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Spatial Variation Assessment of Selected Soil Properties for Precision Field Experimentation

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Abstract

Spatial variation and status of selected soil properties were assessed in a small-sized field, cultivated with irrigated corn. A geo-referenced sampling was performed and twenty four soil samples were collected from two depths (0-30 and 30-60 cm) from 12 different locations in order selected soil properties to be determined. Despite the small parcel size, soil properties exhibited a spatial variability, with coefficient of variance (CV) ranging between 7.0 and15.4% for soil texture, 9.9-12.9% for Cation Exchange Capacity (CEC), 12.8-16.8% for organic carbon (C_{org}) and 15.7-20.6% for total nitrogen (N_{tot}). CV for Bulk Density (BD) and pH were very low in both soil depths indicating rather high stability.CEC, Corg and N_{tot} mean values were higher in the top soils. Increased values for pH, clay and $CaCO_3$ contents in the subsurface samples, may be attributed to partial leaching of exchangeable bases and $CaCO_3$. A strong relation between N_{tot} and C_{org} found indicating that these elements are mainly bound in the soil organic matter (SOM). A strong negative relation also was recorded between clay content and bulk density (BD) of soils, indicating that BD depends primary on soil texture. In addition, other soil properties showed very low or absence of correlation between each other. Prediction maps have indicated variation in soil properties partially caused by different farming practices. The interpolated maps showed clear differences mainly on Clay, $CaCO_3$, SOM, N_{org}. and EC across the surveyed area. Application of a simple ordinary kriging clearly demonstrated the spatial variability of soil properties, which should be taken into consideration for designing field experiments, particularly when split-plot factorial block designs are to be used. As shown in this investigation, this can be realized with decreased field work, and lower total cost for laboratory analyses.

Keywords: soil; field; nutrients; horizon; coefficient of variation.

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1. Introduction

Soil heterogeneity is generally the main factor of variability in farm trials and in many cases there is a great difficulty of its interpretation. Spatial variability of soil properties is inherent in nature variation due to geologic and soil forming factors and part in cultivated soils may be attributed to tillage, fertilization, irrigation, soil leveling e.t.c. It is well known that soil is a non-uniform medium and variability is a direct result of the soil forming factors. Micro-variability of soil properties is a phenomenon which becomes more interesting for researchers working on crop production, fertilization practices or irrigation schemes. Spatial variability in soil properties, nutrient levels, and water content has been well documented [1, 2]. It was found that grain yield, electrical conductivity, Ca, K, Mg, and Na can exhibit significant and large-scale variability within a small area of relatively low topographic relief [1]. Soil variability is also very important in studies related to ecological modeling, environmental assessment and risk, precision farming, and rational management of soil and water resources. The knowledge of the spatial variability particularly in cultivated areas, provides helpful information for a more rational soil use and management [3]. This work conducted in the experimental field of the University of Thessaly, located in Velestino area in the Prefecture of Magnesia, Central Greece (coordinates: $39^{o}2'$N, $22^{o}45'$ E) at an altitude of 70 m a.s.l. The soils of the greater farm area were surveyed in a previous work and six representative soil profiles were studied [4], within a depth >1.5 m, and described according to Soil Survey Staff,1993 [5]. The present study includes only one soil profile in the experimental area, and it was considered typical to take a sufficient number of soil samples to assess soil properties and their variation. In addition, laboratory determinations were performed on those soil properties that affect crop yields e.g. soil texture, pH, macro nutrients, trace elements, electrical conductivity, etc.

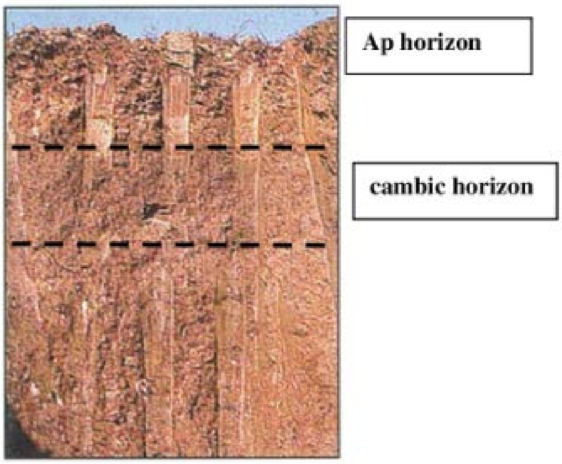

Figure 1: Typical soil profile in the experimental field

The study area has been formed from deposits of dried Lake Karla and is characterized from the partial leaching of calcium carbonate from the surface horizons. The above soil profile (Figure 1) belongs to the order of *Inceptisols*, sub order of *Ochrepts* and according to Soil Taxonomy, 1999 [6] was classified as *Fluventic xerochrept* [7]. Based on main characteristics, and soil colour, parent material, the soil structure development and partial leaching of carbonates, according to the World Reference Base for Soil Resources [7] has been classified as *Calcaro vertic Cambisol* (CMvr). The main objectives of this study were (i) to assess the magnitude of spatial variability of selected soil properties of field cultivated with irrigated corn (ii) to explore the possibilities of the ordinary kriging to demonstrate the spatial variability of the examined properties, which should be taken into consideration for proper establishment of farm experiments to decrease number of samples, laborious field work and laboratory determinations and (iii) to study the status of nutrients and to develop statistical correlations among the measured soil parameters.

2. Materials and Methods

The experimental farm is level (slope <1%), consists of heavy soil texture and was formed from lacustrine deposits of the dried lake Karla. Sampling was carried out within two soil depths 0-30 and 30-60 cm, in order to assess the dispersion of soil properties among samples and the differences between the two depths. Composite soil samples were collected from each location, after mixing of 3- 4 samples taken from the same depth. Samples were carried to the laboratory, air–dried, crushed and passed through a 2 mm sieve. The sampling plan indicated in Figure 2 was used in order to study spatial soil variability, which includes an adequate number of samples to achieve the objectives of this research. Particle-size distribution was determined by the Bouyoucos hydrometer method [8]. Dry bulk density was measured in undisturbed samples, using metal rings of known volume [9]. Cation exchange capacity (CEC) was determined by the ammonium acetate method [10]. The pH values were measured in a 1:1 soil–H_2O suspension [11] and the exchangeable potassium (K^+) and sodium (Na^+) were determined with a flame photometer, after extraction with acetic ammonium (CH_3COONH_4) 1N, at pH 7.0 [12].

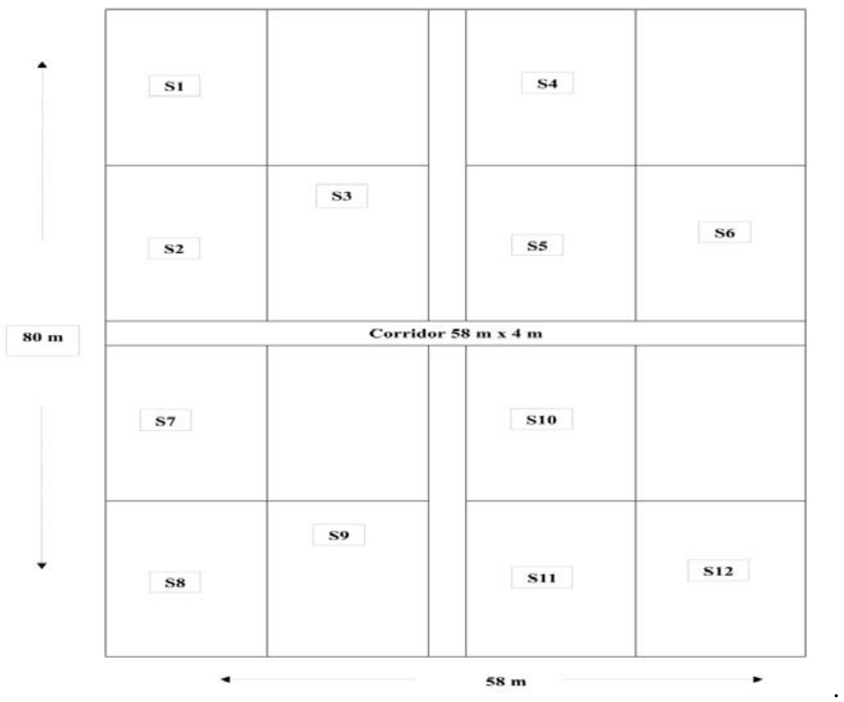

Figure 2: Experimental field and sampling sites (39^{O}02′N, 22^{O}45′E, 70 m a.s.l.)

A modified wet-digestion Walkley and Black method [13] was used for the organic-matter determination. Electrical Conductivity (EC) was measured in soil paste by using an EC meter and the units of measurement are expressed in µS/cm. Soil carbon (C), and total soil nitrogen (N) were determined in the fine ground (<80 mesh) soil samples by elemental analyser. Organic carbon content was estimated as the difference between the total and inorganic form. Soil carbonates were determined by using the volumetric calcimeter method [14]. Plant available phosphorous was measured in the alkaline soils by the Olsen method [15].Variability was estimated using samples from two depths and coefficient of variation (CV) gives a normalized measure of spread about the mean and was estimated using the following equation:

$$\mathrm{CV} = \frac{STD}{m} x100\%$$

where; STD = standard deviation, which is the square root of the sample variance.

m = is the mean value of the population..

Wilding (1985) described a classification scheme for identifying the extent of variability for soil properties based on their CV values, in which CV values of 0-15, 16-35 and > 36% indicate low (least), moderate and high variability, respectively. Also, a method was proposed [16] and a more detailed range in values for CV of the properties are showed in Table 1.

Table 1: Typical range in values for coefficient of variation of selected soil properties (adapted from Mulla and Mc Bratney, 2000)

Property	CV%	Magnitude of variability
pH	2-15	Low
BD	3-26	Low to Moderate
SOM	21-41	Moderate to High
Sand	3-37	Low to moderate
Clay	16-53	Moderate to High
K	39-157	High
P	39-157	High
EC	91-263	High

For the purpose of deciding whether or not data follow the normal frequency distribution, it may be enough to examine the coefficients of skewness and kurtosis. Normality of data was also assessed using the Kolmogorov–Smirnov test before geostatistical analysis. Furthermore, thematic maps concerning the distribution of soil properties (nutrient elements etc.) were compiled by using a Geographical Information System. Ordinary kriging was conducted with ArcGIS 10 to predict soil characteristics at unsampled locations in order to compile prediction maps.

3. Results and Discussion

The majority of soil properties exhibited low coefficient of variation (CV) according to the guidelines and ranges [16, 17] for both soil depths (Table 2, Table 3). Soil pH and BD are among the least variable soil properties for both soil depths, while EC in the top soils CV was 41.9%. The CV values of pH were also very low and estimated 3.4% in studies conducted in North Dakota, USA [18]. Table 2 and Table 3 summarize the results for all soil samples and parameters determined for both surface and subsurface horizons. It can be argued that despite the small size and the uniformity of the study site, a spatial variability for sand, silt and clay content was apparent as reflected by the variation coefficients ranging in the top soils in the orders of 7.0-11.5%. The respective values were 9.9% for CEC, 12.8% for SOM and C_{org}, and 16,1% for $CaCO_3$ content (Table 2). Table 1 shows variations which are classified as “low” due to rather uniform parent material and the small size of the experimental farm. Obvious exceptions comprises the almost invariable bulk density and pH of both top and subsoil with very low values (Table 2, Table 3), apparently due to the low texture variation and the similar farming practices. The results demonstrate that selected soils have a texture with a similar mean sand (25.4-26.3%) and silt (32.6-33.9%) fractions in both depths and a low spatial variability CV<15.0% (Table 2, Table 3). Mean clay content in the surface layers was 39.7% and showed a “low” spatial variation with a CV=7.0%, while the respective mean clay content of the subsurface horizons was 42.0% and CV was 7.2%; this difference in texture, although not significant, may be attributed to factors related to increased SOM of topsoils, and anthropogenic activities such as plowing and rotation schemes, conducted in previous periods.. The mean content of organic carbon in surface samples was low (mean 14.51 g/kg), while the respective mean value for subsurface was 8.67 g/kg (Table 2, Table 3). It can be argued that the prevailing *xero thermic* conditions and intensive farming enhanced the decay of SOM, hence these factors have affected the decreasing of SOM. The average total N content in the surface samples is low and exceeds 1,660 g/kg (Table 2), while the respective concentration in the subsurface samples is 1,020 mg/kg (Table 3). Similar values were recorded at two soils classified as *orthic luvisols* in Czech Republic [19].

Skewness is the most common statistical parameter to identify a normal distribution and results for surface samples range from -0.59 to +1.92, while skewness varied from −1.54 to 1.48 in subsurface samples, indicating that certain soil properties especially C_{org}, were affected by soil management practices [20]. Kurtosis for topsoils ranged from –1.50 to +4.17, and the respective values for subsoil samples ranged between -1.46 and +2.37. The values for asymmetry and kurtosis between *-2* and *+2* are considered acceptable in order to prove normal univariate distribution [21].

Table 2: Descriptive statistics of surface soil properties at the experimental site

samples	**Particle size distribution**			**texture**	**BD**	**CEC**	**pH**	**EC**	**Corg.**	**N**	**SOM**	**CaCO3**
	Sand (%)	**Silt %)**	**Clay (%)**		g/cm^3	**cmol/kg**		**mS/cm**	**g/kg**	**g/kg**	**%**	**%**
S1a	21.6	40.4	38.0	Clay	1.28	33.7	7.6	2.05	17.78	1.90	3.56	9.33
S2a	23.6	36.4	40.0	Clay	1.27	31.0	7.7	1.34	16.07	1.81	3.21	7.30
S3a	24.4	37.2	38.4	Clay	1.28	30.4	7.7	1.29	15.84	2.00	3.17	7.92
S4a	26.0	38.0	36.0	Clay	1.29	27.7	7.6	2.93	13.89	1.27	2.78	8.62
S5a	29.2	32.8	38.0	Clay	1.29	31.5	7.8	0.956	10.91	1.29	2.18	8.62
S6a	30.4	34.4	35.2	Clay	1.31	27.2	7.8	1.12	12.49	1.57	2.50	7.04
S7a	24.4	36.4	39.2	Clay	1.28	27.2	7.6	1.28	14.80	1.63	2.96	7.48
S8a	26.0	30.8	43.2	Clay	1.27	25.0	7.7	0.977	13.89	1.39	2.78	7.04
S9a	30.4	28.4	41.2	Clay	1.28	26.6	7.6	1.24	13.23	1.44	2.65	8.18
S10a	28.8	30.0	41.2	Clay	1.28	25.3	7.7	1.23	14.07	1.78	2.81	6.51
S11a	28.4	29.2	42.4	Clay	1.27	25.8	7.6	1.55	16.34	1.92	3.27	6.60
S12a	22.8	33.2	44.0	Clay	1.26	26.4	7.6	0.763	14.80	1.86	2.96	4.84
Mean	**26.3**	**33.93**	**39.7**		**1.28**	**28.15**	**7.67**	**1.39**	**14.51**	**1.66**	**2.90**	**7.46**
Median	**26.0**	**33.8**	**39.6**		**1.28**	**27.20**	**7.65**	**1.26**	**14.44**	**1.71**	**2.89**	**7.39**
SD	**3.04**	**3.83**	**2.77**		**0.013**	**2.8**	**0.078**	**0.58**	**1.86**	**0.26**	**0.37**	**1.20**
SE	**0.88**	**1.11**	**0.80**		**0.004**	**0.81**	**0.02**	**0.17**	**0.54**	**0,075**	**0.11**	**0.35**
KURTOSIS	**-1,43**	**-1.12**	**-0.88**		**1.97**	**-0.50**	**-0.79**	**4.17**	**0.21**	**-1.5**	**0.24**	**0.90**
SKEWNESS	**-0,01**	**0,06**	**-0.07**		**0.941**	**0.82**	**0.72**	**1.92**	**-0.17**	**-0.29**	**-0.17**	**-0.59**
CV%	**11.5**	**11.3**	**7.0**		**1.0**	**9.9**	**1.0**	**41.9**	**12.8**	**15.7**	**12.8**	**16.1**

Table 3: Descriptive statistics of subsurface soil properties at the experimental site

samples	**Particle size distribution**			**texture**	**BD**	**CEC**	**pH**	**EC**	**Corg.**	**N**	**SOM**	**$CaCO_3$**
	Sand (%)	**Silt (%)**	**Clay (%)**		g/cm^3	**cmol/kg**		**mS/cm**	**g/kg**	**g/kg**	**%**	**%**
S1b	23.2	34.8	42.0	Clay	1.27	33.2	7.9	0.488	8.10	1.10	1.62	9.24
S2b	20.0	33.6	46.4	Clay	1.25	27.7	7.9	0.431	7.56	0.95	1.51	9.15
S3b	25.2	34.8	40.0	Clay	1.28	28.0	7.8	0.453	10.20	1.46	2.04	9.94
S4b	25.2	34.8	40.0	Clay	1.28	25.8	7.9	0.531	7.06	0.86	1.41	11.3
S5b	28.8	33.2	38.0	Clay	1.29	26.6	7.8	0.461	7.35	0.85	1.47	10.7
S6b	26.4	34.4	39.2	Clay	1.28	25.3	7.9	0.395	7.91	0.68	1.58	7.04
S7b	22.4	34.4	43.2	Clay	1.26	25.5	7.9	0.483	8.43	1.12	1.69	7.92
S8b	30.4	30.4	39.2	Clay	1.29	21.2	7.9	0.491	8.00	0.91	1.60	10.0
S9b	32.8	26.0	41.2	Clay	1.29	23.4	7.9	0.528	8.47	0.91	1.69	8.71
S10b	26.8	30.4	42.8	Clay	1.27	24.5	7.8	0.513	12.25	1.29	2.45	7.30
S11b	22.4	31.2	46.4	Clay	1.25	21.7	7.9	0.417	8.90	1.14	1.78	7.74
S12b	20.8	33.2	46.0	Clay	1.25	22.8	8.0	0.404	9.8	0.96	1.95	4.40
Mean	**25.37**	**32.6**	**42.0**		**1.27**	**25.5**	**7.88**	**0.47**	**8.67**	**1.02**	**1.73**	**8.62**
Median	**25.20**	**33.40**	**41.60**		**1.28**	**25.40**	**7.90**	**0.47**	**8.27**	**0.96**	**1.66**	**8.93**
SD	**3.90**	**2.66**	**2.97**		**0.016**	**3.26**	**0.058**	**0.047**	**1.459**	**0.210**	**0.29**	**1.89**
SE	**1.13**	**0.77**	**0.86**		**0.005**	**0.94**	**0.017**	**0.014**	**0.42**	**0.06**	**0.08**	**0.54**
KURTOSIS	**-0.44**	**2.37**	**-1.19**		**-1.46**	**1.83**	**0.65**	**-1.28**	**2.30**	**0.43**	**2.36**	**1.00**
SKEWNESS	**0.50**	**-1.54**	**0.43**		**-0.32**	**1.03**	**-0.06**	**-0.13**	**1.47**	**0.65**	**1.48**	**-0.79**
CV%	**15.4**	**8.2**	**7.2**		**1.3**	**12.9**	**0.73**	**10.0**	**16.8**	**20.6**	**16.8**	**21.9**

All properties, with the exception of EC, of surface soils showed close to normal distribution considering the criteria proposed (21) of skewness and kurtosis values within ± 2. Values for skewness of subsoil horizons were less than ± 2 (Table 3), while mean silt and SOM were slightly greater than ± 2. Apart from clay content, slightly increased values of pH and $CaCO_3$ were found in the subsurface soil layers, due to partial leaching of $CaCO_3$. The pH values of surface layers ranged from 7.6 to 7.8 and mean $CaCO_3$ content was 7.46% (Table 2), while the respective values in the subsurface horizons ranged between 7.8 and 8.0 and mean $CaCO_3$ was 8.62% (Table 3), The slight higher calcium carbonate content of the subsoil covariates with the clay content in both soil layers, as illustrated in Figure 3. This indicates both the original sediment concentration and a partial (slight) leaching due to soil ageing and the existence of a *cambic* horizon B. Mean CEC values were high in both depths due to high clay content, and the values of CV (Table 2, Table 3) can be attributed to uniformity of soil material during the process of its deposition. Also, similar CV ranges were recorded for SOM and N_{tot} which were classified to “Low-moderate” variability class for both depths (Tables 2, 3). The CV for N_{tot} was at narrows levels and ranged between 15.7% for the surface samples and 20.6% for the respective subsurface soils. Spatial variability of total N in soils of Czech Republic also varied and coefficient of variation (*CV*) ranged between 11.1% and 15.7% (19). According to Wilding classification scheme (17) for identifying the magnitude of variability for soil properties, Greek soils show moderate variability for both depths, while the studied Czech topsoils belong to low variability class. The slightly higher variability of Greek soils may be attributed mainly to differences in variability of lacustrine deposits. Despite the existing spatial variability of C_{org} and N_{tot}, a strong correlation was found between total soil nitrogen (N_{tot}) and soil organic carbon (C_{org}), suggesting that these elements are mainly bound in soil organic matter (Figure 3).

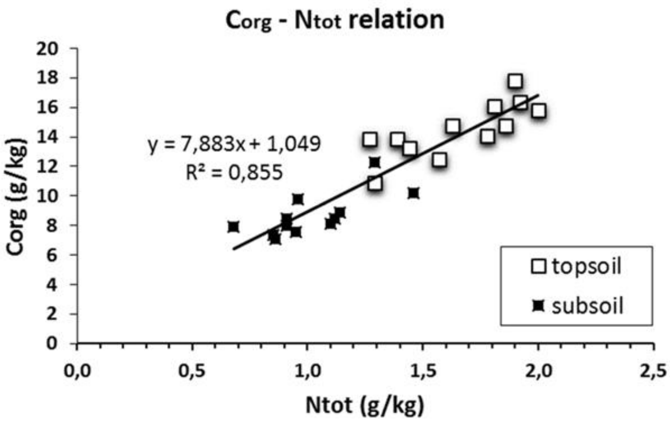

Figure 3 : Relation between organic carbon and total N content in the experimental field, (N=24)

Bulk density values depend on soil texture, and in our investigation the following strong negative relation was found between clay content and bulk density:

Y_{clay} = - 0.004x + 1.456 (N=24, R^2 = 83.8%)

Table 4 summarizes the analytical results for pant available phosphorus (P), and exchangeable Na^+ and K^+ (Table 4). An increased content of exchangeable K^+ and available phosphorus in the surface horizons was observed, which can be attributed to the continuous annual fertilization of crops within the experimental farm. High variation in macronutrient content usually indicates nutrient disorders and may reveal precedent fertilization practices and other farming activities, mainly tillage and irrigation. In our case, despite the small field size, a spatial variability of macronutrient exists especially in the topsoil which ranges between 30.2 and 35.5%, CV is less in the subsoil and was 28.9% for P, 15.8% for $Na^+$and 26.1 % for K^+ (Table 4), respectively. Since all sampling sites have been cultivated, it can be argued that values of variation are “low”, due to small size, the smooth relief and the stable cultivation within an approximate depth 30 cm. A spatial representation of the selected soil properties for the top soil, as resulted after applying a linear interpolation kriging method is depicted in Figure 4.

Spatial variability in soil properties has been shown to influence the spatial distribution of crop yield and is thus considered an important factor when implementing site-specific irrigation and fertilizer practices [22].

Table 4: Variation of macronutrients content in the surface and subsoil samples

Surface samples	P	Na+ Cmol/kg	K+	Subsoil	P	Na+ Cmol/kg	K+
S1a	33.7	0.196	1.2	**S1b**	3.8	0.239	0.5
S2a	21.9	0.196	0.9	**S2b**	2.9	0.191	0.5
S3a	24.4	0.226	1.0	**S3b**	4.3	0.178	0.5
S4a	34.0	0.183	0.9	**S4b**	2.5	0.230	0.4
S5a	10.3	0.170	0.7	**S5b**	2.8	0.200	0.4
S6a	14.6	0.270	0.6	**S6b**	4.5	0.183	0.4
S7a	25.8	0.378	1.6	**S7b**	3.2	0.235	0.5
S8a	15.1	0.174	0.7	**S8b**	3.4	0.243	0.4
S9a	17.8	0.152	1.4	**S9b**	3.4	0.174	0.4
S10a	18.9	0.296	0.8	**S10b**	5.6	0.283	0.4
S11a	23.5	0.204	0.8	**S11b**	2.7	0.257	0.2
S12a	11.3	0.170	0.7	**S12b**	2.4	0.239	0.2
Mean	**19.78**	**0.22**	**0.918**	**Mean**	**3.4**	**0.220**	**0.40**
SD	**7.023**	**0.066**	**0.312**	**SD**	**0.99**	**0.035**	**0.10**
CV%	**35.50**	**30.2**	**34.03**	**CV%**	**28.89**	**15.8**	**26.1**

Bulk density values (Table 2, Table 3) are rather homogeneous (range between 1.25 – 1.29 g cm^3), and the higher values are in accordance with the spots of lowest clay content (NE edge of the field) and vice versa (Figure 4 – lowermost). The mean electrical conductivity was higher in the surface depth (1.39 mS/cm) and lower (0.47 mS/cm) in the subsurface horizons (Table 1 and Table 2) reflecting the impact of fertilization and irrigation practices. These EC mean values have not affected negatively crop yield. However, the higher variation in electrical conductivity (CV%= 41.9) recorded in the topsoils (Table 2) reflects the mobility of soluble salts which can be affected mainly by irrigation, fertilization and micro relief.

Figure 5 shows the contour maps for clay, $CaCO_3$, SOM, organic nitrogen, BD and EC for the surface samples. The maps obtained by kriging depict 10 different micro-regions with soil properties values classified accordingly. However, as Figure 4 also demonstrates, it increases in the surface samples from S to N direction similar to the increase in $CaCO_3$ and the decrease in the clay content.

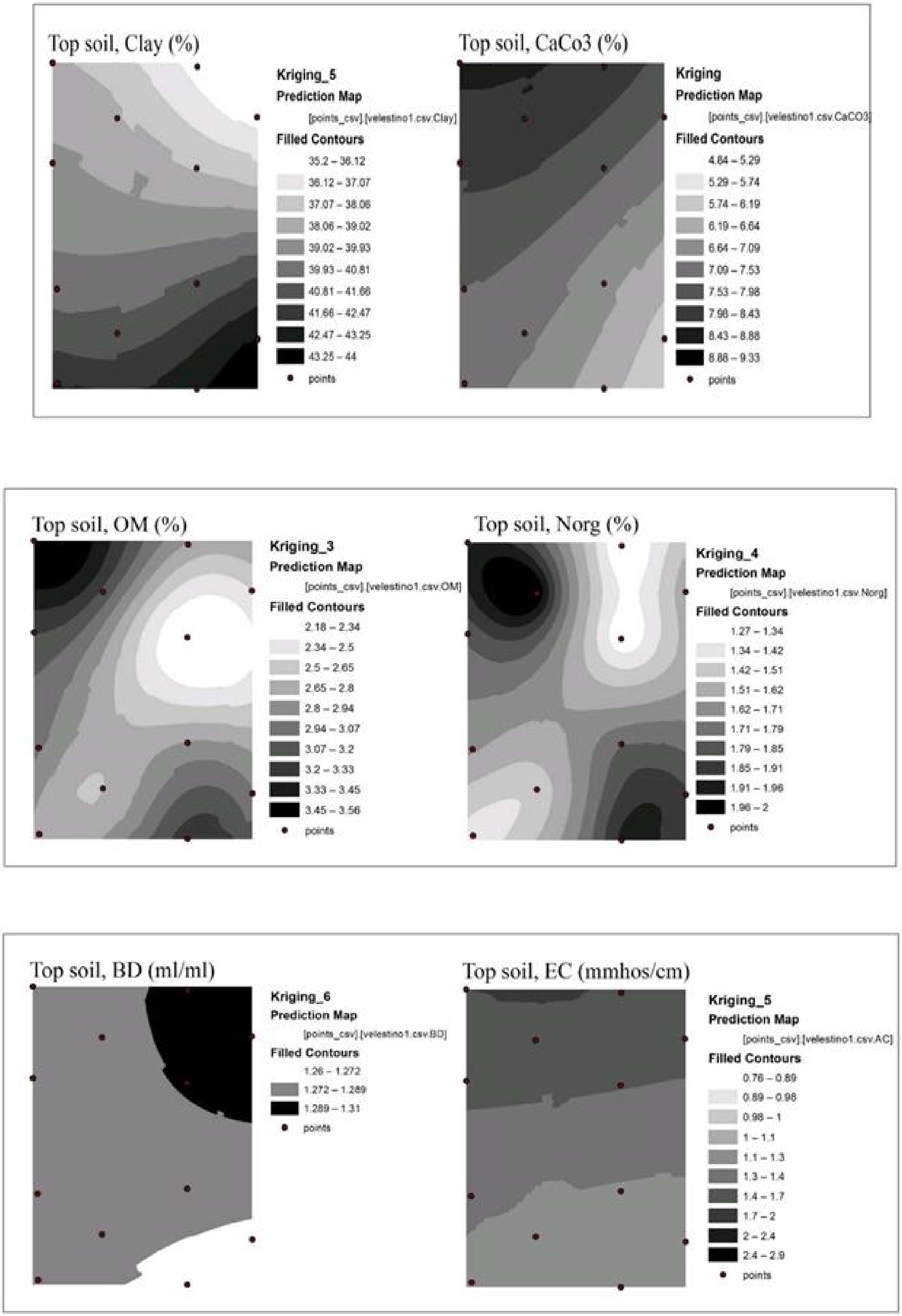

Figure 4: Spatial representation of selected soil properties (top soil: 0-30 cm) as resulted after applying a linear interpolation kriging method

The knowledge of spatial distribution may greatly assist in the implementation of well-executed field experiments with proper designing the topographic patterns (slope, shapes, orientation, etc.) of the treatments and particularly the replications (blocks). This can be realized with a limited field work, laboratory analyses and incorporating a simple GIS kriging algorithm. The result of such exercise is be depicted in Figure 5, where the spatial variation of the selected main soil properties –which by all means may affect crop growth and performance, is clearly demonstrated. Actually, Figure 5 (uppermost) shows the gradual decrease in clay with parallel increase in $CaCO_3$ content in a direction from south to north. In precision agricultural practices, heterogeneity and variation of soil parameters in a field due to tillage should be taken into consideration with other affecting factors for a successful site specific management [23].

It should be underlined that continuous monitoring of soil quality and nutrient values will assist in ensuring soil fertility and land productivity by the application of proper land management and farming practices [24]. However, geostatistical methods have been adopted and used in site-specific management applications, soil sampling strategies and assessment of farm management styles and decisions [18].

The results of the research prove that lateral and vertical uniformity are influenced by soil genesis factors and farming practices (plowing, incorporation of plant residues after harvesting, irrigation, application of soil improvement material). Also, differences in spatial variability of soil chemical properties are probably associated to small variations in relief shape, and these results support the view that lateral fluxes of water create micro environments with different characteristics which may affect water and soil particle movement that enhance spatial variability.

4. Conclusions

The spatial variability of the main soil properties, in small-sized field experimental sites might be substantial, so field work and laborious determinations of samples can be decreased. Different coefficients of variation were recorded among soil properties and soil depth. However, variation values may be attributed to soil genesis factors and human activities related to application of farming practices. The knowledge of variation and its spatial distribution may greatly assist in the implementation of well-executed experiments with proper designing of the treatments. The high variation of P and K^+ should be attributed to differences in management practices, such as fertilization, rather than soil forming factors as soils have similar properties and conditions of climate, topography and parent material. The resulting kriging maps allow more precise identification of nutrients distribution and can be used by researchers to obtain more comprehensive view for assessment of micro environmental conditions. This knowledge may be handled as a tool in experimentation plans for agricultural research, in establishing a more effective water management plan and proper measures regarding land conservation. Geo-reference soil sampling and geo-statistical analysis are valuable tools for interpolation of data and to assess spatial variability at farm scale, in order to be used for delineation of management zones. Furthermore, variable-rate application of inputs might be carried out, decreasing fertilization and water, as a strategy to obtain a more rational cost effective land management. It can be argued that the studied soils are vulnerable to management, and attention should be paid on the selection of proper irrigation method to avoid crusting.

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