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Determination of the relationship between apparent soil electrical conductivity with pomological properties and yield in different apple varieties

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Abstract

Precision horticulture and spatial analysis applied to orchards are a growing and evolving part of precision agriculture technology. The aim of this study was to produce yield and pomological properties maps in order to determine the relationship between these parameters and apparent soil electrical conductivity (EC_a) characteristics in different apple varieties, as well as analyze spatial variation in an apple orchard. This study was carried out at an apple orchard in the Faculty of Agriculture of Ankara University's Haymana Research Station. In this work, apparent soil electrical conductivity values were acquired by using EM38 sensor. These values were used to produce maps and compared with yield and pomological characteristic maps using classical statistics and spatial analyst methods. As a result, the highest value of non-linear regression between EC_a and yield was determined in the 'Red Chief' ($R^2 = 0.94$) while the highest calculated value for yield in cross-sectional area were found to be in 'Jonagold' with $R^2 = 0.44$. The other indexes such as coefficient of variation and Moran's I index were used to determine variability and autocorrelation in each value.

Key words: apparent soil electrical conductivity, yield mapping, pomological properties.

Introduction

In the last few years, apart from the grain production, precision farming method has been also available in other crops, especially in horticultural crops. However, high value horticultural crops have also been investigated such as citrus (Zaman, Schuman, 2006; Ye et al., 2007; Aggelopoulou et al., 2010), olive (Lopez-Granados et al., 2004; Aggelopoulou et al., 2010), apples (Best et al., 2008; Aggelopoulou et al., 2010), grapes (Bramley, Hamilton, 2004; Taylor, 2004; Bramley, 2005; Aggelopoulou et al., 2010), cranberries (Pozdnyakova et al., 2005; Aggelopoulou et al., 2010) and tomatoes (Pelletier, Upadhyaya, 1999; Aggelopoulou et al., 2010). It is often claimed that precision agriculture can offer a great deal to the production of high value crops, and it is also easier to pay for the investment than for lower value crops. However, detailed analyses of yield, soil, fruit quality properties and their interrelationships should be done before changing traditional management practices to site-specific ones (Aggelopoulou et al., 2010).

Precision farming is a management approach to the farm and is not a definable prescriptive system (Dawson, 1997). It identifies the critical factors where

yield is limited by controllable factors, and determines intrinsic spatial variability. The variations occurring in crop or soil properties within a field are noted, mapped and then management actions are taken as a consequence of continued assessment of the spatial variability within the field. The site specific management relies on geospatial information to facilitate the treatment of small portions of field as individual management units. Key technologies include GPS, GIS, electronic sensors, and ruggedized computers for within field data acquisition and operation control. Although it is now relatively easy to collect geospatial data for precision farming, it is more difficult to know how to most effectively use those data in making crop management decisions. An important step in these management decisions is to understand the relationship, on a spatial basis, of crop yields to myriad of agronomic factors which may potentially be causing yield variations (Erzin et al., 2010).

Efficient methods for accurately measuring within-field variations in soil physical and chemical properties are important for precision agriculture (Bullock, Bullock, 2000). Soil EC_a has become one of the

most reliable and frequently used measurements to characterize field variability for application to precision agriculture due to its ease of measurement and reliability (Rhoades et al., 1999; Corwin, Lesch, 2003). For instance, it has been previously studied by Domisch and Giebel (2004) using soil electrical conductivity recalculated to a soil temperature of 25°C (EC_{25}) to generate a soil textural map. The result showed that the weighted silt content influenced soil electrical conductivity. EC_{25} -values between 0 and 10 $mS.m^{-1}$ could be allocated to sand or loamy sand profiles, EC_{25} -values between 10 and 20 $mS.m^{-1}$ to sand or loamy sand over loam profiles, and EC_{25} -values between 20 and 30 $mS.m^{-1}$ to sandy loam or loam profiles. Sudduth et al. (2005) try to relate EC_a data to measured soil properties across a wide range of soil types, management practices, and climatic conditions. In this study correlations of EC_a with clay content and cation exchange capacity (CEC) were generally highest and most persistent across all fields and EC_a data types. Other soil properties (soil moisture, silt, sand, organic C, and paste EC) were strongly related to EC_a in some study fields but not in others. Regressions estimating clay and CEC as a function of EC_a across all study fields were reasonably accurate ($r^2 \geq 0.55$). Thus, it may be feasible to develop relationships between EC_a and clay and CEC that are applicable across a wide range of soil and climatic conditions.

Precision agriculture studies relating crop yield directly to EC_a have met with inconsistent result due to the complex interaction of soil properties that influence the EC_a measurement, thereby confounding results (Corwin, Lesch, 2003). These soil properties include soil salinity, clay content, organic matter, bulk density (ρ_b), and soil temperature (Rhoades et al., 1999; Corwin, Lesch, 2003).

In instances where yield correlates with EC_a , spatial measurements of EC_a can be used in a precision agriculture context (Corwin, Lesch, 2005). They studied the relationship between cotton yield and apparent soil electrical conductivity. The result showed that the correlation of EC_a to yield at the sixty studied sites was 0.51. The moderate correlation between yield and EC_a suggests that some soil properties influencing EC_a measurements may also influence cotton yield.

Precision horticulture and spatial analysis applied to orchards are a growing and evolving part of precision agriculture technology. The aim of this discipline is to reduce production costs by monitoring and analysing orchard-derived information to improve crop performance in an environmentally sound manner. Georeferencing and geostatistical analysis coupled to point-specific data mining allow to devise and implement management decisions tailored within the single orchard (Manfrini, 2009). Aggelopoulou et al. (2010) described the yield and quality of apples and consider the potential for site-specific management of these parameters in their study related to apple orchard. In this study the yields of the two apple varieties 'Red Chief' and 'Fuji' were measured and found to be

related with several quality characteristics in negative correlation. The general patterns of spatial variation in several variables suggested that changes in topography and aspect had important effects on apple yield and quality.

In this study we produced yield and some pomological properties maps such as yield in tree cross sectional area, trunk cross sectional area (TCSA) and canopy area (CA) maps, in order to determine relationship between these parameters and soil electrical conductivity (EC_a) characteristics in different apple varieties, as well as analyze spatial variation in apple orchard.

Materials and methods

Site description. The study site was a 0.5 ha apple orchard of Ankara University's Haymana Research Station (36 473722 E, 4384978 N in universal transverse mercator (UTM) coordinate system) (Fig. 1).

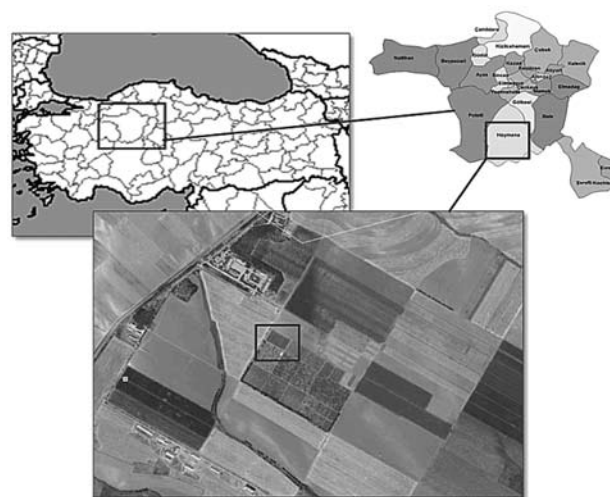


Figure 1. Map showing the location of Haymana Research Station and its apple orchard

The laboratory results of soil sampling using soil texture triangle showed that soil texture is clay (soil texture triangle, showing the 12 major textural classes, and particle size scales as defined by the USDA). The results of soil texture analysis were given in Table 1.

Table 1. Results of soil texture analysis

Sample No.	Depth cm	Sand %	Silt %	Clay %
1	20	27.6	16.4	56.0
2	30	26.4	17.3	56.3
3	40	25.5	17.5	57.0
4	60	25.3	17.6	57.1
5	90	25.7	16.1	58.2
6	120	25.2	15.4	59.4
7	20	25.6	20.8	53.6
8	30	21.2	22.6	56.2
9	40	23.5	19.6	56.9
10	60	23.9	17.4	58.7
11	90	22.8	15.4	61.8
12	120	25.3	14.1	60.6

The orchard was planted in 2003 with seven apple cultivars: ‘Royal Gala’, ‘Red Chief’, ‘Breaburn’, ‘Mondial Gala’, ‘Jonagold’, ‘Fuji’ and ‘Mitch Gala’. The orchard has 21 rows, 3 rows with 38 trees for each cultivar (Fig. 2). The inter-row spacing is 3 m and the intra-row tree spacing is 1.5 m. There are also extra rows with all the varieties in 4 rows and 38 trees in each row.

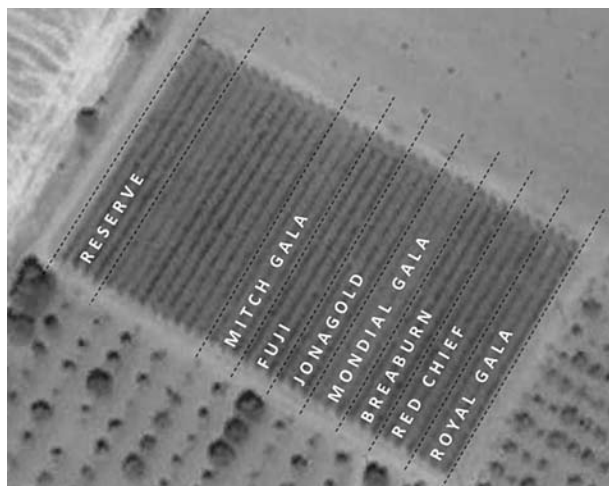


Figure 2. The placement of trees and order of varieties

EM38 and principle of operation. The soil electrical conductivity was measured using the EM38 instrument. The instrument as shown in Figure 3 is a commercially available soil contact-less sensor working on the principle of electromagnetic induction.

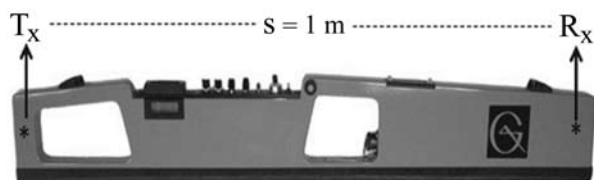


Figure 3. The photograph of the EM38 sensor showing the location of transmitter coil (T_x), receiver coil (R_x) and inter coil spacing

The EM38 is a widely-used example of an electromagnetic instrument for soil sensing developed by “Geonics” Ltd. (Ontario, Canada). It comprises two electrical coils, one a transmitter (T_x) and the other a receiver (R_x), placed 1 metre apart in a wooden frame, a battery and digital readout. The transmitter current generates eddy-like loops in the ground. These currents also generate a secondary magnetic field and the ratio between the secondary and primary fields are proportional to the electrical conductivity of the ground material. The depth of soil penetration depends on the inter-coil spacing, the height of the instrument above the ground and chosen operation mode (1.5 meter in vertical and 0.75 meter in horizontal mode).

The transmitting coil induces a magnetic field that varies in strength with depth in the soil. The rela-

tive strength of the magnetic field is illustrated by the relative diameter of the circles in Figure 4. The magnetic field is strongest about 40 cm below the soil surface and has an effective sensing depth of about 1.5 m. A receiving coil reads primary and secondary “induced” currents in the soil. It is the relationship between these primary and secondary currents that measures soil conductivity. In Figure 4, the thicker circles illustrate soils that are better conductors of electrical current. Clay soils have a higher electrical conductivity than coarser textured soils, so when a clay horizon is nearer the surface (Fig. 4 b), the EM sensor reading is higher. Deeper top soils having a clay horizon further below the soil surface (Fig. 4 a) are less conductive to electrical current and have lower EM readings.

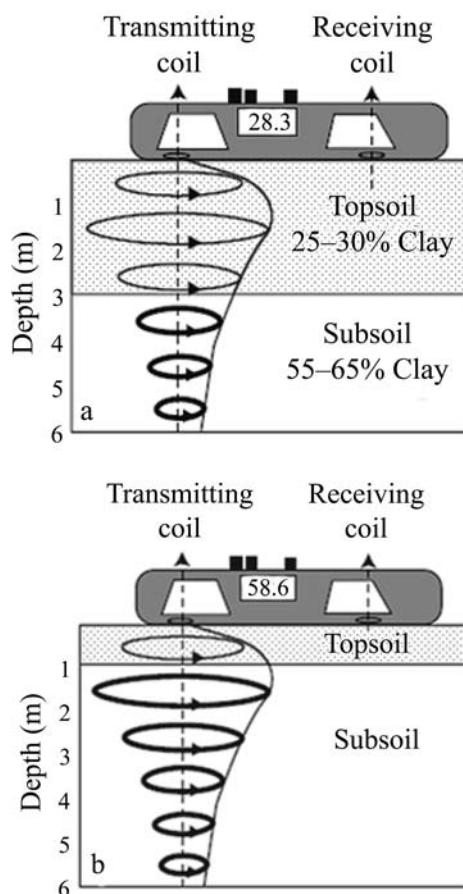


Figure 4. EM38 principle of operation in soils

EC_a data acquisition. To determine apparent soil electrical conductivity, the on-the-go EM38 survey was conducted on the entire study area along the rows, 3 m transects near the tree root zone area (0.5–1 m from each tree). The EC_a data collection process was carried with EM38 sensor that is equipped with both global positioning system (GPS) receiver and field PC was carried at the height of approximately 20 cm above the soil surface in vehicle dipole orientation at three replications where the measurements were taken at a constant speed of progress. A GPS receiver was used to geo-reference EC measurement. The readings were transferred to Allegro field PC at the required position. In order to get EC_a data from the EM38 sensor

the reading was acquired every 2 seconds and saved in *.G38 extension (Geonics EM38 data format) after georeferenced with coordinate data got from GPS receiver.



Figure 5. Non-contact EM38 sensor using EM principle to measure apparent soil electrical conductivity

Yield and pomological data collection. Spatial distribution of apple yield in each variety of trees, also pomological features data were collected using random sampling methods and GPS. Pomological features and yield data were collected during June and September 2010 harvest season respectively. To determine yield per unit cross sectional area, at first trunk cross sectional area (TCSA) was determined from circumference measurements just above the graft line of each tree and then used to calculate yield per unit cross sectional area data. The canopy area of each tree was aquired using the width and length of canopy in ellipse equation. All of these data combined with geographic information data were used to produce yield and pomological characteristics maps and compare with apparent soil electrical conductivity map. Apparent soil electrical conductivity map was produced using *ArcGIS 9.3* software.

Classical statistics and spatial variability maps and interpolation method. The descriptive statistics (mean, variance, coefficient of variation, correlation) were carried out with *Excel Microsoft Office* software. The coefficient of variation (CV%) has also been used for expressing variability on a relative basis allowing the variability of different parameters to be compared.

$$CV\% = \frac{\delta}{\mu} \times 100,$$

where δ and μ are standard deviation and arithmetic mean of the population, respectively.

In order to produce maps, the coordinate of each sample trees was determined using GPS receiver and converted to XYZ files using *Excel* software. EC_a readings were also converted to XYZ files using existing software (Dat38). Afterward *Excel* files were saved as *.dbf extension files (dBASE filename) and then

were converted to maps with GIS software such as *ArcGIS 9.3*. In order to interpolate each map, polynomial regression method was chosen as one of the map interpolation methods (Akdemir, Blackmore, 2004). Then, the behaviour of each parameter was investigated in recorded point by using polynomial curves and determined their relationship in terms of apparent soil electrical conductivity (EC_a), yield and canopy area by calculated R^2 values in linear regression method. In addition, in order to determine the relationship between apparent soil electrical conductivity and yield in every apple variety R^2 values were calculated using non-linear regression method.

In addition, we used Moran's autocorrelation coefficient to quantify whether the distribution of a trait among a set of species is affected or not by their phylogenetic relationships.

Moran's I is an index of the degree of spatial autocorrelation, as described by Cliff and Ord (1981):

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n (x_i - \bar{x})^2}.$$

The global autocorrelation (I) is computed for the variable of interest (X) based on the variable mean (\bar{x}) and contiguity matrix W_{ij} for all n spatial units indexed by i, j . The expected mean and variance for random distributions is determined as:

$$E(I) = \frac{1}{(n-1)}$$

$$E_N(I) = \frac{n^2 S_1 - n S_2 + 3 S_0^2}{S_0^2 (n^2 - 1)},$$

where

$$S_0 = \sum_{i=1}^n \sum_{j=1}^n W_{ij},$$

$$S_1 = \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n (W_{ij} + W_{ji})^2,$$

and

$$S_2 = \sum_{i=1}^n \left(\sum_{j=1}^n W_{ij} + \sum_{j=1}^n W_{ji} \right)^2.$$

Then the test statistic under a null hypothesis of complete spatial randomness is:

$$Z = \frac{I - E(I)}{\delta^2(I)}.$$

Positive values of I indicate spatial dependence among values. If $Z \geq 1.96$ and $I \approx 1.0$ then X is strongly spatially structured at the $\alpha = 0.025$ level of confidence; if $Z \leq -1.96$ and $I \approx -1.0$ then X is uniform at $\alpha = 0.025$; if $-1.96 < Z < 1.96$ and $I \approx 0$ then X is uncorrelated.

Anselin (1995) showed that Moran's I can be applied locally to evaluate the degree of autocorrelation for a given location, where the summation for i, j is over a local neighbourhood, resulting in a value

I_i computed for each sample. The localized Moran's I provides a test of locational relevance of the global Moran's I index and thus serves to provide locational information on deviations from an expectation of strict stationarity (Anselin, 1995). As with the global Moran's I index, large positive values indicate strong local autocorrelation. In addition, the expected value, variance, Z statistic and probability of Z were computed for each sample. The Moran's I index was computed using the global Moran's I index tool in *ArcGIS 9.3* software.

Results and discussion

Classical statistics. Table 2 is a summary by variety of apple trees that shows apparent soil electrical conductivity distribution, yield and pomological feature variability in terms of coefficient of variation.

For this reason, in order to investigate spatial variation of each parameter, average and standard deviation (SD) of each series of data was determined and used to calculate coefficient of variation. As a result, apparent soil electrical conductivity was changed between 25–42 mS.m⁻¹ and shows clay soil texture (Clay, 2006) as the laboratory results proved it. In addition, calculated CV% (coefficient of variation) and the variable range are given in Table 2.

Table 2. Coefficient of variation (CV%) of apparent soil electrical conductivity, yield and pomological characteristics for all varieties of apple tree

Variety	Coefficient of variation (CV%)				
	Yield/ tree	Yield/ TCSA	TCSA*	CA*	EC _a *
'Royal Gala'	73.62	67.95	20.94	27.16	6.8
'Red Chief'	76.66	75	33.64	39	7.1
'Breaburn'	96.5	75	20.99	25.27	8.78
'Mondial Gala'	128.5	74.3	28.36	37	10.55
'Jonagold'	66.93	57.14	34.28	21.24	14.97
'Fuji'	56.51	38.1	27.5	34.57	9.51
'Mitch Gala'	37.66	50	23.45	24.58	11.63

* TCSA – trunk cross sectional area (cm²), CA – canopy area (m²), EC_a – apparent soil electrical conductivity (mS.m⁻¹)

According to the results, in all varieties, apparent soil electrical conductivity shows no certain changes in CV% (CV% < 15) but this value was in optimum range of variation (15 < CV% < 50) for trunk cross-sectional area. The calculated value for yield and other pomological features shows high variability (CV% > 50), but this value was less for 'Mitch Gala' and 'Fuji' varieties.

Furthermore, a non-linear regression method was used to show the relationship between yield and apparent soil electrical conductivity. The same method was also used to determine the relationship between yield/TCSA and apparent soil electrical conductivity.

Table 3 shows the R² values in different apple varieties. This analysis shows a strong relationship between yield and apparent soil electrical conductivity in 'Red Chief' variety with 0.94 and the same value was determined for yield/TCSA and apparent soil electrical conductivity in 'Jonagold' as 0.44.

Table 3. Yield and yield per trunk cross sectional area (TCSA) compared to apparent soil electrical conductivity (EC_a) using non-linear regression value (R²)

Variety	Yield/tree to EC _a	Yield/TCSA to EC _a
'Royal Gala'	0.01	0.02
'Red Chief'	0.94	0.09
'Breaburn'	0.03	0.23
'Mondial Gala'	0.15	0.23
'Jonagold'	0.14	0.44
'Fuji'	0.25	0.04
'Mitch Gala'	0.19	0.03

Spatial variability and interpolation. Apparent soil electrical conductivity map, yield and some pomological characteristics maps were performed with *ArcGIS 9.3*. Measurements of EC_a, yield per tree and yield per trunk cross sectional area (TCSA) and canopy area (CA) were used to produce interpolated spatial maps using natural neighbour method in spatial analyst tools. Figure 6 show the distribution of measured soil and tree parameters.

According to coefficient of variation (CV%), there is not any significant distribution in apparent soil electrical conductivity but this value showed variability in some parameters in different varieties as described in previous section. In addition to this parameter, Moran's I index was calculated as an index that shows whether the parameters distribution is clustered or dispersed. Table 4 shows Moran's I index and Z score values for all varieties in the orchard.

The results obtained with calculation of Moran's I index showed that 'Red Chief' variety was proximately less than 5% clustered, while the other varieties were not correlated by yield per tree. In comparison with TCSA, all the varieties were uncorrelated. In spite of being less than 5% clustered by CA in 'Breaburn', the values show less than 5% dispersed by EC_a in the same variety. Table 5 gives the results of being dispersed, clustered or uncorrelated (random) in all of the varieties.

Apart from the Moran's I indexes that were determined, in order to compare the behaviour of changes in terms of sample points the polynomial regression curves were produced for each parameter. In this comparison of data the polynomial curves were produced for each variety as shown in Figure 7.

As it is clear from the Figure 7, there is the same behaviour in all varieties in terms of yield per tree, yield per trunk cross sectional area (TCSA) and

canopy area (CA) but apparent soil EC_a and TCSA data in spite of having similar curves do not show the same behaviour in comparison with the other parameters. Apparent soil electrical conductivity increased in all the varieties except for 'Royal Gala' and this increase in EC_a data was followed by TCSA values. What can

be interpreted from the chart below is that there is rising trend in all the parameters such as yield per tree and tree cross sectional area, TCSA, CA and apparent soil EC_a in 'Mondial Gala', 'Jonagold', 'Fuji' and 'Mitch Gala'. However, there is not any significant relation between the parameters in other varieties.

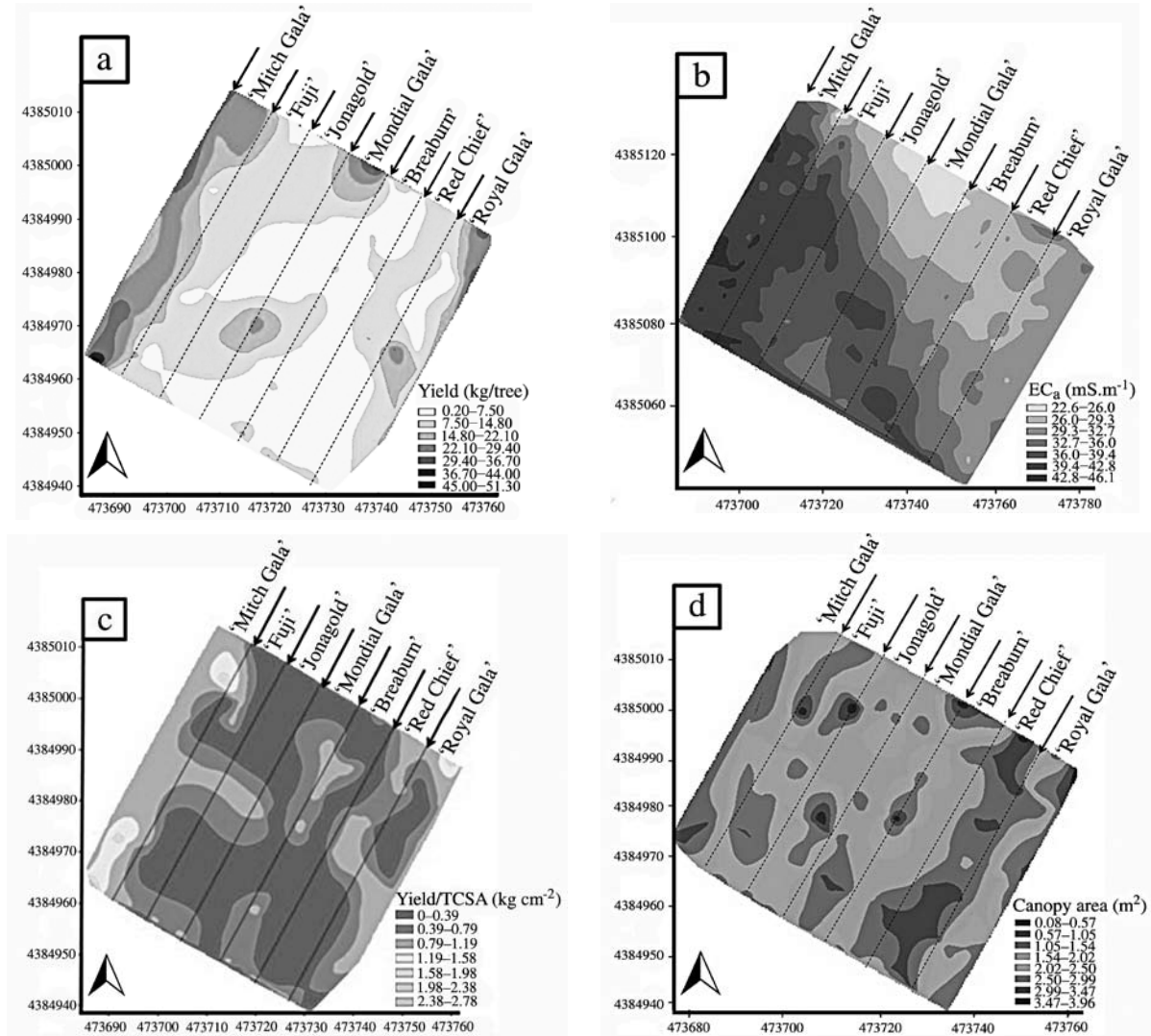


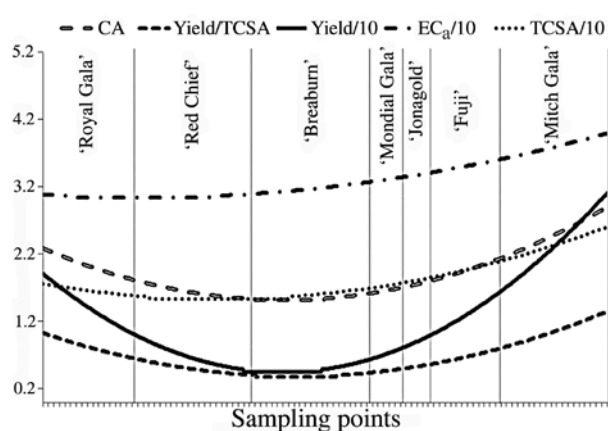
Figure 6. Natural neighbored map of soil electrical conductivity and tree characteristics: a) yield per tree, b) apparent soil electrical conductivity (EC_a), c) yield per trunk cross sectional area (TCSA) and d) canopy area (CA)

Table 4. Moran's I index (spatial autocorrelation) and Z score values for yield per tree, apparent soil electrical conductivity (EC_a), yield per trunk cross sectional area (TCSA) and canopy area (CA)

Variety	Yield/tree		EC_a		Yield/TCSA		TCSA		CA	
	Moran's I index	Z score	Moran's I index	Z score	Moran's I index	Z score	Moran's I index	Z score	Moran's I index	Z score
'Royal Gala'	-0.11	-0.29	0.07	0.8	0.11	1.1	-0.16	-0.54	-0.23	-0.98
'Red Chief'	0.52	2.12	-0.41	-1.38	0.55	2.2	-0.03	0.08	-0.02	0.13
'Breaburn'	-0.37	-1.42	-0.5	-1.98	-0.34	-1.24	-0.15	-0.47	0.46	2.27
'Mondial Gala'	-0.85	-1.24	-1.42	-2.71	-0.66	-0.91	0.45	1.3	-0.48	-0.62
'Jonagold'	-0.6	-0.97	0.63	2.16	-0.71	-1.66	-0.15	0.29	-0.37	-0.44
'Fuji'	-0.24	-0.6	0.2	1.16	-0.49	-1.46	0.02	0.45	0.06	0.71
'Mitch Gala'	-0.34	-1.2	0.04	0.35	-0.11	-0.26	0.35	1.53	0.01	0.21

Table 5. Results of computed Moran's *I* index and Z score showing dispersed, clustered or random

Variety	Yield/tree	EC _a	Yield/TCSA	TCSA	CA
'Royal Gala'	Random	Random	Random	Random	Random
'Red Chief'	Less than 5% clustered	Somewhat dispersed	Less than 5% clustered	Random	Random
'Breaburn'	Somewhat dispersed	Less than 5% dispersed	Random	Random	Less than 5% clustered
'Mondial Gala'	Somewhat dispersed	Less than 1% dispersed	Random	Somewhat clustered	Random
'Jonagold'	Random	Less than 5% clustered	Somewhat dispersed	Random	Random
'Fuji'	Random	Somewhat clustered	Somewhat dispersed	Random	Random
'Mitch Gala'	Somewhat dispersed	Random	Random	Somewhat clustered	Random

**Figure 7.** Polynomial curves used to interpolate the behaviour of changes in terms of sampling points

Conclusions

To determine the relationship between the apparent soil electrical conductivity (EC_a) and tree parameters such as yield and pomological characteristics numerous techniques have been applied. Using these techniques and from the data presented, it can be concluded that:

1. There is significant variability in yield per tree and yield per trunk cross sectional area (TCSA) in all the varieties in terms of coefficient of variation (CV%), whereas calculated CV% values do not show any significant variation in the other parameters such as soil EC_a and TCSA and canopy area (CA).

2. The spatial variability of being clustered or dispersed as shown by Moran's *I* index, determined that there were not any significant changes in distribution of measured parameters. While the Moran's *I* index shows autocorrelation in 'Red Chief' in terms of yield per tree and yield per trunk cross sectional area values, only 'Breaburn' having autocorrelation in apparent soil electrical conductivity values.

3. Polynomial curves were plotted to show the changes of measured parameters in recorded points. The results showed the similar changes between yield per tree, yield per TCSA and CA. The same beha-

viour was also observed between apparent soil EC_a and TCSA in all varieties.

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Išmatuoto dirvos elektrinio laidumo ir ryšio tarp obelių įvairių veislių derliaus pomologinių savybių nustatymas

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Santrauka

Sodams taikoma tiksloji sodininkystė bei erdvinė analizė yra besiplėtojanti ir besivystanti tiksliosios žemdirbystės dalis. Tyrimų tikslas – sudaryti derliaus bei pomologinių savybių žemėlapius, siekiant nustatyti ryšį tarp šių rodiklių ir išmatuoto dirvos elektrinio laidumo (EC_a) įvairių veislių obelių savybių, taip pat išanalizuoti erdvinę variaciją obelių sode. Tyrimai atlikti Ankaros universiteto Žemės ūkio fakulteto Haymana tyrimų stoties obelių sode. Tyrimų metu dirvos laidumo vertės išmatuotos EM38 jutikliu. Šie duomenys panaudoti žemėlapiams sudaryti, kurie buvo palyginti su derliaus ir pomologinių savybių žemėlapiams, taikant klasikinius statistinius bei erdvinės analizės metodus. Didžiausia netiesinės regresijos tarp EC_a ir derliaus vertė nustatyta veislės ‘Red Chief’ ($R^2 = 0.94$), didžiausia apskaičiuota vertė derliui skerspjūvio plote nustatyta veislės ‘Jonagold’ ($R^2 = 0.44$). Kiti rodikliai – variacijos koeficientas ir Morano I indeksas – buvo naudojami siekiant nustatyti kiekvienos vertės variaciją ir autokoreliaciją.

Reikšminiai žodžiai: išmatuotas dirvos elektrinis laidumas, derliaus kartografavimas, pomologinės savybės.