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Assessment of Soil Heterogeneity in an Experimental Field and Possible Effects on Yield Performance of Maize Hybrids *(Zea Mays L.)* – A Preliminary Study

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Abstract

The main objective of this study was to examine if the degree and direction of soil heterogeneity in an experimental field would affect yield performances of 10 different maize hybrids *(Zea mays L.)*. Analyses for soil reaction (pH), electrical conductivity (ECs) and soil organic carbon (SOC) were conducted following a sampling grid; bare soil spectral response in the infra-red (IR) range was also recorded in the same locations using a handheld sensor. Geostatistical analyses showed that there was significant variability in soil conditions among strips of maize hybrids (especially for EC), as well as along most of the strips; and also, several hot spots of high or low values were detected for all measured properties. As a result, the experimental design and statistical analysis followed for comparing yield performances of the hybrid varieties was expected to be biased due to differentiated soil conditions. Therefore, a more sophisticated analysis is suggested to be designed, with a view to identifying management zones within the experimental field.

Keywords: maize (corn) hybrids; NDVI; field experiment; geostatistical analysis; management zones

1. Introduction

1.1 Maize hybrids

Maize is widely cultivated throughout the world, with the United States producing 40% of the world's harvest; other leading countries are China, Brazil, Mexico, Indonesia, India, France and Argentina. According to FAO annual reports, global production was 817 million tons in 2009, more than rice (678 million tons) or wheat (682 million tons); in 2009, over 159 million hectares of maize were planted worldwide, with a yield of over 5 tons/ha.

Maize requires a mean daily temperature higher than 19 ◦C, or a mean of the summer months higher than 23 ◦C and a minimum temperature for germination at 10 ◦C. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. Maize needs 450 to 600 mm of water per season, which is mainly acquired from the soil moisture reserves. About 15 kg of grain are produced for each millimetre of water consumed. The total leaf area at maturity may exceed one square metre per plant. The assimilation of nitrogen, phosphorus and potassium reaches a peak during flowering. Each ton of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg of potassium from the soil (Plessis, 2003). Because of its shallow roots, maize is susceptible to droughts, intolerant of nutrient-deficient soils, and prone to be uprooted by severe winds.

Generally, maize yield is highly correlated with N concentrations in soil and N update levels (following most possibly an exponential relationship), as it has been illustrated by several older and recent studies (Liang et al., 1996; Scheper and Hollan, 2012).

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Conducting experiments on maize yield in similar geographic latitudes in Greece, Almaliotis et al. (2002) showed that performance was positive correlated to pH and organic matter (among other soil properties), whereas it was negative correlated to the soil's electrical conductivity (ECs). Both correlations, however, were not statistically significant. (Hamdy et al., 2002) have reported that response of yield to soil texture is higher than that of salinity according to a series of experiments. (Van Es et al. 2006) conducted 3-year yield experiments in the 142-ha Cornell University Experimental Farm at Willsboro, NY, USA, focusing on two soil types (namely, a clay loam and a loamy sand soil). The study showed only moderate potential for varying N application within fields based on soil type and drainage conditions, suggesting however that seasonal differences in N dynamics greatly affect maize N response.

Maize hybrids are created by crossing or breeding two different inbred parent lines with desired characteristics to combine into a hybrid. There are several reasons for trying new maize hybrids, such as higher performance, adaptation to local soil and climate conditions, lower seed and cultivation cost, etc. Farmers value hybrids because they are stronger and perform better across different environments than their inbred parent lines or open pollinated varieties. With the impacts of climate change and rising populations, hybrids play an important role in combating world hunger. Creation of new competitive maize hybrids, however, is time consuming, demanding, and costly. Thousands of intersections of germplasm and more than one million experiments are held every year around the world. Eventually, less than 1% of hybrids resulting from crosses will pass the rigorous evaluation and will be channelled to trade.

Agricultural experiments can be established in the field, in the greenhouse and in the laboratory. Experiments in the field are held under true cultivation conditions, but have a serious limitation: variety trials are often conducted in heterogeneous fields, i.e. under spatially differentiated soil conditions, terrain characteristics, or microclimate, a fact that might affect an objective comparison of crop growth and yield of the tested plants. These limitations can be reduced if an appropriate number of replications, randomly assigned in the field are also incorporated in the plot plans; however, due to high cost of experimentation this is rarely done and crops are planted in parallel rows (Petersen, 1994).

Therefore, an experimental field should be examined for the degree of its spatial and directional heterogeneity and the significance of difference of crop growth conditions between hybrid varieties before conducting any experiment. Nowadays very precise assessment of soil properties and yield variability and their potential range can be supported by precision agriculture (PA) methodologies and relevant technologies. PA aims at adjusting and fine-tuning land and crop management to the needs of plants within heterogeneous fields (Bouma, 1997). Therefore, knowledge of heterogeneity degree in soil properties and other field features will allow the experimenter to employ unbiased statistical methods and thus interpret the experimental results objectively.

1.2 Objectives of the study

The main objective of this study was to assess if there is spatial heterogeneity and towards o which direction of soil conditions in an experimental field could affect yield performance of 10 maize hybrid varieties *(Zea mays L.);* or in other words, to examine if performances of the different hybrids would be independent of their location in the experimental field.

The study was divided into three phases:

- In the first phase, yield performance of the maize hybrids was recorded. This experiment was organised and conducted by a private company, in an agricultural field in Kokkinogeia village, in north Greece. The outputs were provided as averages of 20 sample measurements per variety (i.e. 200 samples in total).
- In the second phase, three soil chemical properties were measured in soil samples extracted throughout the field on a regular grid (7 soil samples corresponding to each hybrid). These properties were: soil reaction (pH), electrical conductivity (ECs), and soil organic carbon (SOC). The experiment was organised and conducted by PerrotisCollege, Dept. of Environmental Systems Management, Laboratory of Precision Agriculture (www.perrotiscollege.edu.gr). In addition to that, the spectral response of bare soil in terms of the Normalised Difference Vegetation Index (NDVI),, was recorded in the the area where the soil samples were taken (in situ) , using a handheld device (Trimble Greenseeker®).

Since the mid 1970's, NDVI has been the most common vegetation index –among many broadband indices- used to estimate vegetation biomass, plant health status or leaf area index (LAI) in agricultural applications (Rouse et al., 1974; Guyot et al., 1992). Some studies exhibit strong correlations of NVDI and soil carbon (Kunkel at al., 2001; Burgheimer et al., 2006; Zhou et al., 2007; Bousch et al., 2010), thus creating expectations that NDVI could be able to record within-field heterogeneity adequately, thus supporting management zone delineation and precision farming. Magri et al. (2006), however, who studied five farms in New York for three continuous years using three-band bare soil imagery, showed that NDVI was not well correlated with soil fertility indicators and moreover any relation was seasonally inconsistent.

- In the third phase, the degree and direction of field heterogeneity was assessed.

The null hypothesis (Ho) of the study was that the statistical analyses conducted (by the company) for maize hybrid performance evaluation were valid, considering that the soil conditions did not exhibit high variability among and within the 10 hybrids tested. The alternative hypothesis (Ha) was that the field exhibited significant directional variabilityand therefore, this variability should be taken into account in the statistical analysis, which should then be appropriately adjusted.

1. Materials and methods

2.1 The study site

The experimental field was located close to the village Kokkinogeia, in the regional unit of Drama, Greece, and had an extent of 0.840 ha (60 m x 140 m), as a part of an agricultural parcel (Fig. 1). The exact geographic location of the field is: 23o 55' 44'' E, 41o 10' 55'' N; or x: 493880 m, y: 4558660 m using the Greek national projection system (EPSG: 2100).

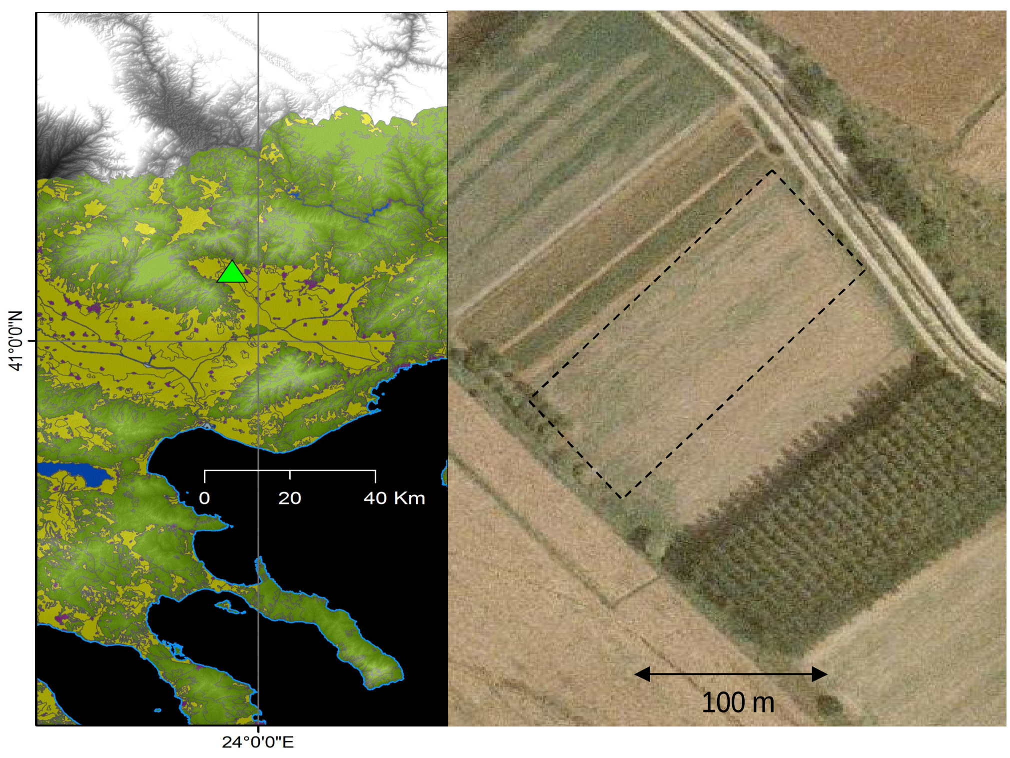


Fig. 1 Left hand side: the location of the study site in Kokkinogeia, Drama (in yellow, the extents covered by agricultural land uses); right hand side: the experimental field as shown in recent air photos of the Greek cadastral agency (dash-line shows the exact surface of the conducted experiment).

Long term climate data of monthly mean temperature and rainfall (in terms of rain height and rainy days) were collected from the weather station of Serres, the closest station to the study site, approx. 30 km to the west; source: Hellenic National Meteorological Service, HNMS (Fig. 2).

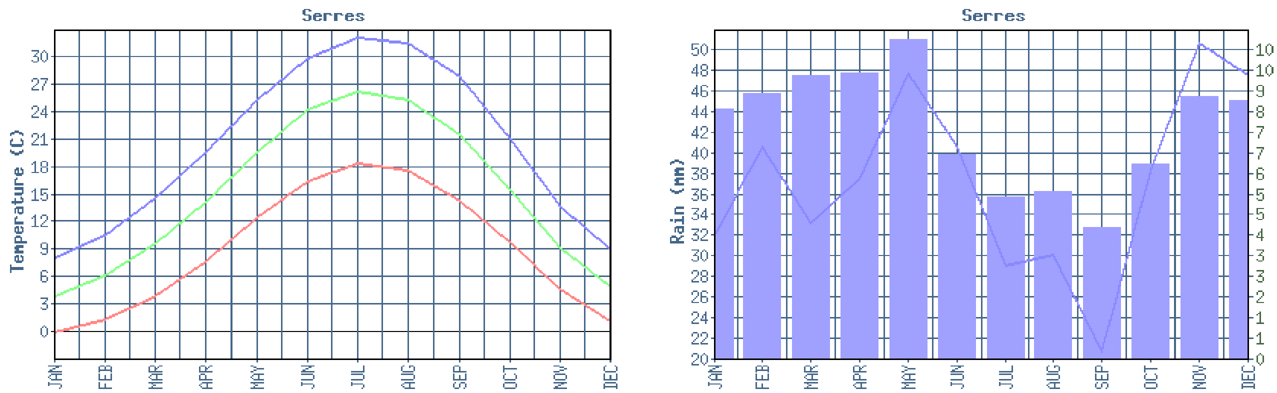


Fig. 2 Left hand side: **m**onth-step maximum, minimum, and average air temperature values (in ^{o}C) for the weather station of Serres city; right hand side: monthly rain height values (mm) (bars) and number of rainy days (line) for the weather station of Serres city (source: HNMS).

The field was divided into 6-m wide and 140-m long strips per hybrid, which included 8 plated rows of each hybrid (row width: 0.75 m). For each hybrid, 20 plants were collected along the strip, from the 4th and 5th row (middle rows) of each hybrid; external lines were not sampled in order to avoid possible border effect. Soil samples were taken at 0 to 30 cm depth every 20 m along the strips, resulting in a total of 70 soil samples from throughout the field (7 replicates from each maize hybrid strip x 10 hybrid strips) (Fig. 3).

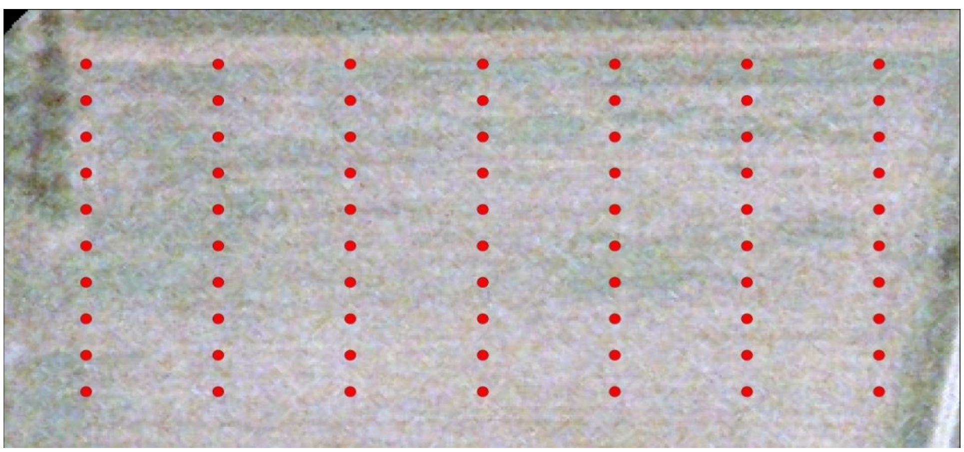


Fig. 3 An illustrated plot of the experimental field: 6-m wide and 140-m long maize hybrid strips their corresponding names (air photo background).

2.2 Data and measurements

The maize plants were sampled by the American Genetics at a total of 200 locations (20 plants x 10 hybrids) for recording their performance and other characteristics, such as number of siblings and number of cobs. Yield performance was measured at 15% moisture and the values ranged from 1333 to 1620 g/m^2 with an average at 1525 g/m^2 and a coefficient of variation of 6%.

Beyond fertilizer applications (and especially N), which are directly controlled by the farmers or experimenters, the tested soil properties in combination are considered to be among the most critical parameters for the growth of maize. The soil analyses were conducted at the Precision Agriculture Laboratory of Perrotis College (www.perrotiscollege.edu.gr). For SOC determination, the wet combustion method was employed (Walkley and Black, 1934; Walksley, 1947) while, for pH and ECs, using the 1:1 ratio soil:water mixture a combination pH+EC electrode was applied. The NDVI was measured in the soil samples, both under wet and dry soil conditions using a handheld NDVI sensor (Trimble® Greenseeker®).

The soil reaction (pH) values ranged from 6.6 to 7.6 with an average of 7.14, median 7.2 and mode 7.2. The electrical conductivity (EC) values ranged from 0.09 to 0.47 (dS/m) with an average of 0.32, median 0.35 and mode 0.40. Soil organic content (SOC) values ranged from 0.14 to 2.23, with an average of 1.23, median 1.15 and mode 1.5. Finally, the NDVI values of the soil samples ranged from 0.103 to 0.133, with an average of 0.120, median 0.120 and mode 0.120.

Therefore, the recorded soil values were found to lie in normal ranges for maize cultivation requirements. The maize plant is adaptable to a variety of soil conditions; however, the optimum soil environment comprises a soil of medium texture, deep, well-drained, with high organic matter content, neutral pH, and electrical conductivity (EC) smaller than 0.68 dS/m. It has been observed that the crop yield decreases up to 34% in acidic soils. Adding calcium could help to improve the acidity of the soil in order to increase yields again. Also, the crop yield is seriously affected when electrical conductivity is larger than 1.4 dS/m. This can be avoided through good drainage of the field.

None of the measured properties was highly correlated to another and therefore, all of them were considered independent and were used in the analysis. Only measurements of NDVI in wet and dry soil were found positively dependent and thus dry soil measurements were only included in further analysis (Fig. 4).

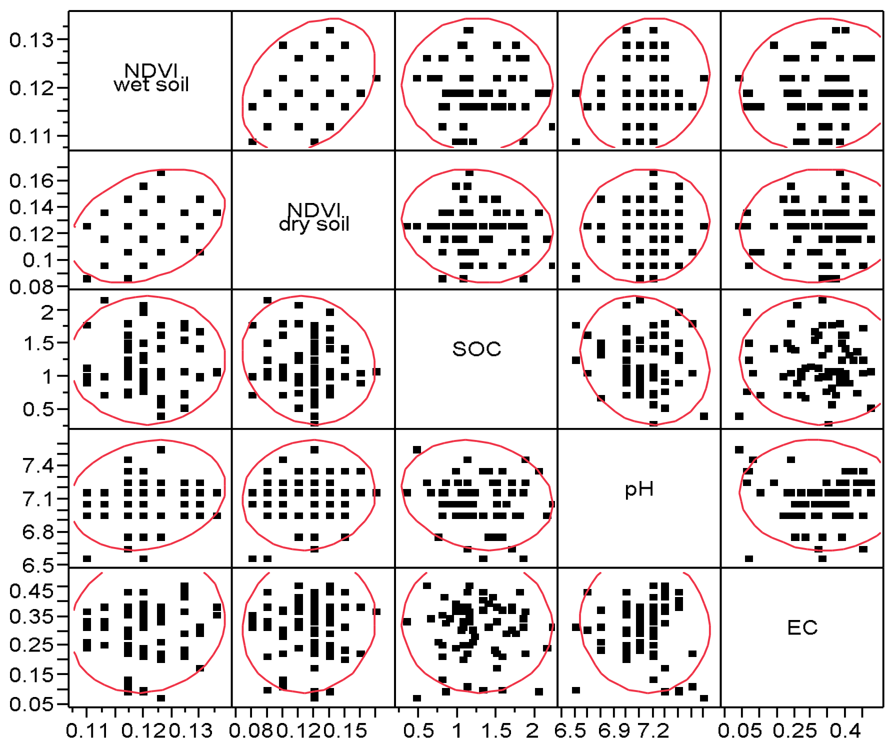


Fig. 4 Multiple scatterplots of the measured physicochemical soil properties.

2.3 Methodology overview

Considering that yield performance of the tested hybrids was provided by the company as a single value per hybrid variety (i.e. one value per strip and not for every extracted sample along the strips), the yield performances could be compared between them only as averages; therefore, the effect of soil properties on the yields could be judged only as lumped values between hybrid strips. Consequently, the analysis of this problem involves both non-spatial and spatial statistics. Explorative descriptive statistics and t-test are used to detect possible significant differences between and a long hybrid strips. This is necessary in order to study if soil properties heterogeneity affect yield performance of the hybrids. Then, soil properties are studied as a complete set (irrespective to their strip), in order to detect direction and degree heterogeneity in the field as a whole; spatial autocorrelation, directional global trend, and hot-spot analysis are applied.

2. Results and discussion

3.1 Descriptive statistics

As a result, the values of every measured soil property were averaged per hybrid and the descriptive statistics were extracted in order to compare them with performance values of the coinciding hybrids (Table 1).

Table 1: Range of soil properties and yield performance per hybrid

HYBRID Nr & Name	pH	EC (dS/m)	SOC (%)	NDVI (avg wet & dry soil)	YIELD (g/m^2)
1: AGN 601	7.13	0.35	1.45	0.125	1530
2: AGN 541	6.91	0.36	1.21	0.118	1518
3: AGN 642	7.04	0.37	1.13	0.117	1333
4: AGN 625	7.23	0.37	1.19	0.117	1613
5: PR 1758	7.26	0.33	1.33	0.120	1601
6: Jolly	7.19	0.31	1.10	0.124	1619
7: AGN 720	7.17	0.27	1.23	0.121	1620
8: PR Y43	7.03	0.27	1.37	0.119	1503
9: AGN 715	7.11	0.36	1.51	0.123	1522
10: AGN 757	7.30	0.24	0.81	0.119	1434
avg	7.14	0.32	1.23	0.12	1529
std	0.12	0.05	0.20	0.00	92.4
CV	2%	15%	16%	2%	6%
min	6.91	0.24	0.81	0.12	1333
max	7.30	0.37	1.51	0.13	1620

Further, the averaged values were graphed per hybrid in order to support visual comparison of soil conditions between hybrids (Fig. 5).

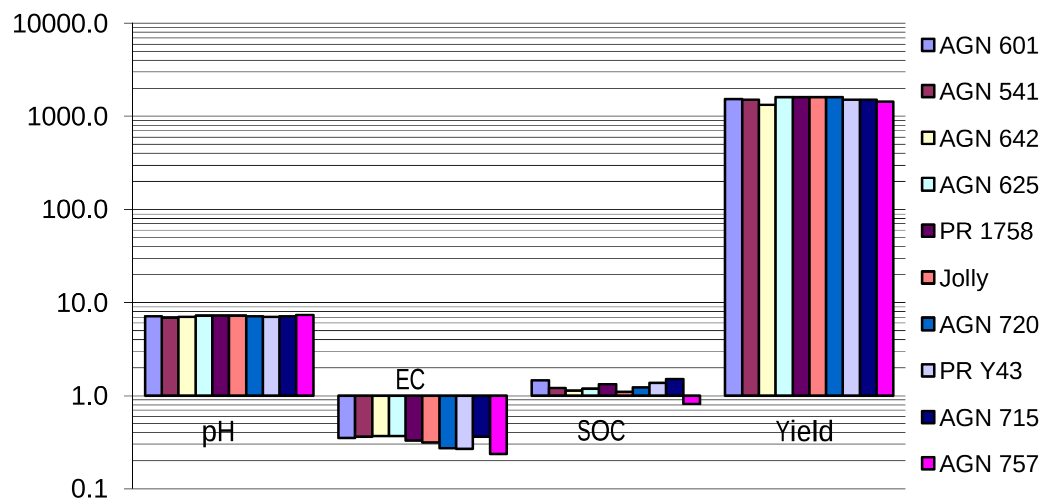


Fig. 5 Comparison of soil properties measured (averages of pH, EC, SOC%, and yield, respectively) per maize hybrid (logarithmic scale).

Examination of soil variation along the strips was necessary, as a future experiment, might be designed in this direction and heterogeneity degree should be known in advance. Using the coefficient of variation (CV) as a measure of within-strip variability, some specific strips showed to contain a highly variable set of values; for example, the strip of AGN757 had a CV of 58% for EC and 49% for SOC, while the strip of AGN720 had a CV of 39% for EC and 48% for SOC.

On the other hand, some hybrid strips, such as AGN601 and AGN625 had low CV for EC and SOC, i.e. 10% and 8% for EC and 29% and 22% for SOC, respectively. Variations in pH values were lower than 4% in all cases (Fig. 6).

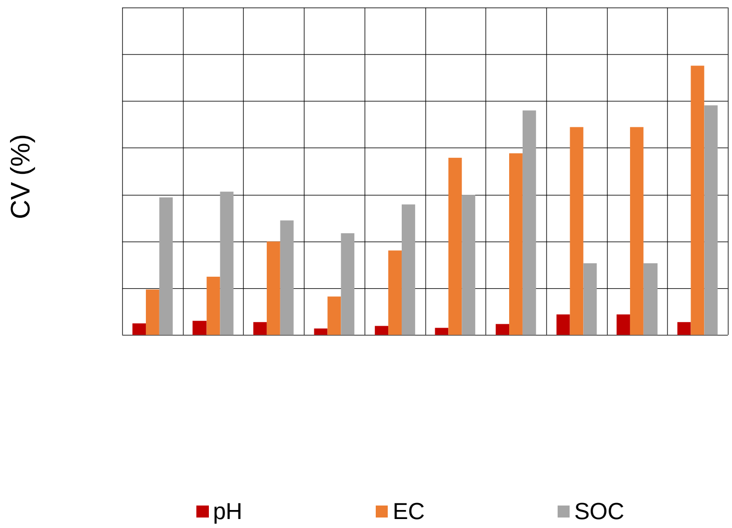
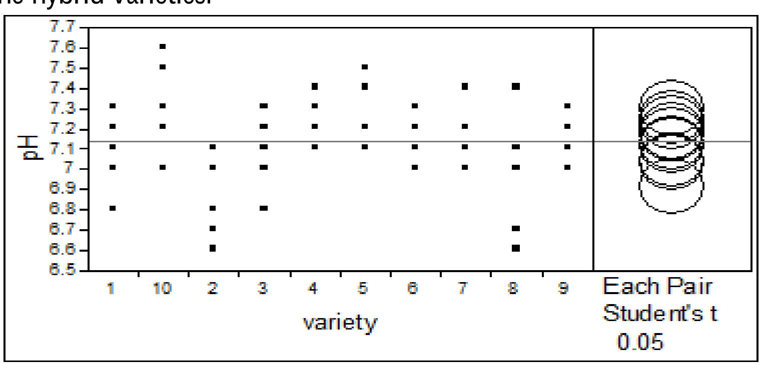


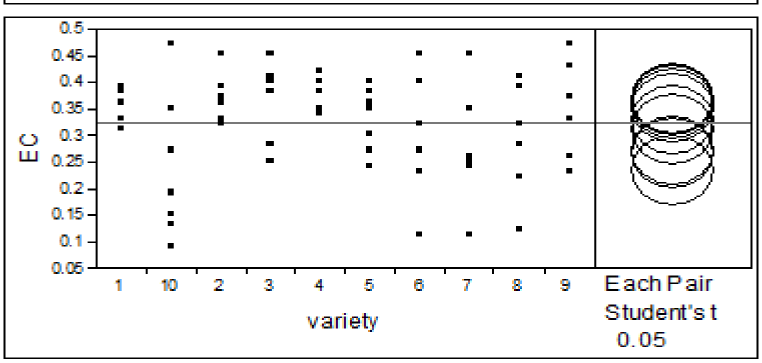
Fig. 6 Coefficient of variation (CV %) of the measured soil properties within every hybrid strip

3.2 *T*-tests

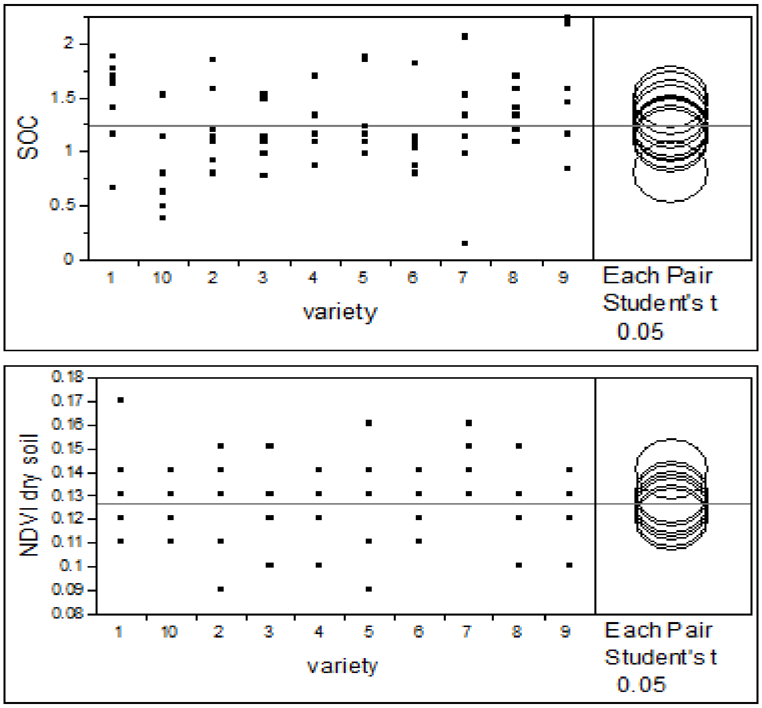
In order to assess the significance of differentiation for the examined soil properties (including the NDVI measurements) per hybrid variety, one-way pair analysis using the *t* test was conducted; this type of analysis reveals how significantly different are the tested groups for a specific property (Student, 1908). Here, the tested groups corresponded to the different hybrid varieties (Fig. 7). The comparison of the means (considering 7 replications per variety) showed that there are significant statistical differences for all the data recorded (i.e. soil properties and NDVI) among the hybrid varieties.



Group					Mean
10	A				7.30
5	A				7.25
4	A	B			7.2285714
6	A	B	C		7.1857143
7	A	B	C		7.1714286
1	A	B	C		7.1285714
9	A	B	C		7.1142857
3		B	C	D	7.0428571
8			C	D	7.0285714
2				D	6.9142857



Group					Mean
4	A				0.37000000
3	A				0.36714286
2	A	B			0.36428571
9	A	B	C		0.36000000
1	A	B	C		0.35142857
5	A	B	C	D	0.32857143
6	A	B	C	D	0.31142857
7		B	C	D	0.27142857
8			C	D	0.26571429
10				D	0.23571429



Group		Mean
9	A	1.5057143
1	A	1.4485714
8	A	1.3714286
5	A	1.3257143
7	A	1.2328571
2	A B	1.2142857
4	A B	1.1914286
3	A B	1.1271429
6	A B	1.1000000
10	B	0.8071429

Group		Mean
7	A	0.14142857
1	A B	0.13142857
6	A B	0.13000000
4	A B	0.12714286
3	A B	0.12571429
10	A B	0.12428571
5	B	0.12142857
9	B	0.12142857
8	B	0.12142857
2	B	0.12000000

Fig. 7 One-way analysis using Student's t test for the measured soil properties per hybrid variety; varieties correspond to groups, numbered from 1 to 10 (refer to Table 1 to link variety number to name).

3.3 Geostatistical analysis

The full soil dataset was tested for spatial autocorrelation, which for a given a set of features and an associated attribute, evaluates whether the pattern expressed is clustered, dispersed, or random. The spatial autocorrelation of the samples was measured using the Global Moran's I index, according to which, the values of pH, EC, and SOC were found to follow a completely random distribution in the experimental field (I values: 0.051686, 0.094623, and -0.030664, respectively), whereas NDVI values of soil samples were found to be somehow clustered (0.224573).

The soil dataset was further analysed using Ripleys K-function, which determines whether features, or the values associated with features, exhibit statistically significant clustering or dispersion over a predefined range of distances. The graphical output of this method shows that the soil dataset is distributed clearly dispersedly at all possible distances (between 0 and 140 m, i.e. all along the experimental field) (Fig. 8).

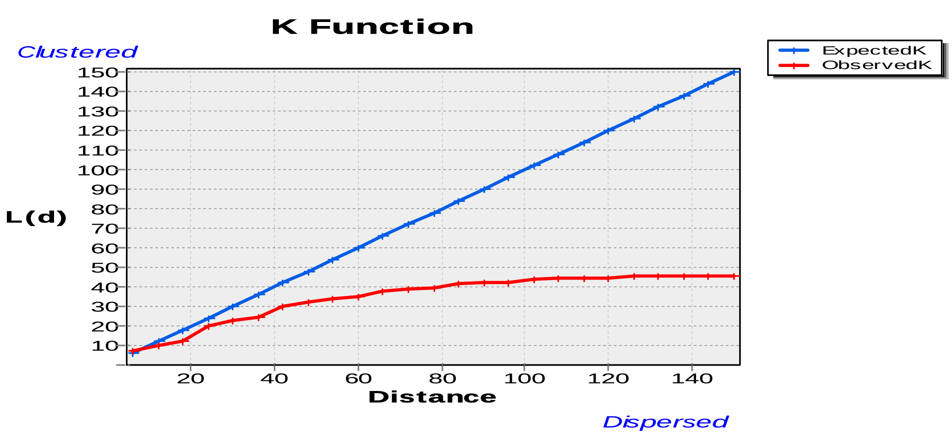


Fig. 8 The Ripleys K-function applied for the soil dataset of the experimental field.

Further, the directional trend was tested for the soil dataset, by implementing 3-dimensional plotting the experimental field. The value of every selected attribute was projected in two directions onto planes that are perpendicular to the map plane. A second-order polynomial curve was fitted to each projection. The findings indicate that there is a directional trend across hybrid strips (therefore, between hybrids) for all attributes and especially for EC. With regard to a long strips direction, a clear trend could not be detected (Fig. 9).

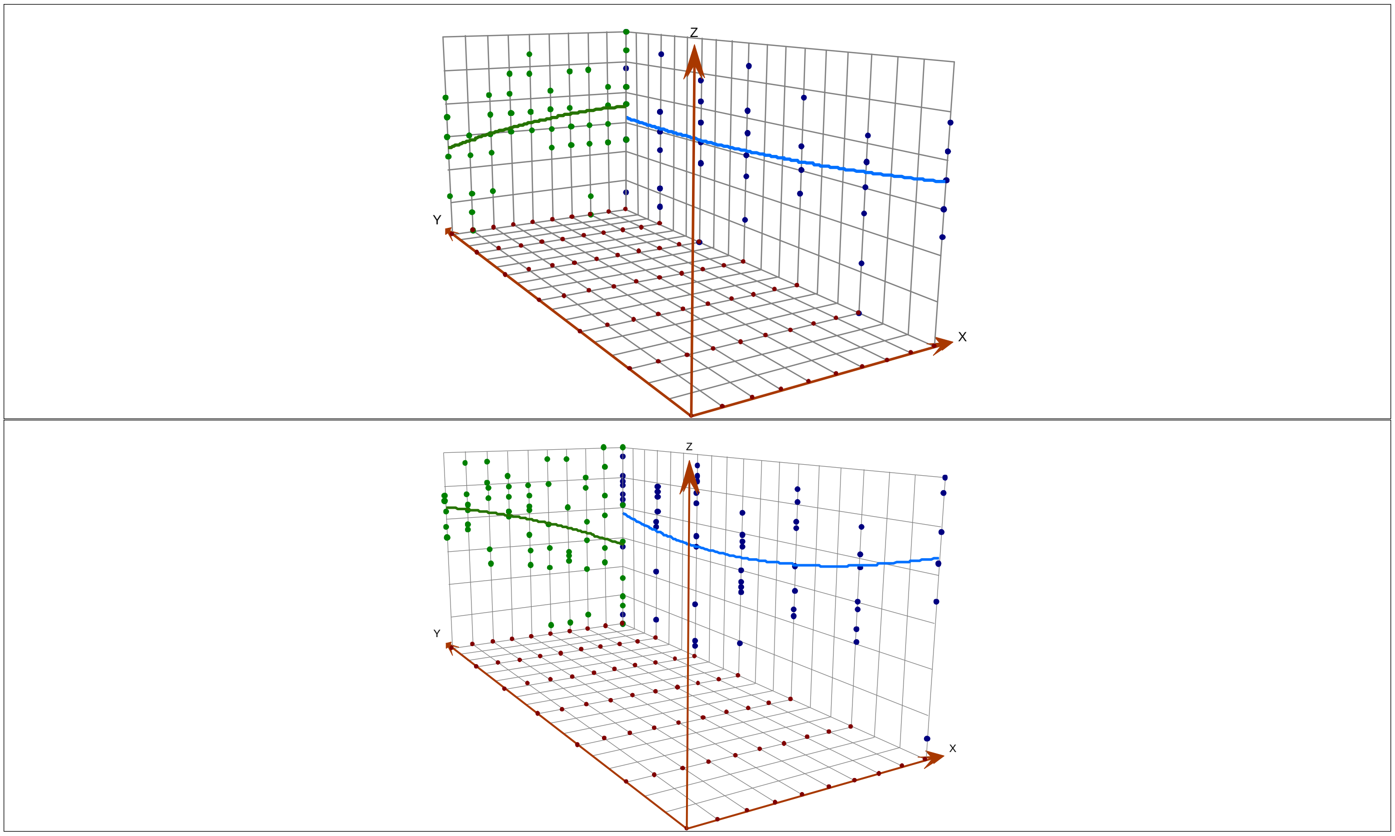


Fig. 9 Trend analysis for pH (top) and EC (bottom).

Finally, a hot spots analysis using the Anselin Local Moran's I statistic was applied, in order to allocate sites in the experimental field that should be avoided, or should be treated with caution. The analysis distinguishes between a statistically significant cluster (0.05 level) of high values (denoted by HH), cluster of low values (denoted by LL), outlier in which a high value is surrounded primarily by low values (denoted by HL), and outlier in which a low value is surrounded primarily by high values (denoted by LH) (Fig. 10).

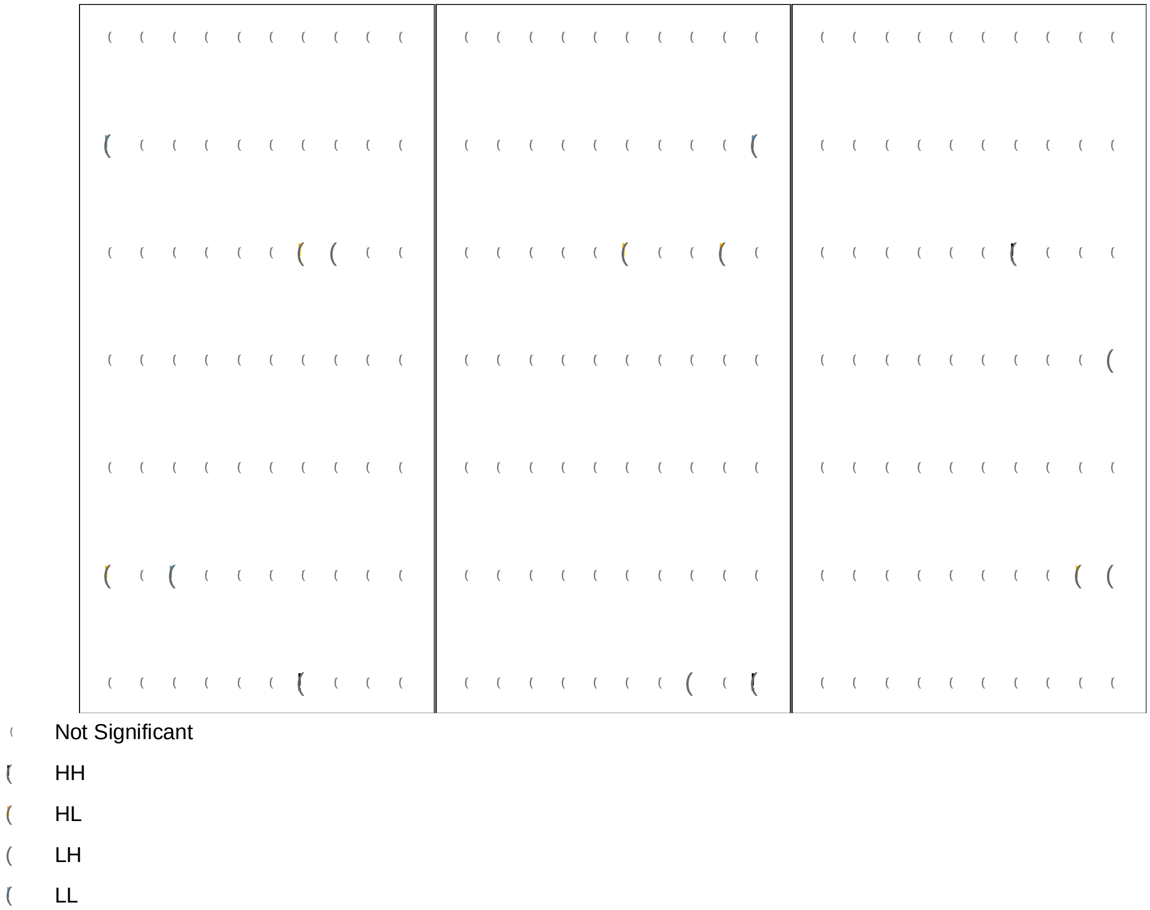


Fig. 10 Hot-spot analysis for pH, EC, and SOC (from left to right, respectively).

3. Conclusions and outlook

In a preliminary study of soil properties in the experimental field of Kokkinogeia, they were found to follow a completely random distribution. At the same time, significant variability in soil conditions was detected across the field, i.e. between maize hybrids (especially for EC), as well as along most of the cultivation strips. Moreover, the soil dataset was found to be distributed clearly dispersedly at all possible distances within the experimental field. Finally, several hot spots of high or low values were detected at different sites and for all possible measured properties.

Consequently, the specific experimental design and consequent the statistical analysis followed by the company in order to compare mean yield performances of the examined hybrid varieties was possible to have been biased in some degree from site-specific soil conditions. Also, a different direction of the hybrid strips (e.g. vertical to the followed) would be expected also to be biased. As a result, the null hypothesis of this study has to be rejected and therefore, a more sophisticated type of analysis, by identifying and delineating management zones within the experimental field is suggested.

The significant differences and the high degree of variation in soil conditions throughout the experimental field suggest the requirement for site-specific management of the crop (Blackmore, 1991). In an attempt to outline potential management zones, the soil measurements were interpolated using the median polish-Kriging method (available in Manifold GIS software) with all sample values included.

There are two advantages of Median polish Kriging over universal Kriging: first, the mean component of the model is estimated by the outlier resistant method of median polishing, which gives less biased residuals for estimating the structure function; and second, the variogram of the dataset is not assumed to be known a priori (Cressie, 1993).

Mzuku et al. (2005) have applied this method in maize cultivations for precision farming purposes in Colorado. According totheir specific limitations and objectives, different strategies could be followed by farmers. As an example, the surfaces of the recorded soil properties (pH, ECs, and SOC) were normalized and composited by multiplication assuming equal effect, thus resulting in a composite value Z, i.e.:

$$Z = (pH/6.9)*(EC/0.16)*(SOC/0.7) \quad 1)$$

For a clearer mapping result, Z was reclassified. High Z-values correspond to high differentiations from the minimum soil property values, thus revealing zones of extreme variations for all properties on average (Fig. 11).

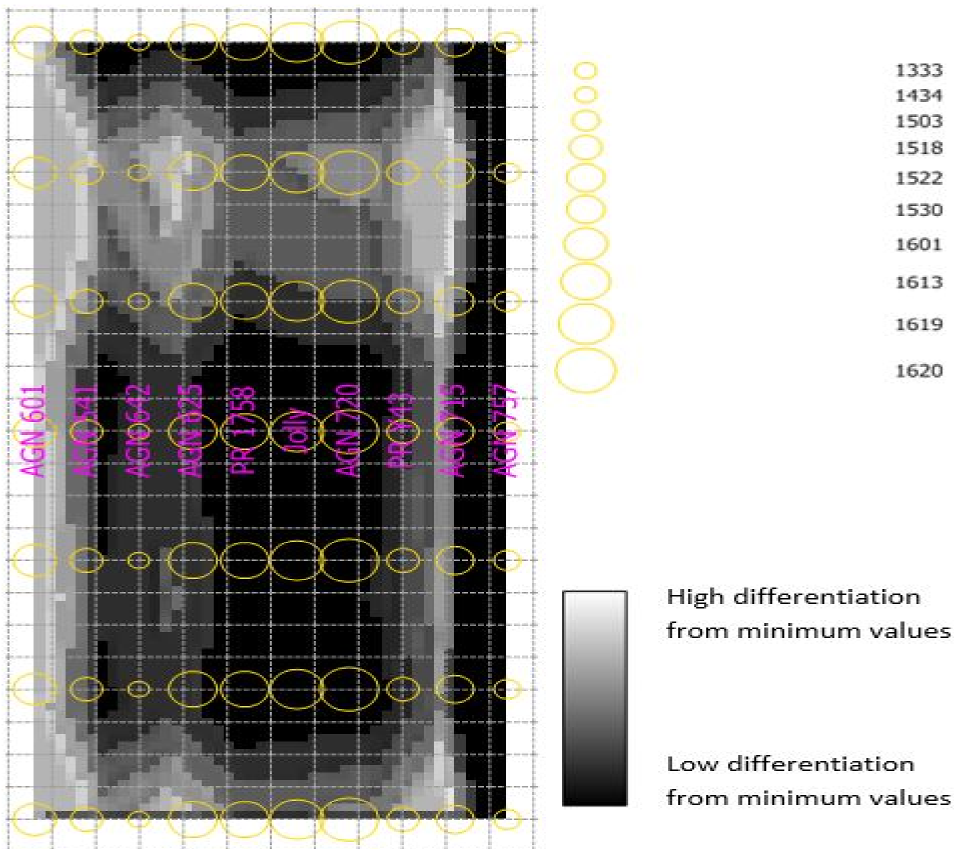


Fig. 11 Management zones based on a composition of normalized soil properties surfaces and overlaid yield performances mapped as graduated symbols (background mapping grid 5x5 m; origin of the coordinates at bottom-left).

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