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RESEARCH PAPER

# Spatial variability of soil chemical attributes and productivity and the chemical and physical properties of oranges

Rafaela F. Nicolau, Erivelto Mercante, Marcio F. Maggi, Eduardo G. de Souza, and Eloi Gasparin

Western Paraná State University, Campus Cascavel. Rua Universitária, 2069 - JD. Universitário Prédio de Desenvolvimento de Protótipos. Cep: 85819-110. Cascavel, Paraná, Brazil.

**Abstract**

**R.F. Nicolau, E. Mercante, M.F. Maggi, E.G. Souza, and E. Gasparin. 2014. Spatial variability of soil chemical attributes and productivity and the chemical and physical properties of oranges. Cien. Inv. Agr. 41(3):337-347.** The purpose of this study was to analyze the spatial variability of soil properties and productivity and the chemical and physical properties of oranges (Monte Parnaso variety) in their geographical quadrants. This experiment was conducted in a commercial orange orchard in the municipality of Nova Laranjeiras in the State of Paraná, Brazil. A GPS receiver and a total station were used to measure the spatial location of the fruit and to determine which quadrant they were located in. In this experiment, 13 trees were studied. Twelve fruits were evaluated in each geographical quadrant, and 156 fruits were considered. After harvest, the productivity was expressed as kg per quadrant (kg quadrant$^{-1}$). Next, physical tests (equatorial diameter (EqD), total fruit mass (TFM), juice yield (JY)) and chemical tests (total soluble solids (TSS), total titrable acidity (TTA), the TSS/TTA ratio, and the ascorbic acid (AA) content) were conducted in the laboratory. In addition, the data were subjected to analysis by descriptive statistics and geostatistics to determine the spatial variability of the physical and chemical properties of the oranges, the variations of the soil properties and the correlations between the following parameters: the pH properties of the fruit and Zn; TFM and K; EqD and K, and C and TSS. The orchard varies spatially, especially regarding the EqD, TFM, JcP, TSS and AA for the quadrants with the highest values (the Northwest, Southeast, Northeast, Southwest and Southeast, respectively). The soil potassium and zinc contents were strongly correlated with the physical and chemical properties of the orange fruits.

**Key words:** Citriculture, geostatistics, spatial variability.

## Introduction

Orange crops are important for the national and world economy, with an estimated global production of 51.3 million tonnes and a Brazilian national production of 18.6 million tonnes for the 2012/2013 harvest season. The export of orange juice for the 2012/2013 harvest season should be 2% greater than the volume observed in 2011/2012 because the United States and the European Union are the largest consumers of oranges and because Brazil is the world's top exporter of oranges (USDA, 2013). Considering

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Corresponding author: rafa.nicolau@hotmail.com

the importance of oranges, studies are currently being conducted to optimize the orange production cycle and to seek nutritional quality.

Precision agriculture and geostatistics are important tools for assessing the spatial variability in orchards and plants. In addition, these tools can be associated with the physical and chemical analysis of the fruit. The nutritional factors of the soil and the plant and the attack of pests and diseases, weather factors, the geographical location of the fruit on the plant and the intensity of light may influence the nutritional quality of the fruit and interfere with production.

Mann *et al*. (2011) used variograms to obtain parameters for evaluating spatial dependence. Considering our aim to describe the spatial variability of the soil and orange production in a citrus fruit orchard, we assumed that the technique of Mann *et al*. (2011) was efficient for this estimation. Cross-validation is a technique that is used to evaluate estimation errors that can be used to compare predicted values with sample values (Issaks and Srivastava, 1989). According to Faraco *et al.* (2008), cross-validation is considered appropriate for the best adjustment. The kriging estimator is considered linear when it is composed of a linear combination of data. This estimator uses the spatial dependence among the near sample, which is demonstrated by the semivariogram for estimating values in any position within the field without tendency and with minimum variance (Carvalho and Assad, 2005).

In an experiment that sought to map productivity using geostatistics in citrus orchards (both irrigated and non-irrigated), Farias *et al*. (2003) observed greater spatial variation in productivity and fruit size in sections that were irrigated. These authors reached the conclusion that geostatistics and precision agriculture were important tools for establishing variability for the area under study. Oliveira *et al*. (2009) assessed the spatial variability of macronutrients in orange trees and on the ground and correlated them with productivity and fruit size. These authors concluded that maps showing productivity and fruit size have a high degree of spatial variability and that productivity was affected by the number of fruits per plant rather than by the size of the fruit. In contrast, Zucoloto *et al*. (2011) studied the spatial variations of soil physical characteristics and productivity, which were represented by several variables, such as the number of fruit per plant, the total fruit mass and the average mass per fruit within a citrus fruit orchard. To accomplish this task, these authors used geostatistical techniques. Overall, these authors observed that the number of fruits per plant and the total fruit mass per plant were not significantly correlated with the spatial distribution of clay. Thus, the clay content did not influence citrus fruit production.

Analyses that are conducted by dividing the bough of the tree into quadrants are usually used for the chemical analysis of plant leaves, a process which consists of collecting leaves from the average perimeter of the height of the bough and includes all of the quadrants while avoiding leaves with mechanical damage due to insects, as described by Oliveira *et al.* (2009). In contrast, Junior *et al*. (1994a) and Junior *et al*. (1994b), observed a statistically significant difference for Ca relative to the collection quadrant of the leaves.

The influence of the sun on the physical and chemical quality of 'Ponkan' tangerines was assessed by Detoni *et al*. (2009), who concluded that the fruit collected in the East-West quadrant of the plant, where more sunlight occurred, had a greater weight and longitudinal diameter. Ramos *et al*. (2003) studied the physical and chemical characteristics of Willowleaf tangerines (Caí cultivar of *Citrus deliciosa*) based on the geographical position and concluded that the position of the fruits (from East to West) did not influence the analyzed characteristics, except for total soluble solids content, which was greater in the upper third of the plants.

The purpose of this study was to analyze the spatial variability of the physical and chemical attributes and the productivity of orange trees and the soil physical and chemical properties relative to the geographical quadrants in which they occurred.

**Materials and methods**

The study was conducted using "Monte Parnaso" oranges (*Citrus sinensis* [L.] Osbeck) with *Poncirustrifoliata* (L.) Raf. as a receptacle for grafting. The experimental area is located in Nova Laranjeiras, in the midwestern region of the State of Paraná, with an area of approximately 10 thousand square meters and central co-ordinates of 25º23'03'' South and 52º34'27'' West. The soil in the area is classified as a typical dystroferric RED LATOSOL according to Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) (2006) and is made up of 76% clay. The climate of the region is Humid Subtropical (Cfa) according to the Köppen classification system and experiences rare frosts, an average temperature of 20 ºC, an annual rainfall of 1,900 mm and an average air humidity of 75% (Caviglione *et al*., 2000).

When georeferencing the area, the soil collection locations and the trees in each sample, the GPS Trimble GeoExplorer 2005 receptor *datum* WGS-84 was used, with C/A code and a TOPCON GTP-7505 total station. Because the studied orchard is a commercial orchard, it was not possible to analyze a larger number of trees. Consequently, 13 trees and 156 fruits were studied, with three fruits per geographical quadrant, in 2011. The fruit were georeferenced and harvested in June 2011 for physical and chemical analyses and to study their productivity. Soil was collected for chemical analysis from samples that were composed of four simple subsamples and were collected in the projection radius of the tree bough.

Productivity was estimated by adapting the methodologies of Farias *et al*. (2003) and Triboni and Barbosa (2004). Each sample tree was divided into four quadrants, Southwest (SW), Northwest (NW), Southeast (SE) and Northeast (NE). Next, all of the fruits in each quadrant were counted. After harvesting, three fruits were randomly selected from each quadrant and weighed separately. The arithmetic mean of the fruit weights was used to estimate the productivity of the orchard for each quadrant.

Physical and chemical analyses were conducted at the Quality Control Laboratory for Agricultural Products – LACON, UNIOESTE, Cascavel campus, State of Paraná, Brazil. The fruits used to quantify the productivity were also used to measure the equatorial diameters (EqD), total fruit mass (TFM), juice yield (JY), total soluble solids (TSS), and total titrable acids (AA) (IAL, 2008).

Initially, the data were analyzed using exploratory statistical techniques. The position measures, such as the median and the arithmetic mean were observed, and measures of dispersion, such as spread, standard deviation, variance and coefficient of variation (CV) were determined along with measures of shape, such as kurtosis and asymmetry. The normality of the data was verified using the Shapiro-Wilk and Anderson-Darling tests at a significance level of 5%. Data normality was assumed when at least one of these tests confirmed normality.

To verify the degree of correlation between the soil variables and the physical and chemical attributes of the fruit, the Spearman non-parametric correlation coefficient was used, as shown in Equation 1. The correlation coefficient levels can be positive or negative and are classified as a perfect correlation when the coefficient is 1, as a very strong correlation when it varies from 0.9 to 1, as a strong correlation when it varies from 0.6 to 0.9, as a regular correlation when it varies from 0.3 to 0.9, as a weak correlation when it varies from 0 to 0.3, and as a null correlation when it is 0 (Andriotti, 2010).

$$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \quad (1)$$

A spatial analysis was executed to assess the spatial variability of the studied properties because the degree of spatial dependence between the samples due to the adaptations in the semivariograms using theoretical model adjustments must be determined. The spatial dependence was classified according to Cambardella *et al*. (1994) by considering the index of spatial dependence (ISD) as strong when the semivariogram had a nugget effect of ≤25% of the threshold, moderate when the nugget effect was between 25 and 75%, and weak when the ISD was ≥ 75%. The ISD is described in Equation 2.

$$IDE = \frac{C_0}{C_1+C_0} x100 \quad (2)$$

where $C_0$ is the nugget effect and $C_1$ is the contribution.

Cross-validation is a technique that is used to evaluate estimation errors and allowed us to compare the predicted values to the sample values (Isaaks and Srivastava, 1989). Cross-validation was used to determine the best model for the theoretical semivariogram. The data interpolation was conducted using kriging. The inverse of the distance was used when the data were spatially dependent, and the inverse of the distance was used when there was a pure nugget effect (i.e., when the data were not spatially dependent). Statistical and geostatistical analyses were performed using the software R® 3.0 version.

## Results and discussion

Soil analysis was performed during the experiment, and the verified chemical attributes included Zn concentrations of less than 3.0 mg dm$^{-3}$. This Zn deficiency is common in Brazil and potentially results from phosphate fertilization (Costa and Oliveira, 2001). The Fe concentrations varied between 15 and 40 mg dm$^{-3}$, the P concentrations varied between 6.1 and 9.0 mg dm$^{-3}$, and the soil P concentrations were appropriate. Fidalski *et al*. (2007) and Panzenhagen *et al*. (2008) observed similar values for the same attributes in studies on citrus fruit. These results are justified by the low mobility of P. Furthermore, the K concentrations were greater than 0.30 cmolc dm$^{-3}$, which is considered very high. In addition, Ca (>4.0 cmolc dm$^{-3}$), Mg (>0.80 cmolc dm$^{-3}$), C (>35.0 g kg$^{-1}$), Cu (>1.7 mg dm$^{-3}$) and Mn (>30.0 mg dm$^{-3}$) were high. Excessive Ca concentrations can block Mg and K absorption, which results in a greater K deficiency and reduces the fruit size (Koller, 2006). Furthermore, the high Cu concentration was potentially related to the presence of micronutrients in various fungicides that are used for disease control in citrus fruit. The symptoms of Cu toxicity include growing drop, leaf fall, fructification and fruit size reduction (Koller, 2006). The verified high Mn concentrations in the soil potentially resulted from low soil aeration due to soil compaction and excess humidity (according to Costa and Oliveira (2001)). However, Prates *et al*. (2011) indicated that high Mn concentrations in the soil potentially resulted from the use of pesticides and/or fertilizers, in which manganese is a common constituent.

Descriptive statistics of the properties of the oranges were determined for each quadrant (Table 1). According to Azevêdo (2003), a ripe fruit is defined by a minimum juice content (35 to 45%), TSS (9-10 °Brix) and TSS/TTA (8.5-10). In our results, the juice yield and TSS values were within the acceptable range, but the TSS/TTA ratio was below the ideal range for classification as ripe due to the high ATT values. The mean values for AA were within the quality standards established by Unicamp (2010) and at least 25 mg 100 g$^{-1}$. Koller (1993) stated that the “Monte Parnaso” variety is not very productive, with an average productivity of 15 kg per tree. Thus, in this experiment, the values ranged from 14 to 17 kg per quadrant.

**Table 1.** Descriptive analysis of the fruit properties in 2011.

| Quadrants | Properties | Mean | Median | Spread | SD | CV (%) | Kurtosis | Skewness |
|---|---|---|---|---|---|---|---|---|
| Southwest | EqD (mm) | 78.65 | 79.94 | 31.00 | 6.90 | 8.77 | -0.24 | -0.29 |
| | TFM (g) | 258.20 | 260.60 | 272.50 | 62.36 | 24.15 | -0.29 | 0.26 |
| | JcP (%) | 43.38 | 44.00 | 27.70 | 6.39 | 14.73 | -0.13 | -0.54 |
| | SST (ºBrix) | 9.39 | 9.20 | 2.00 | 0.84 | 9.01 | -0.54 | 0.18 |
| | TTA (%) | 1.79 | 1.78 | 1.73 | 0.93 | 21.92 | -0.17 | 0.52 |
| | TSS/TTA | 5.48 | 5.40 | 4.80 | 1.26 | 22.95 | -0.80 | 0.26 |
| | AA (mg 100 mL$^{-1}$) | 54.09 | 55.25 | 37.90 | 9.12 | 16.89 | -0.87 | -0.16 |
| | Productivity (kg quadrant$^{-1}$) | 15.52 | 14.80 | 11.80 | 3.84 | 24.72 | -1.25 | 0.34 |
| Northwest | EqD (mm) | 79.95 | 80.13 | 32.89 | 7.76 | 9.70 | -0.39 | -0.48 |
| | TFM (g) | 264.20 | 256.40 | 302.30 | 71.71 | 27.14 | -0.55 | 0.21 |
| | JcP (%) | 44.88 | 44.40 | 16.70 | 4.24 | 9.45 | -0.57 | -0.11 |
| | SST (ºBrix) | 9.38 | 9.00 | 4.20 | 0.98 | 10.41 | -0.03 | 0.59 |
| | TTA (%) | 1.74 | 1.67 | 1.34 | 0.36 | 20.52 | -0.77 | 0.43 |
| | TSS/TTA | 5.58 | 5.60 | 4.20 | 1.04 | 18.67 | -0.53 | 0.06 |
| | AA (mg 100 mL$^{-1}$) | 53.67 | 53.20 | 36.00 | 8.58 | 15.98 | 0.11 | 0.41 |
| | Productivity (kg quadrant$^{-1}$) | 14.02 | 13.79 | 19.15 | 5.09 | 36.32 | -0.25 | 0.08 |
| Southeast | EqD (mm) | 79.27 | 79.87 | 23.43 | 5.64 | 7.11 | -0.44 | 0.16 |
| | TFM (g) | 260.00 | 262.90 | 226.60 | 53.55 | 20.60 | -0.66 | 0.10 |
| | JcP (%) | 41.97 | 42.40 | 14.70 | 3.35 | 7.99 | -0.07 | -0.55 |
| | SST (ºBrix) | 9.37 | 9.30 | 2.50 | 0.99 | 10.54 | -0.67 | 0.01 |
| | TTA (%) | 1.79 | 1.76 | 1.18 | 0.33 | 18.49 | -1.34 | 0.15 |
| | TSS/TTA | 5.13 | 5.15 | 4.10 | 1.05 | 20.46 | -0.94 | -0.26 |
| | AA (mg 100 mL$^{-1}$) | 55.17 | 54.70 | 31.80 | 6.89 | 12.50 | -0.19 | 0.30 |
| | Productivity (kg quadrant$^{-1}$) | 17.64 | 18.16 | 12.36 | 3.72 | 21.12 | -0.90 | -0.62 |
| Northeast | EqD (mm) | 79.19 | 79.77 | 22.93 | 4.94 | 6.24 | 0.49 | 0.14 |
| | TFM (g) | 260.50 | 258.80 | 210.40 | 44.04 | 16.91 | 1.03 | 0.77 |
| | JcP (%) | 42.15 | 41.72 | 20.80 | 5.04 | 11.95 | -0.29 | -0.50 |
| | SST (ºBrix) | 9.21 | 9.00 | 4.50 | 0.98 | 10.64 | 0.69 | 0.91 |
| | TTA (%) | 1.83 | 1.85 | 1.32 | 0.30 | 16.27 | 0.01 | 0.53 |
| | TSS/TTA | 5.13 | 5.10 | 3.70 | 0.83 | 16.11 | -0.39 | 0.06 |
| | AA (mg 100 mL$^{-1}$) | 54.31 | 53.30 | 43.00 | 9.05 | 16.67 | 0.37 | 0.71 |
| | Productivity (kg quadrant$^{-1}$) | 17.15 | 17.09 | 20.85 | 5.89 | 34.35 | -0.79 | 0.23 |

SD = Standard Deviation; CV = Coefficient of Variation; EqD = Equatorial Diameter; TFM = Total Fruit Mass; JcP = Juice Production; TSS = Total soluble solids; TTA = total titrable acidity; TSS/TTA = ratio between total soluble solids and total titrable acidity; AA = Ascorbic Acid.

Castro *et al*. (2013) assessed the juice yield, TSS and TSS/TTA in several types of oranges and found RS values within the ideal and acceptable range. The TSS values ranged from 7 to 12 ºBrix, and the TSS/TTA values ranging from 4 to 11 ºBrix. Tomasetto *et al*. (2009) assessed juice production relative to two graft bearers and concluded that the values were within the acceptable ranges. Duarte *et al*. (2011) estimated properties such as juice yield (JY) and found values that were greater than reported by Azevêdo (2003). However, the TSS values were between 7 and 12 ºBrix, and the TSS/TTA values varied between 3 and 18 ºBrix. Topuz *et al.* (2005) confirmed AA values (42.68 mg 100 mL$^{-1}$) that were above the minimum defined by Brazil (2000) and were below the other values found in this study. In addition, these values were similar to those found by Khalid *et al.* (2012), who showed AA values of between 23 and 32 mg 100 mL$^{-1}$.

In the spatial analysis of the data (Table 2), the TFM properties and productivity in the southwest, the JY in the northwest, the EqD in the southeast and the TSS in the northeast indicated a pure nugget effect and did not present any spatial dependence. The ISD was considered strong (TFM, JY – southeast), moderate (JY, TSS, TTA, TSS/TTA, AA – southwest; EqD, TFM, TSS, TTA, TSS/TTA, AA. productivity – northwest; RRA, TSS/TTA, AA – southwest; EqD, TFM, TSS, TTA, TSS/

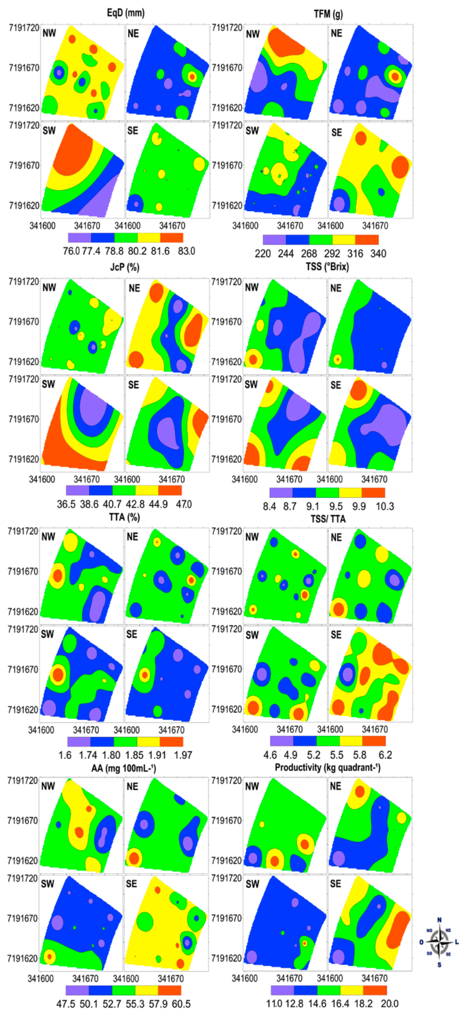


**Figure 1.** Maps showing the spatial variability of the properties of oranges relative to their respective quadrants for 2011. (NW = Northwest, NE = Northeast, SW = Southwest, SE = Southeast. EqD = Equatorial Diameter, TFM = Total Fruit Mass; JY = Juice Yield; TSS = Total soluble solids; TTA = Total titrable acidity; TSS/TTA = ratio between total soluble solids and total titrable acidity; AA = Ascorbic Acid.)

**Table 2.** Models and parameters of the semivariograms for the properties of the oranges in 2011

| Quadrants | Attributes | Model | C0 | C1 | C0+C1 | a | ISD |
|---|---|---|---|---|---|---|---|
| Southwest | EqD (mm) | Gau | 44.25 | 2.10 | 46.35 | 57.99 | 95.48 |
| | TFM (g) | - | - | - | - | - | - |
| | JcP (%) | Gau | 28.65 | 16.88 | 45.53 | 57.81 | 62.93 |
| | TSS (ºBrix) | Gau | 0.49 | 0.24 | 0.74 | 30.79 | 67.01 |
| | TTA (%) | Gau | 0.08 | 0.08 | 0.16 | 13.68 | 50.96 |
| | TSS/TTA | Gau | 0.82 | 0.41 | 1.23 | 10.26 | 66.67 |
| | AA (mg 100 $mL^{-1}$) | Exp | 42.28 | 81.54 | 123.83 | 11.11 | 34.15 |
| | Productivity (kg $quadrant^{-1}$)* | - | - | - | - | - | - |
| Northwest | EqD (mm) | Sph | 30.09 | 22.57 | 52.67 | 18.16 | 57.14 |
| | TFM (g) | Gau | 2.40 | 3.60 | 6.00 | 25.08 | 40.00 |
| | JcP (%) | - | - | - | - | - | - |
| | TSS (ºBrix) | Sph | 0.41 | 0.60 | 1.01 | 32.37 | 40.60 |
| | TTA (%) | Sph | 0.04 | 0.11 | 0.16 | 300.27 | 27.85 |
| | TSS/TTA | Sph | 0.55 | 0.74 | 1.29 | 4.32 | 42.56 |
| | AA (mg 100 $mL^{-1}$) | Exp | 51.58 | 48.35 | 99.93 | 11.24 | 51.61 |
| | Productivity (kg $quadrant^{-1}$)* | Sph | 8.54 | 22.62 | 31.16 | 26.49 | 27.42 |
| Southeast | EqD (mm) | - | - | - | - | - | - |
| | TFM (g) | Sph | 0.00 | 0.006 | 0.01 | 39.02 | 25.00 |
| | JcP (%) | Exp | 3.22 | 12.50 | 15.72 | 63.84 | 20.51 |
| | TSS (ºBrix) | Sph | 0.02 | 0.01 | 0.03 | 54.00 | 75.73 |
| | TTA (%) | Exp | 0.07 | 0.05 | 0.12 | 9.54 | 59.83 |
| | TSS/TTA | Gau | 0.55 | 0.47 | 1.02 | 11.27 | 54.10 |
| | AA (mg 100 $mL^{-1}$) | Sph | 31.72 | 21.63 | 53.34 | 17.34 | 59.46 |
| | Productivity (kg $quadrant^{-1}$)* | Exp | 14.41 | 6.92 | 21.33 | 26.40 | 67.57 |
| Northeast | EqD (mm) | Sph | 18.11 | 10.56 | 28.67 | 13.77 | 63.16 |
| | TFM (g) | Sph | 1.58 | 1.58 | 3.17 | 28.41 | 50.00 |
| | JcP (%) | Sph | 16.34 | 9.39 | 25.73 | 37.79 | 63.50 |
| | TSS (ºBrix) | - | - | - | - | - | - |
| | TTA (%) | Sph | 0.05 | 0.05 | 0.10 | 14.63 | 48.48 |
| | TSS/TTA | Gau | 0.47 | 0.23 | 0.70 | 12.25 | 67.00 |
| | AA (mg 100 $mL^{-1}$) | Gau | 57.72 | 42.05 | 99.77 | 12.05 | 57.85 |
| | Productivity (kg $quadrant^{-1}$)* | Exp | 11.54 | 12.99 | 24.53 | 17.88 | 47.06 |

*Pure nugget effect; Sph = Spherical Model; Exp = Exponential Model; Gau = Gaussian Model; EqD = Equatorial Diameter; TFM = Total Fruit Mass; JcP = Juice Production; TSS = Total Soluble Solids; TTA = Total Titrable Acidity; TSS/TTA = Ratio between total soluble solids and total titrable acidity; AA = Ascorbic Acid; C0 = Nugget effect; C1 = Contribution; C0 + C1 = Threshold; a = Reach; ISD = Index of Spatial Dependence.

TTA, productivity – northeast) and weak (TFM, JY – southeast), according to the classification proposed by Cambardella *et al*. (1994). The spatial analysis of the data in this study agreed with the results of Zucoloto *et al*. (2011) (except that TFM had a pure nugget effect to the southwest and the adjusted model in the northeast was the Gaussian model), who assessed the spatial variability of the total fruit mass using a spherical model and considered the ISD as moderate. Siqueira *et al*. (2010) checked the spatial dependence for the TSS, TTA, TSS/TTA and juice yield (JY) attributes and found results that were similar to those in this study, with weak and moderate spatial dependence for TSS, moderate dependence for TTA and TSS/TTA and strong and moderate dependence for juice yield (JY).

When assessing the non-parametric Spearman correlation between the soil properties and the physical and chemical properties of the oranges, a strong positive correlation was found between the EqD and K (0.78) and TFM and K (0.75) attributes because this soil chemical property affects the size of the fruit (Koller, 2006). In addition, we observed a strong positive correlation between the pH of the fruit and the Zn content, potentially due to the low soil Zn concentration, which would inhibit the growth and production of the fruit and reduce the juice content (Malavolta *et al*., 1997).

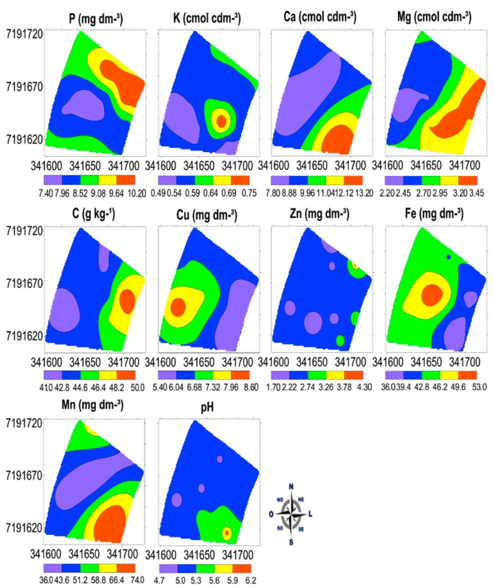


**Figure 2.** Maps of the spatial visibility of the soil properties for 2011. (P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; C = organic carbon; Cu = copper; Zn = zinc; Fe = iron; Mn = manganese).

An EqD map is presented in Figure 1, which showed a low variation of between 76 and 83 mm. This low variation can also be observed through the coefficient of variation, which is considered low for this attribute. However, when considering the quadrants, the values of each quadrant stand out. In the maps related to the TSS/TTA properties, we observed similarities between the NW, NE and SW quadrants. Thus, without any significant variations between the maximum and minimum values of the properties of the oranges, we confirmed the variability and made sure that the defined standard of setting-out variables did not occur for the characteristic studies using the maps.

The spatial variability of the soil characteristics can be observed in Figure 2, in which strong associations can be observed between the soil characteristics and the physical and chemical properties of the oranges, especially for the following characteristics: fruit pH and fruit Zn content; TFM and K; EqD and K, and C and TSS.

**Table 3.** Models and parameters of the semivariograms for the soil properties in 2011.

| Attribute | Model | Model | C0 | C1 | C0+C1 | a |
|---|---|---|---|---|---|---|
| P | Sph** | 1.62 | 1.71 | 3.33 | 50.45 | 48.77 |
| K | Exp*** | 0.01 | 0.01 | 0.03 | 30.79 | 46.43 |
| Ca | Gau**** | 2.08 | 2.86 | 4.93 | 39.34 | 42.10 |
| Mg | Exp*** | 0.24 | 0.28 | 0.51 | 37.63 | 45.91 |
| C | Exp*** | 20.28 | 16.38 | 36.66 | 33.35 | 55.32 |
| Cu | Sph** | 0.86 | 0.89 | 1.75 | 42.76 | 49.06 |
| Zn * | - | - | - | - | - | - |
| Fe | Sph** | 24.43 | 33.59 | 58.02 | 41.05 | 42.11 |
| Mn * | - | - | - | - | - | - |
| pH * | - | - | - | - | - | - |

C0 = Nugget effect; C1 = Contribution; C0+C1 = Threshold; a = Reach; ISD = Index of Spatial Dependence.* Pure Nugget Effect; ** Spherical Method; *** Exponential Method; **** Gaussian Model.

The orchard shows some spatial variations in the physical and chemical properties of the fruits between the disposition quadrants on the bough, mainly for equatorial diameter (EqD), total fruit mass (TFM), juice yield (JY), TSS and ascorbic acid, with the northwest, southeast, northeast, southwest and southeast quadrants having the highest values, respectively.

Using the non-parametric Spearman coefficient, we confirmed strong positive associations between the soil chemical properties (especially the potassium and zinc contents) and the physical and chemical properties of the orange tree fruits (Table 3).

Geostatistics and precision agriculture are important tools for appraising and modeling the properties of orange trees. However, some of these properties do not show a spatial dependence.

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**Resumen**

**R.F. Nicolau, E. Mercante, M.F. Maggi, E.G. Souza y E. Gasparin. 2014. Variabilidad espacial de las propiedades químicas del suelo y de la productividad y propiedades físicas y químicas de los frutos de naranjos. Cien. Inv. Agr. 41(3):337-347.** El objetivo de este estudio ha sido analizar la variabilidad espacial de los atributos del suelo, de la productividad y de las propiedades físicas y químicas de los frutos de la variedad de naranja " Monte Parnaso", en relación a los cuadrantes geográficos en que se ubican los frutos analizados. El experimento se realizó en un huerto comercial de naranjos en Nova Laranjeiras, Estado de Paraná, Brasil. En el procedimiento de georreferenciación de la área y de cada árbol de la muestra, se utilizó un GPS y una estación total para medir la localización espacial de la fruta y luego la definición de qué cuadrante se ubicaban. En el experimento, se utilizaron 13 árboles en las cuales se analizaron tres frutas por cuadrante geográfico de cada árbol, por un total de 156 frutas. Después de la cosecha se estimó la productividad en kg cuadrante$^{-1}$ y en el laboratorio fueran realizados análisis física (diámetro ecuatorial (ED), masa total de la fruta (MT), rendimiento de jugo (RS)) y químicos (sólidos solubles totales (SST), acidez titulable (AT), relación SST/AT y ácido ascórbico (AA)) de la fruta. Los datos fueron sometidos a análisis de la estadística descriptiva y de la geoestadística señalando la variabilidad espacial de las propiedades físico-químicas de las naranjas y los atributos del suelo y también correlación entre los atributos de la fruta pH y Zn, MT y K, ED y K y finalmente SST y C. El huerto tiene variaciones espaciales principalmente para los atributos diámetro ecuatorial, masa total de la fruta, rendimiento del jugo, SST y ácido ascórbico, siendo los cuadrantes con mayores valores fueron, respectivamente, noroeste, sureste, noreste, suroeste y sureste. Especialmente potasio y zinc, las propiedades del suelo, fuertemente correlacionados con las propiedades físicas y químicas de las frutas de color naranja.

**Palabras clave:** Cítricos, geoestadística, variabilidad espacial.

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