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SPATIAL INFLUENCE OF PHYSICAL AND CHEMICAL PARAMETERS ON MANAGEMENT ZONE DEFINITION IN APPLE ORCHARDS

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ABSTRACT: Precision agriculture adoption in Brazilian apple orchards is still incipient. This study aimed at evaluating the spatial variability of certain soil properties as soil density, soil penetration resistance, electrical conductivity, yield, and fruit quality in an apple orchard through digital mapping, as well as assessing the correlation between these factors by means of geostatistics, establishing management zones. Forty representative points were set within 2.5 hectares of apple orchard, wherein soil samples were collected and analyzed, besides measurements of fruit quality (Brix degree, size or diameter, pulp firmness and color) to generate an overall index quality. We concluded that the fruit quality indexes, when isolated, did not show strong spatial dependence, unlike the index of fruit quality (FQI), derived from a combination of these parameters, allowing orchard planning according to management zones based on quality.

KEYWORDS: apple trees, precision fruit-growing, electrical conductivity in orchards.

INFLUÊNCIA ESPACIAL DE PARÂMETROS FÍSICO-QUÍMICOS DE SOLO NA DEFINIÇÃO DE ZONAS DE MANEJO EM POMAR DE MAÇÃS

RESUMO: A aplicação da agricultura de precisão em pomares de maçã no Brasil ainda é incipiente. O objetivo do presente trabalho foi avaliar a variabilidade espacial, através de mapeamento digital, da densidade do solo, resistência do solo à penetração, condutividade elétrica, produtividade e qualidade dos frutos em um pomar de maçãs e verificar a correlação entre estes fatores através de uso de geoestatística para o estabelecimento de zonas de manejo em pomar de maçã. Foram estabelecidos 40 pontos representativos em 2,5 hectares de pomar, de onde foram coletadas e analisadas amostras de solo e mensurados dados relativo à qualidade dos frutos (°Brix, calibre ou diâmetro, firmeza e cor), utilizados para geração de um índice geral de qualidade de frutos, também mapeado. Concluiu-se que os índices de qualidade de frutas isolados não apresentaram forte dependência espacial, ao contrário do índice de qualidade dos frutos (IQF), derivado da junção desses parâmetros, permitindo o planejamento do pomar segundo zonas de manejo baseadas na qualidade.

PALAVRAS-CHAVE: macieiras, fruticultura de precisão, condutividade elétrica em pomares.

INTRODUCTION

Fruit farming is in constant evolution around the world. Hence, progress monitoring is a key aspect when targeting high productive efficiency and expected profitability achievement. This is expected through a well elaborated planning of all actions to be taken in the field, as well as proper use of new technologies (ARNÓ et al., 2009).

The advanced knowledge and correct characterization of Brazilian orchards relies on obtaining a series of information procedures that surpass the traditional production model. In this

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way, opportunities to apply Precision Agriculture (PA) techniques are created as a planning tool for the productive environment and subsequent support for decision-making (COELHO, 2003).

The basis of PA application, which incorporates a great number of georeferenced points, distributed in plots and enabling description of spatial variability, has been pointed as an economic obstacle to a more widespread use in Brazilian fruit growing. However, it is through detailed sampling that spatial variations are analyzed by means of geostatistical application, enabling subsequent elaboration of maps and delimitation of differentiated management areas (FARIAS, 2002).

Regarding fruit-growing and other perennial crops, as well as chemical parameters, physical parameters also undertake a dimension of greater importance once physical management of soils is only possible in long intervals, such as decades. Therefore, variables like soil density and resistance to penetration must be investigated as they can directly affect plot yield and fruit quality. In this sense, the application of remote sensors that enables description or correlation of real parameters with results produced in mapping, would allow a substantial reduction of costs and increased technology adoption (CIRANI & MORAES, 2010).

One of the methods that have been tested in several areas in Brazil, and now in precision fruit growing, is the electrical conductivity analysis of soils (MOLIN et al., 2005). Its aim in fruit-growing areas is to combine with important factors of soil such as clay content, soil-water content, cation exchange capacity, exchangeable calcium and magnesium content, obstruction layer depth, and organic matter content to establish management zones (MOLIN & CASTRO, 2008).

The aim of this study was to evaluate spatial variability, through digital mapping, of soil density, soil penetration resistance, electrical conductivity, fruit quality, and yield, in an apple orchard and verify correlation between these factors through geostatistics, for the establishment of management zones.

MATERIAL AND METHODS

The experimental area was set in a commercial apple orchard located in the city of Vacaria, RS, Brazil. It was composed of two plots of Fuji variety, Nagafu-6 clone, 13 years old, distributed in ten lines chosen from a total of 40, distributed so there was alternation between a line with sampling points and one without.

Each of them consisted of around 230 plants distant 4.0 m from each other in lines and approximately 1.4 m in between plants, totaling approximately 9,200 plants in 2.5 hectares, with the research project in the first year.

The predominant orchard soil is typical dystrophic Dark-red Latosol (Oxisol), common in the Vacaria-RS region (EMBRAPA, 1999), which is characterized by gently wavy to wavy reliefs, climate categorized as Humid Subtropical, altitude classified by Köppen as Cfb (PEEL et al., 2007), and annual average rainfalls of around 1,400 mm year^{-1}, according to data from the local meteorological station.

Soil management in adult orchards is carried out with native vegetation coverage between lines, and mechanical or chemical hoeing on a 1-metre strip for each side from plant line. Fertilization follows recommendation proposed by ROLAS (2004) method, according to soil analysis at every three years.

Forty sampling points were marked and georeferenced with the aid of a submetric DGPS receptor, TRIMBLE brand, GEO XT model, distributing an approximate exploratory range with 8 points along two apple-tree lines from where material was taken for soil conventional analysis in commercial laboratory, according to figure 1.

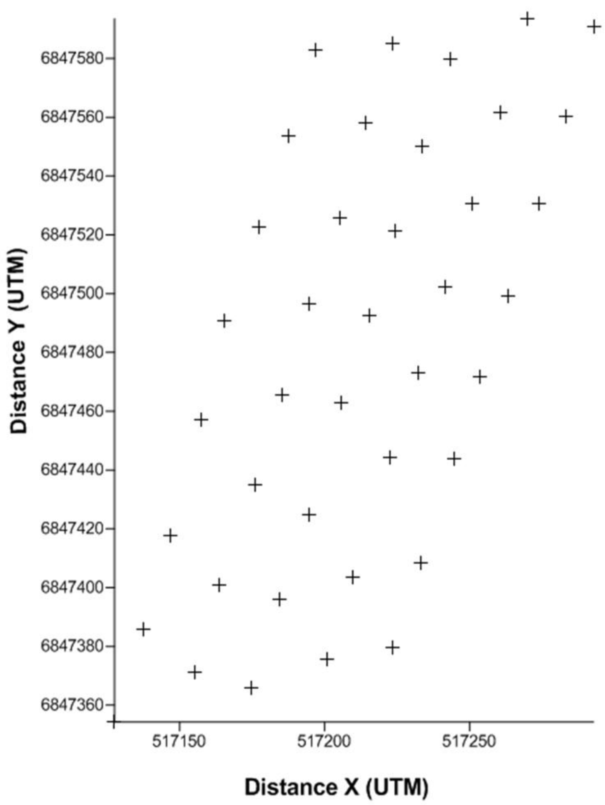


FIGURE 1. Diagram of points within plots according to UTM coordinates.

Regarding the same area, soil electrical conductivity analysis was also carried out (µS cm^{-1}), in 0-30cm and 0-90cm depths, using a magnetic induction sensor (conductivimeter), Veris brand, 3100 model, that allows conductivity readings in the two depth zones individually and towed by a tractor of 75 cv. The reading was conducted between lines, with 1-second intervals between collections and generated 4,994 data.

In addition, at each of the 40 points the mechanical resistance of the soil to penetration was obtained (MPa) (CAMARGO et al., 2009) using a penetrometer of manual plunger, which was used to collect data in and between lines, in strips of 0-10cm depth. Soil samples were collected at each point according to standards recommended by ROLAS (2004) for clay content analysis and variables related to soil chemistry, which were determined in a certified commercial laboratory (ARSHAD et al., 1996).

In order to collect the fruits, each point was represented by the plant always located at its right side. To determine yield per plant and yield per point, 10 representative samples were collected, as three fruits of average weight from either side of the representative plant were selected at random. Moreover, the total number of fruits was counted in each sampled plant and multiplied by the average weight to obtain yield estimates in kg $plant^{-1}$ at each point.

From the total of 40 sampling points, other variables relating to fruit quality were acquired: a) Size, measured with a mechanical caliper (related to fruit diameter inversely proportional to number of fruits contained in a standard box of 18.0 kg.); b) °Brix concentration (% de soluble solids in sucrose solution) through refractometry, refractometer ITREFD-45 (precision 0.1%); c) Pulp firmness (pressure of pulp obtained with penetrometer of Fruit Pressure Tester brand FT 327 model, with 8mm nozzle, in kg*f*, with precision 0.5%+2 digits); d) Color "L" (dimensionless, measures luminosity of surface, measured by colorimetry), color "a" (dimensionless, measures variation between green and red of surface through colorimetry), measured with portable digital colorimeter Minolta, CR-400 model.

Each one of these variables was numerically classified in one of the following four categories, low, average, good, and high, receiving values from one (low) to four (high).

Categorization was necessary to evaluate promptly the fruit quality and through a sum for each point, it was possible to devise a fruit quality index - FQI (dimensionless). The higher the accumulated value, the better is the product quality (fruit).

Spatial variability data relating to soil and apple production was analyzed with the aid of geostatistics that verified existence or not of spatial dependence in accordance with sampled distance, with a range of 40 georeferenced points. Data were analyzed through descriptive statistics to determine mean, variance, standard deviation, variation coefficient, maximum and minimum values, asymmetry, and kurtosis. The spatial dependence analysis was conducted through construction and adjustment of semivariograms with a mathematical model of greater adjustment. The criteria to choose the greatest adjustment were based according to VIEIRA (2000), in the trial-and-error method combined with parameters of the jack knifing validation tool. According to VIEIRA et al. (2010), the manually adjusted semivariogram models resulted in better parameters of jack knifing due to freedom of choice for the user, of better adjustment in distinct regions of semivariogram.

The spatial dependence degree (DD) was calculated, which refers to the proportion in percentage of nugget effect (C_1) in relation to plateau (C_0+C_1), considering, according to ZIMBACK (2001), weak dependence <25%, moderate dependence from 26% to 75% and strong dependence > 75%.

When the existence of spatial dependence is identified, the use of kriging as an interpolator enables generations of values in non-sampled points with no tendency and with minimum variation. Interpolated values allow construction of isoline maps.

In order to calculate descriptive statistical analysis and geostatistics, the GEOESTAT program was used (VIEIRA et al., 1983). Isoline maps were generated in the Surfer program (GOLDEN SOFTWARE, 1999).

RESULTS AND DISCUSSION

The descriptive statistical analysis aimed to conduct a data exploratory analysis and resulted, based only on the sampling set, in values of means, minimum, and maximum values within the standards for sampled data, which is, outlier values were not observed. This result indicates that the sampling set by itself will not distort results from the geostatistics analysis to be applied subsequently (Table 1).

The majority of soil physical and chemical data presents low to moderate variation, except from electrical conductivity that presented the highest values of VC (63.95% and 55.9%). The high sampling density (4,994 data) and the high EC variation, with great difference between minimum and maximum values, resulted in asymmetry and kurtosis values distant from zero, indicating non-normality of data frequency distribution, according to Kolmogorov-Smirnov test. Non-normality was also identified for penetration resistance between lines and organic matter.

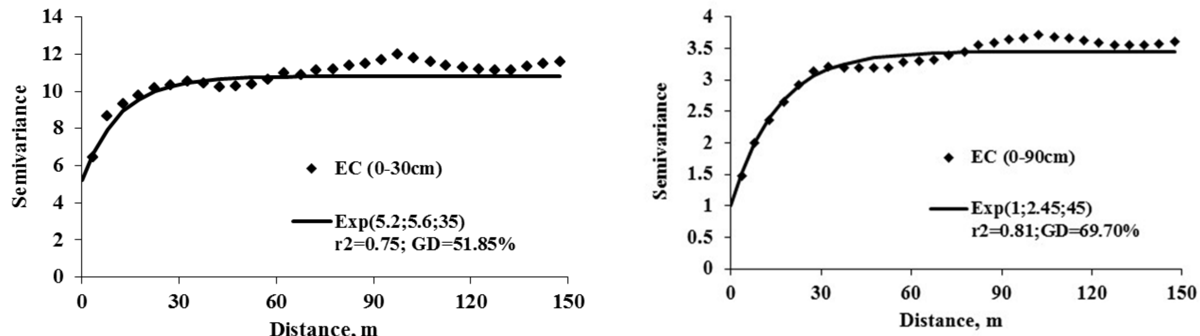
Regarding statistical results related to fruit quality, there was also predominant variation from low to average, except from color “a” (50.23%), and the asymmetry and kurtosis values indicate normal frequency distribution, except from FQI.

TABLE 1. Descriptive statistics of soil-related factors: penetration resistance (PR, MPa) in plant line and between plant lines from 0 to 10 cm depth; clay content (Clay, %); pH in water; organic matter content (OM, %); cation exchange capacity (CEC, $cmol_c\ dm^{-3}$); base saturation (V, %); soil electrical conductivity (EC, $\mu S\ cm^{-1}$) from 0 to 30 cm and from 0 to 90 cm depths. Fruit quality related factors as size, ^{o}Brix, pulp firmness (Firmness), color "L", color "a", fruit quality index (FQI), and fruit yield (Yield, kg $plant^{-1}$).

Variables	Mean	Variance	Deviation	V.C.	Minimum	Maximum	Asymmetry	Kurtosis	Kolmogorov Smirnov test (D)
Physical and Chemical of soil									
PR line	3.667	1.183	1.088	29.67	1.86	5.88	0.1938	-0.9335	0.1229*
PR between lines	6.188	0.4659	0.6826	11.03	4.21	6.86	-0.9731	0.5474	0.18746
Clay	41.2	40.88	6.394	15.52	26	55	-0.3334	-0.2909	0.11083*
pH water	6.945	0.2107	0.4591	6.61	5.7	7.8	-0.8127	0.7837	0.13596*
Organic matter	3.582	1.025	1.012	28.26	1.1	5	-1.399	0.9905	0.26004
CEC	19.57	2.869	1.694	8.655	14.7	23.5	-0.1688	0.7168	0.06509*
V (%)	86.71	33.4	5.78	6.666	65.4	93.2	-1.644	3.712	0.13066*
EC 0- 30 cm	5.169	10.93	3.306	63.95	0.1	35.8	2.374	9.396	0.13946
EC 0- 90 cm	3.332	3.47	1.863	55.9	0.1	23.9	2.564	11.29	0.15584
Fruit quality									
Size	138.6	53.4	7.308	5.272	125	150	-0.084	-0.819	0.07704*
^{o}Brix	12.91	1.134	1.065	8.251	11.1	16.8	1.236	3.235	0.1209*
Firmness	16.08	0.9486	0.9739	6.056	13.92	18.08	-0.056	-0.217	0.08385*
Color “L”	56.65	12.04	3.47	6.126	47.87	62.84	-0.929	0.803	0.11792*
Color “a”	8.557	18.48	4.298	50.23	1.8	20.27	0.509	0.062	0.0874*
FQI	11.9	1.938	1.392	11.7	10	15	0.427	-0.439	0.16598
Yield (kg $plant^{-1}$)	25.37	76.07	8.722	34.38	9.478	37.1	-0.567	-0.5372	0.23893*

VC – Variance coefficient (%); *Indicates Normal distribution – Normality test 5% (Kolmogorov Smirnov).

The semivariograms adjusted by spherical, exponential e Gaussian functions presented spatial dependence for the majority of soil physical and chemical parameters, with prevalence of spherical adjustment model, in accordance with GREGO & VIEIRA (2005) who demonstrated that the spherical model was adjusted to all soil physical attributes, considered the major model in soil science studies (Figure 2). A spatial dependence for soil variables was not achieved only for penetration resistance (PR) measured in crop line, and for organic matter (MO), a phenomenon called “Pure Nugget Effect” (Table 2). Considering sampling distance, the high fluctuation in short-distance of these data might have prevented their semivariogram adjustment. The fruit quality parameters presented spatial dependence with spherical and Gaussian adjustment, with exception of ^{o}Brix, color “L”, color “a”, and production per plant, where it was not possible to apply an adjustment function and, therefore, did not present spatial dependence, causing the “pure nugget effect”.



A B

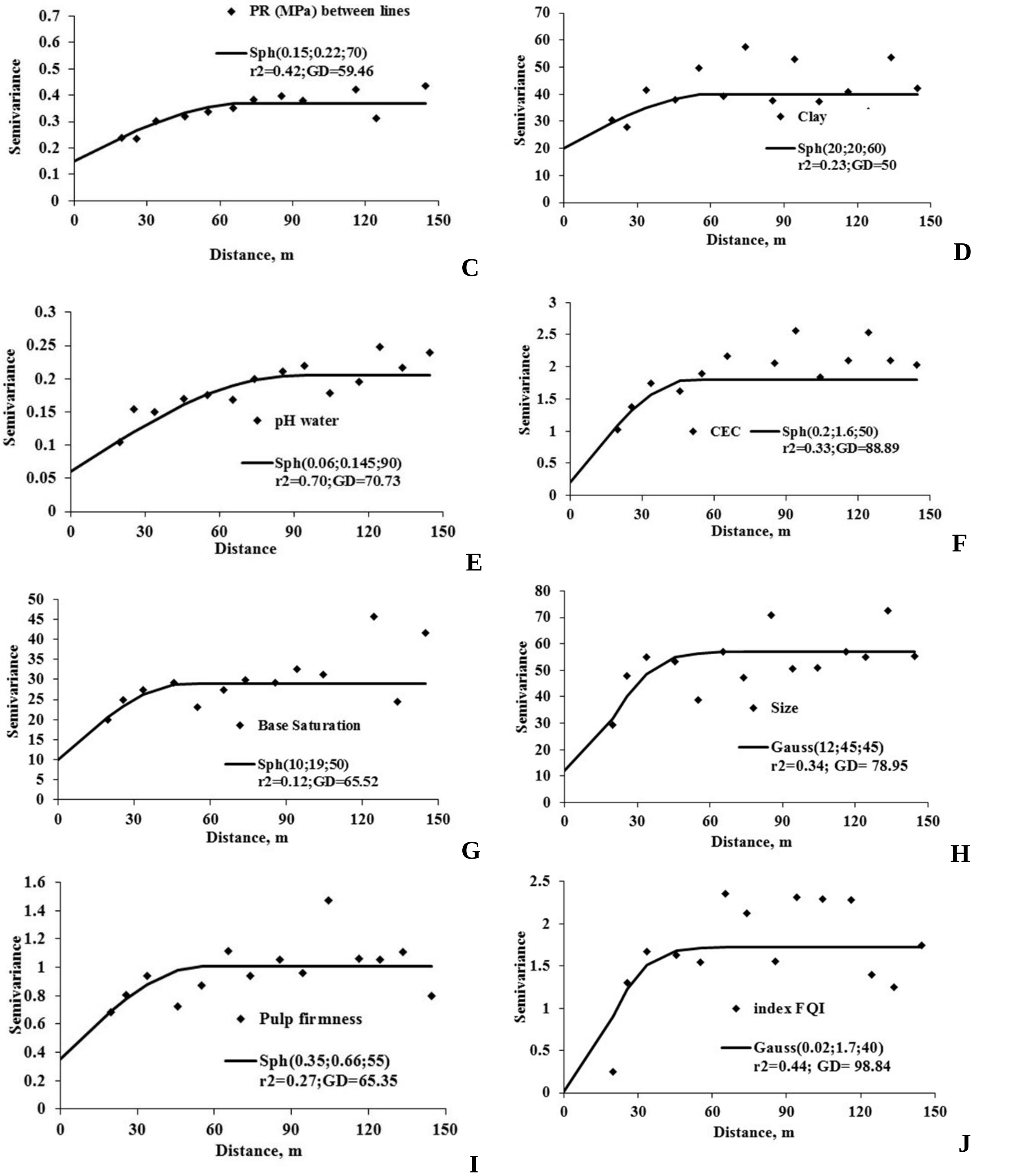


FIGURE 2. Model-adjusted semivariograms and adjustment parameters (adjustment model - nugget effect, structural variance, and range) obtained from data analysis of apple orchard that showed spatial dependence structure. EC – electrical conductivity between 0 and 30 cm (A) and between 0 and 90 cm (B) depths; PR - penetration resistance between lines (C); clay content (D); pH in water (E); CEC – soil cation exchange capacity (F); base saturation (G); fruit size (H); fruit pulp firmness (I); and fruit quality index (J). 29,214 pairs in the first distance lag (3.6 m) for EC data and 43 pairs in the first distance lag (19.68 m) for remaining data.

Spatial dependence reach varied from 35 to 90 m, which means that spatial dependence occurs in this distance range for the variables in this field, supporting similar studies from BIFFI & RAFAELI NETO (2008), about spatial dependence in apple and of CALDERON et al. (2008), about correlation between spatial variability and mango production.

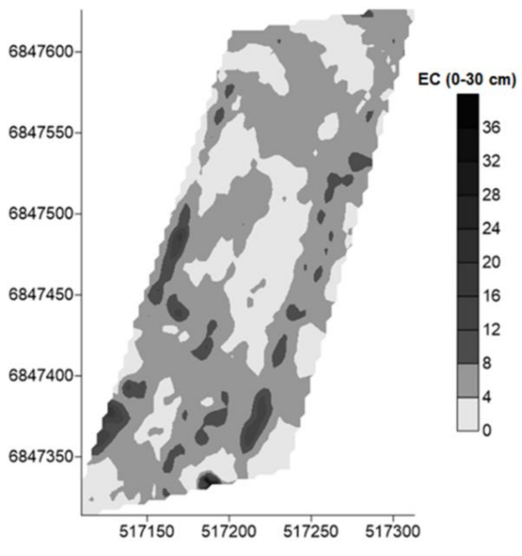
Regarding parameters where semivariogram adjustments were possible, spatial dependence degree (DD), varied from moderate to strong (Table 2), according to ZIMBACK (2001) classification, which indicates that spatial variability occurs in lower distances than the spatial dependence range and for the sampled distance, closer neighbors are similar, which proves the geostatistics hypothesis.

TABLE 2. Adjustment model, adjustment correlation coefficient, classification and degree of spatial dependence for factors related to soil and fruit quality.

Variables	Adjustment model	Correlation coefficient	Dependence degree	Classification of dependence degree
		Physical and chemical of soil		
PR line	Pure Nugget Effect			
PR between lines	Spherical	0.42	59.46	Moderate
Clay	Spherical	0.23	50.00	Moderate
pH water	Spherical	0.70	70.73	Strong
Organic matter	Pure Nugget Effect			
CEC	Spherical	0.33	88.89	Strong
V (%)	Spherical	0.12	65.52	Moderate
EC 0- 30cm	Exponential	0.75	51.85	Moderate
EC 0- 90cm	Exponential	0.93	71.01	Strong
		Fruit quality		
Size	Gaussian	0.05	78.95	Strong
^{o}Brix	Pure Nugget Effect			
Firmness	Spherical	0.10	65.00	Moderate
Color "L"	Pure Nugget Effect			
Color "a"	Pure Nugget Effect			
FQI	Gaussian	0.03	98.84	Strong
Fruit yield (kg plant^{-1})	Pure Nugget Effect			

PR – soil penetration resistance; CEC – cation exchange capacity; V – base saturation; EC – electrical conductivity; FQI – fruit quality index

The variables in which semivariograms presented spatial dependence were submitted to interpolation through kriging and construction of isoline maps due to interpolated values (Figure 3). It suggests that conductivity up to 30 cm, soil CEC, and penetration resistance between lines present stain similarities with greater values in the same directions of the sampled area; however, further studies conducting samplings in other periods are necessary to identify spatial correlation between soil variables.



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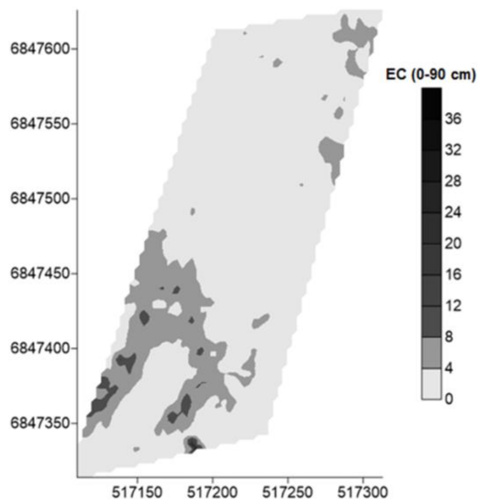
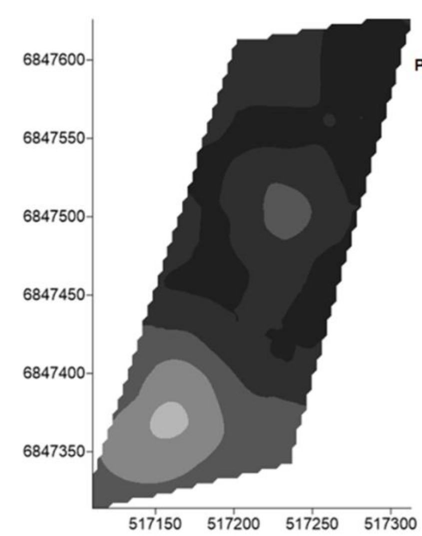


B


PR between lines
7.5
7
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6
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5
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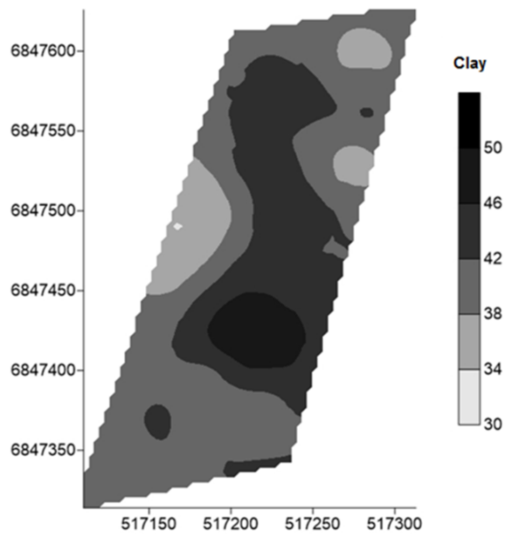
C


Clay
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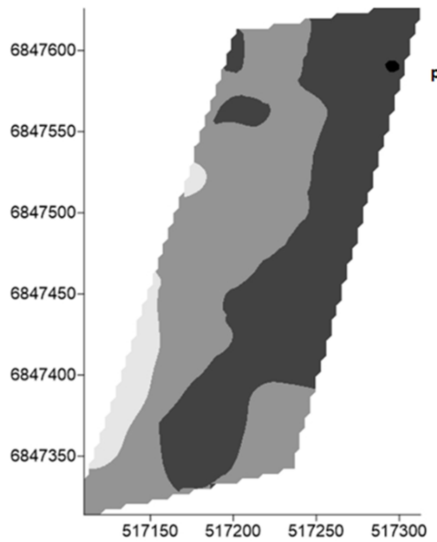
D


pH in water
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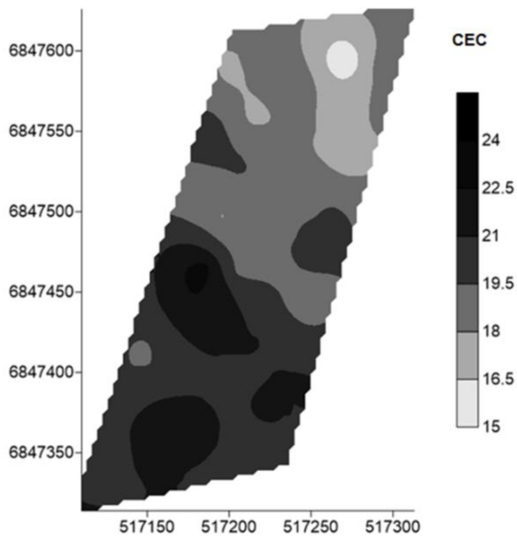
E


CEC
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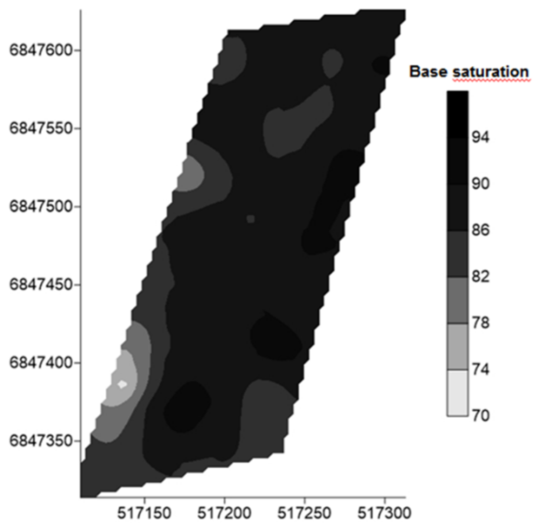
Base saturation
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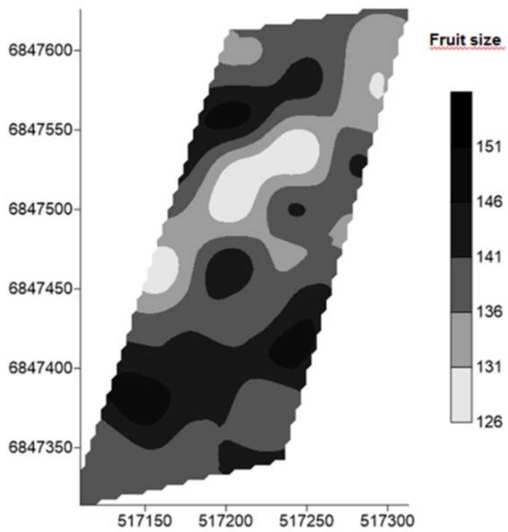
Fruit size
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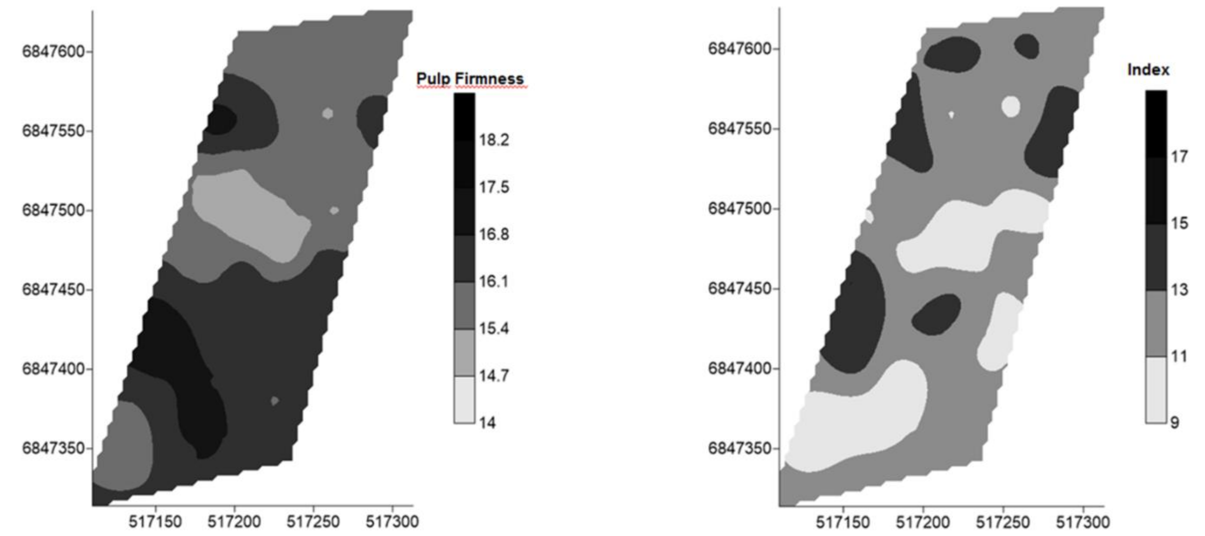
H



I J

FIGURE 3. Isoline maps from krigged values of soil and plant variables with spatial dependence: EC - electrical conductivity between 0 and 30 cm (A) and 0 and 90 cm (B) depths, in µS cm^{-1}; PR - penetration resistance between lines, in MPa (C); clay content, in % (D); pH in water (E); CEC – soil cation exchange capacity, in cmol$_c$ dm^{-3} (F); base saturation, in % (G); fruit size, in mm (H); fruit pulp firmness, in pounds (I); and fruit quality index, dimensionless (J).

Regarding maps related to fruit quality, strong similarities were not visually observed between variability stains, however, in places of greater fruit firmness and size, in the bottom part of the area, the lowest penetration resistances also occurred, greater EC at 30 cm and greater soil CEC, indicating similarity in spatial distribution of fruit quality, soil fertility and soil penetration resistance. This was expected once greater water storage in this area enables greater extraction efficiency through roots, reflecting on fruit quality.

Although yield data was collected in only 10 out of the 40 georeferenced points within the area, it presented significant variation through regions with 9.5 kg plant^{-1} up to 37.1 kg plant^{-1}; however, it was not possible to determine spatial dependence due to the low number of samples. Forthcoming years will require yield data to be collected over all 40 points in order to confirm the presence of spatial dependence through geostatistics analysis.

The values were submitted to Surfer software, for map generation through triangulation using linear interpolation; spatial dependence was disregarded, except for analysis of distribution standards that could assist in future samplings.

However, fruit-growing yield must be regarded differently from production-expressed yield like sugarcane or grains, which are strongly based on produced mass or volume per area (CAMPOS et al., 2009; GUEDES FILHO et al., 2010), as the parameters related to fruit quality present greater relevance. In Figure 4, different levels of production groups can be observed, with an average of 25 kg plant^{-1} in the area.

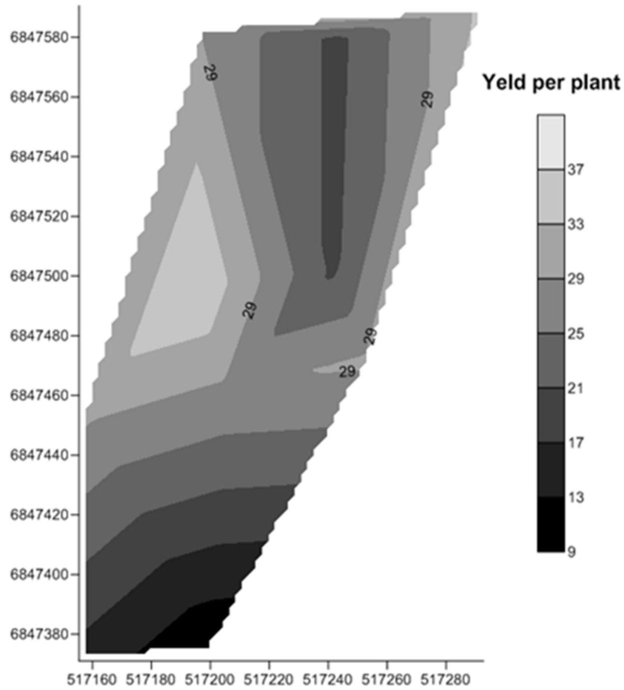


FIGURE 4. Distribution map of fruit yield, in kg plant^{-1}, by triangulation with linear interpolation, which does not consider spatial dependence.

By using information provided by the landowner about the existing drainage network position, it was possible to associate indirectly the soil conductivity, mainly at 30cm depth, with the presence of sub-surface water, because the places with greater response values to the conductivimeter presented greater water accumulation.

During visual analysis of maps, it was possible to verify inverse performance between conductivity and clay, which must be reevaluated in the future. VALENTE et al. (2012) have already observed the relationship between water and conductivity in a study, and NASCIMENTO et al. (2011) have already examined the dependence to local conditions of temperate fruit trees using a conductivimeter.

In this area, the low representativeness might be related to the fact that conductivimeter was used during an intense draught season, in which water was accumulated within field channels and could be identified and best used for apple growth in these places. These results are in accordance with those obtained with peach by TERRA et al. (2011), and according to what was expressed in the yield map of central and side right region. However, this performance must be evaluated in the future.

CONCLUSIONS

The soil electrical conductivity maps presented high variation and minor spots caused by the high number of sampling points (4,994), demonstrating high variability even in small orchard areas. The isolated fruit quality indexes (Brix, size or diameter, pulp firmness, and fruit color) did not present spatial dependence, contrary to the fruit quality index (FQI), derived from the joining of these parameters, which enables orchard planning according to management zones, based on quality.

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