31*	*20.62*	*0.466*
EC (µS/cm)	*316.500*	*850.000*	*484.200*	*139.21*	*28.75*	*1.428*
Cl (meq/100g)	*0.600*	*5.383*	*1.420*	*1.00*	*70.42*	*2.835*
P (ppm)	*3.074*	*11.271*	*7.323*	*1.56*	*21.30*	*-0.220*
O.M. (%)	*0.209*	*0.575*	*0.391*	*0.10*	*25.58*	*0.248*

Correlation matrix for soil traits shows a highly significant positive correlation among electrical conductivity (EC), Na and Cl content. No significant correlation has been found for all the other pairs of soil parameters (table 2).

Table 2. Correlation matrix between soil traits pairs

		K	*Na*	*EC*	*Cl*	*P*	*Lime*	*O.M.*
K		1						
	Sig.							
Na		0.185	1					
	Sig.	0.355						
EC		0.171	0.618**	1				
	Sig.	0.393	0.001					
Cl		0.203	0.569**	0.663**	1			
	Sig.	0.310	0.002	0.000				
P		0.184	-0.017	0.084	-0.142	1		
	Sig.	0.357	0.934	0.676	0.479			
O.M.		-0.112	0.292	0.268	-0.023	0.356	0.132	1
	Sig.	0.578	0.139	0.176	0.911	0.068	0.511	

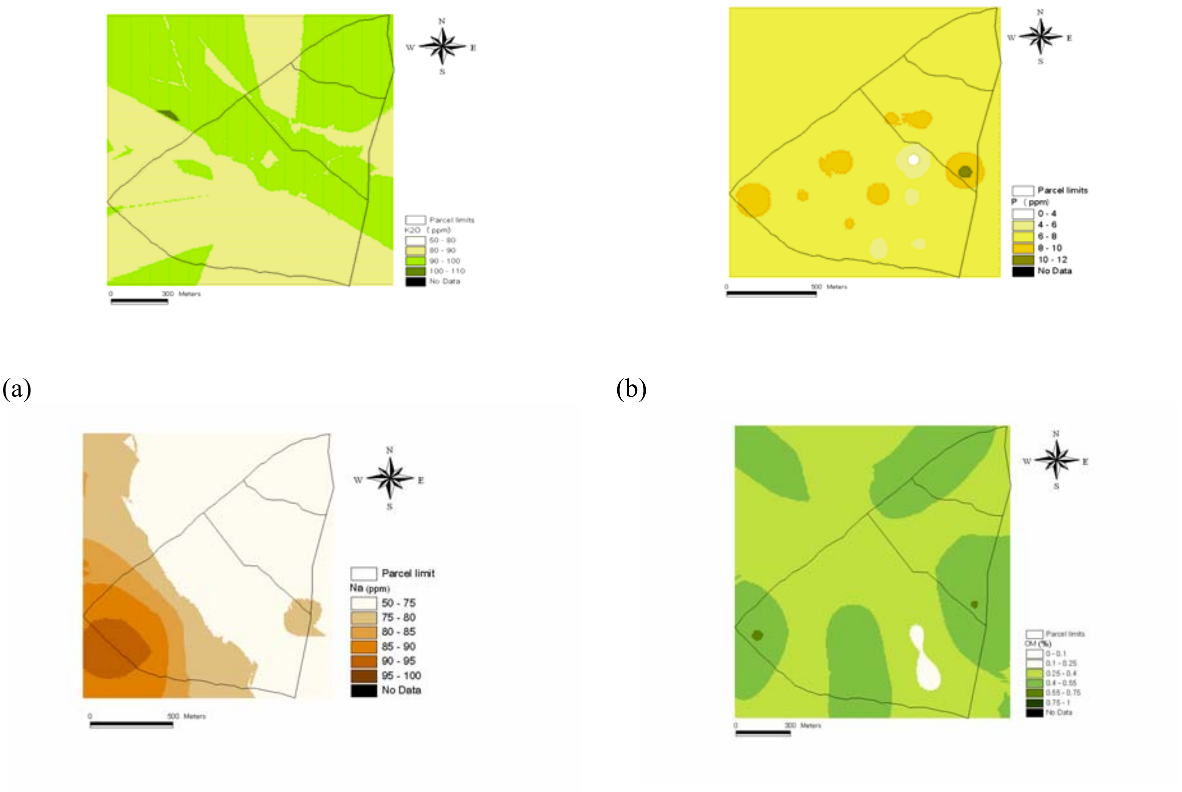
** Significant correlation at the level of 0.01 (bilateral).

The geostatistical analysis indicated different spatial distribution models and spatial dependence levels for the soil properties (Table 3). Sodium, lime, and O.M. were strongly distributed in patches. Phosphorous was moderately spatial dependent, and K did not follow a spatial correlated distribution. Exponential, spherical, Gaussian, and pure nugget models were fitted to the soil characteristics. Potassium followed the pure nugget model (Table 3); P, O.M., and Na followed spherical spatial distribution model (Table 3). Range values varied from 182.21 m (P) to 411.88 m (O.M.).

Gradients appear in the spatial distribution of both Na and O.M.. Conversely the spatial distribution of P_2O_5 seems like a spot one. The K_2O content in the soil varies between 80 and 100 ppm, and the parcel is divided in two parts. Half of the total surface has a soil concentration between 80 and 90 ppm (figure 1).

Table 3. Geostatistical analysis of the leaf nutrients in the two sampling years

Parameter		*Nugget Semivariance Ratio*[a] (%)	*Still*	*Dependence level* (%)	*Range* (m)	*Spatial distribution model*[b]	*MSE*[c]
K_2O		600	600	100	0	Pure nugget	16760.5
Na		0.946	4.3	22	355.84	S, spherical	5.5
P_2O_5		0.72	2.16	33.3	182.21	M, spherical	0.64
O.M.		0.0014	0.0039	15.1	411.88	S, spherical	0.000026
Carbohydrates	leaves	0.00009	0.00257	3.5	293.80	S, spherical	0.00000013
	wood	0.009	0.009	100	0	Pure nugget	0.00000067

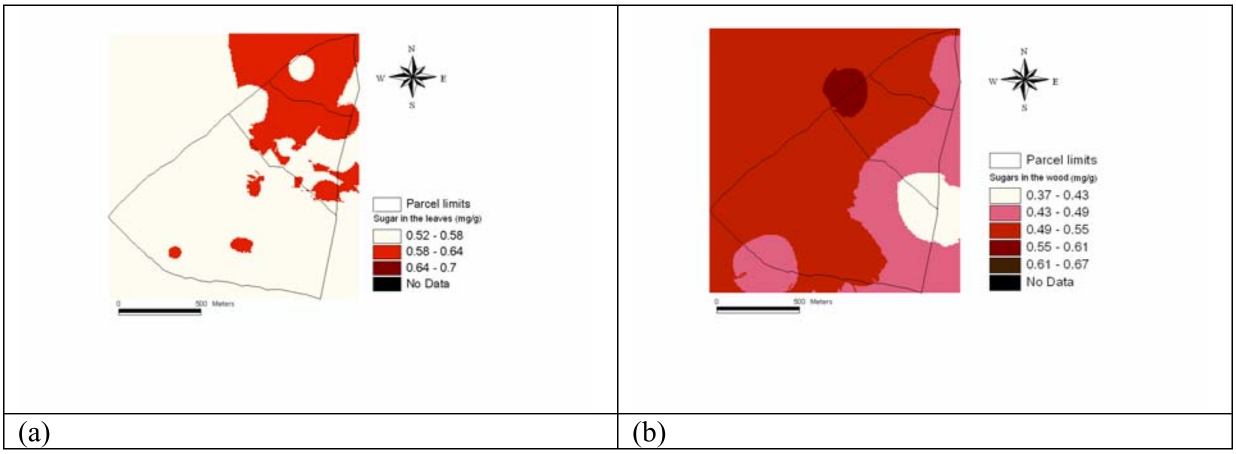


(a) (b)

(c) (d)

Figure 1. Maps of estimated (a) K; (b) P; (c) Na; and (d) O.M. spatial distribution.

Carbohydrates contents in both leaves and wood were used to estimate plant nutrition level. Carbohydrates concentration in the leaves exhibited a strong spatial distribution (Table 3) and followed spherical models. In contrast, the spatial distribution of wood sugars concentration followed pure nugget model. Sugar leaf concentration was above 0.50 mg/g DM, with very small variation on the whole surface: from 0.50 to 0.64 mg/g; in the wood, this concentration was under 0.50 mg/g in an important part of the toposequence, with more variation than in the leaves: from 0.37 to 0.67 mg/g.



(a) (b)

Figure 2. Maps of estimated (a) sugar concentration in the leaves; (b) sugar concentration in the wood, spatial distribution.

Discussion

The spatial variation observed in soil parameters should not be surprising, since the values of variables are usually the result of an intrinsic variation in soil properties and management practices. Idem the plant nutrition indicators variation is caused by intrinsic variation in plant organs and environmental influence (Mallarino et al., 1999). Classical statistics did not show the strongly patchy distribution of soil parameters and provided mean values that produced medium and large CV for all the soil properties. Lopez-Granados et al. (2002), Cambrella and Karlen (1999) and Geypens et al. (1999) found similar general trends and reported CV in agreement with those reported in this study. The large nugget semivariance and the non-spatial dependence for K, suggest that the lag h apparently did not characterize the spatial variation, and that an additional sampling of this variable at smaller lag distances and in larger number 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 from 0.05 to 0.2 m depth, and no spatial correlation in the lower layer (0.2 – 0.3 m). These results are similar to those reported in this study where sampling had concerned the 1 m depth layer. They hypothesized that intrinsic variations, such as intensive tillage, may control the strongly spatially dependent soil variables. However, Lopez-Granados et al. (2002) found a strong spatial dependence for K until the depth of 0.35 m in southern Spain. This phenomenon might be explained by high mobility of K in sandy soils with low cation exchange capacity, which can be accentuating leaching effects of strong rains characterising 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 different studied soil parameters showed high differences between ranges. This finding has been reported by several other studies (Lopez-Granados et al., 2002, Cambarrdella et al., 1994, Robertson et al., 1997). A larger range indicates that observed values of the soil variable are influenced by other values of this variable over greater distances than soil variables which have smaller ranges (Lopez-Granados et al., 2002). Organic matter content had a range of more than 400 m, that indicates that its values influenced neighbouring values of O.M. over greater distances than other soil variables. On the other hand 50% of the whole surface of the toposequence had low K_2O content which is near the limit threshold of 80 ppm (Gargouri and Mhiri, 2002). This situation may lead to the appearance of K deficiency during high demand periods specially in the southern part of the toposequence where the Na concentration is high (more than 90 ppm). Near the whole surface the toposequence has soil phosphorus content under the threshold of 8 ppm (Gargouri and Mhiri, 2002) with the presence of spots with very low content, i.e. less than 4 ppm. This situation raises the necessity of P and K fertilization, and, in the case of potassium, precision fertilization may be used. One can notice the very low organic matter content especially in the south-eastern part of the toposequence.

Geostatistics applied to leaf sugar content showed that this variable is strongly spatial dependent. Conversely, wood sugar content is slightly spatial dependent and the applied model is the pure nugget.

Thus, the sugars content in the leaves seems to be dependent of the spatial distribution of some soil properties. The highest leaf sugar contents had been observed in the area with better K contents. On the other hand, it was found that wood sugar content was low in areas with high Na content. This phenomenon may be caused by the concentration of these assimilates in leaves to balance the stress caused by the presence of Na. Similar results had been described by Krueger (1994).

This study provided a first look on using geostatistics and mapping to understand the relationship between some soil fertility components and olive tree nutrition and should be considered as a first attempt to better understand the combined influence on olive tree nutrition and production of some soil fertility components. However much work still remains to be done in order to verify this kind of approach and to make possible in the future the development of a global, comprehensive Soil Fertility Index to integrate all significant soil fertility components.

Acknowledgments

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