

## Spatial variability of the yield and physical properties of orange (*Citros sinensis* [L.] Osbeck cv. Monte Parnaso) fruits

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### Abstract

Precision agriculture (PA) is used as a tool in the citrus industry and aims to increase production reduce costs and search for answers to explain the spatial variability of yield. The aim of this study was to model the spatial variability of yield and physical properties of fruits of orange trees in relation to the geographic quadrant where the fruits are on the trees. The experiment was carried out in a 1 ha commercial orchard of orange trees cv. Monte Parnaso. A GPS receiver and a total station were used to georeference the experimental area and the position of each sampled tree in the area, as well as the location of the geographic quadrant where the fruits sampled were on the trees. Twelve fruits were collected from each of the 13 sampled trees, resulting 39 fruits per quadrant, totalling 156 fruits each crop-year (2011 and 2012). Yield was estimated after the harvest (kg.quadrant<sup>-1</sup>). Physical analyses were performed for each fruit, measuring the following physical properties: equatorial diameter, total mass and juice yield. We conducted analysis of descriptive statistics and spatial variability in the data through techniques related to geostatistics. The results showed the highest spatial variability between the quarters for the juice yield and yield, and the verified juice yield was within the acceptable standard by regulatory bodies.

**Keywords:** orange fruits, spatial dependence, geographic quadrants, variability, physical properties.

**Abbreviations:** PA\_precision agriculture; TA\_total titratable acidity; CV\_coefficient of variation; ED\_equatorial diameter; HLB\_huanglongbing; DSD\_degree of spatial dependence; TM\_total mass; NE\_northeast; NW\_northwest; JY\_juice yield; SE\_southeast; SW\_southwest; TSS\_total soluble solids.

### Introduction

The orange is the most produced and commercialised fruit in the world; however, the main problem for producers is to manage the spatial variability, since there are several factors that may be involved related to production, such as, pest infestation outbreaks and diseases, soil type, soil compaction and management (Molin, 2010), soil-relief relationship and water movement in the soil (Siqueira et al., 2010). Understanding the spatial variability of yield and physical properties of the soil, as well as the study of the temporal variability when properly available to farmers who adopt precision agriculture, can improve the management options and enable modern agriculture that is economically competitive and environmentally sustainable (Molin & Rabelo, 2011; Bernardi et al., 2014).

The growth potential of agribusiness and the emergence of new technologies, innovation and research have promoted the dynamism of the citrus sector. The use of precision agriculture in the citrus industry aims to increase production, reduce costs and search for answers to explain the spatial variability of yield. According to this concept, Molin et al. (2012) characterised the spatial variability of fruit yield, soil fertility and occurrence of plant failures caused by declining citrus and rust or *huanglongbing* (HLB) and concluded that

the variability found in the studied parameters demonstrated the importance of nutritional and phytosanitary localised management as tools to ensure efficiency in the fruit production.

Siqueira et al. (2010) used the landforms to predict the spatial variability of soil and orange attributes. The orange properties evaluated were total soluble solids (TSS), total titratable acidity (TA), TSS/TA ratio, production, juice yield (JY) and fruit size, performed during three months (July, August and September). The results showed that the spatial and temporal variability of soil and orange attributes are influenced by the relief, especially the temporal variability of the orange attributes that influence the ripening gradients.

Cruz et al. (2010) evaluated whether the exposure of plants and tangerine fruits to heatstroke influence the physicochemical characteristics. They concluded that fruits located in the western quadrant of the tree canopy presented higher TSS values and greater size, and smaller acidity in relation to fruits positioned in the eastern quadrant. Lemos et al. (2012) evaluated the physicochemical characteristics of the sweet orange fruits [*Citrus sinensis* (L.) Osb] collected at different positions of the canopy: heights (basal, middle and apical), both sides (opposite sides of the canopy, between

lines –east and west) and two positions (periphery and 30 cm inside the canopy). They concluded that the sampling point within the parameters required for a better quality of orange varied for the different positions in the canopy.

In this context, the aim of this study was to model the spatial variability of yield and physical properties of fruits of orange trees in relation to the geographic quadrant where the fruits are on the trees.

## Results and Discussion

### Statistical Analysis

Descriptive analyses of the physical properties and orange yield in relation to geographic quadrants were carried out for two years, 2011 and 2012 (Table 1). Considering the ideal standards for maturation of an orange fruit proposed by Azevêdo (2003) and CEAGESP (2011), the minimum JY is from 35 to 45%; the average values collected were from 41.9 to 44.9% in 2011 and from 43.4 to 48.7% in 2012, thereby determining that JY values are within acceptable standards.

According to Koller (2006) the variety Monte Parnaso is not very productive, averaging 15 kg.tree<sup>-1</sup>. The average yield found in the experiment was 16 kg.tree<sup>-1</sup> for the year 2011 and 17 kg .tree<sup>-1</sup> for 2012.

Duarte et al. (2011), working with the Valencia orange, found JY values ranging from 53 to 56% and fruit weight ranging from 141 to 190 g. Castro et al. (2013) evaluated JY, TSS and TSS/TA in some orange cultivars and found JY values within acceptable standards according to Azevedo (2003) and CEAGESP (2011), ranging from 36 to 57%, which is similar values to those found in this paper. Santarosa et al. (2013), in a study to assess the variation of intensity and frequency of pruning, found TM values similar to those found in our experiment, 280 g, especially in the control treatment (224 g).

### Geostatistical Analysis

Table 2 shows an analysis of the spatial variability model with the parameters of the adjusted models to semivariograms. The pure nugget effect was found, the data do not present spatial dependence indicating that these attributes were not influenced by the spatial location of the fruit on the tree canopy, for year 2011 the attributes TM and yield in SW quadrant, JY in NW quadrant and ED in SE quadrant.

The spatial dependence radius considered in this study was 110 m, which was the maximum distance. Therefore, the variables that did not show that the pure nugget effect can be considered as dependent variables for not having a longer range than the maximum distance consistently to reality.

For the degree of spatial dependence (DSD) for the variables studied, in 2011, it was classified as weak spatial dependence (nugget effect  $\geq 75\%$ ) ED in SW quadrant. In 2012 ED and TM in SW quadrant was classified as strong spatial dependence (nugget effect  $\leq 25\%$ ) in 2011 TM and JY in SE quadrant and in 2012 the yield in SW and NE quadrant. The other variables were classified as moderate spatial dependence (nugget effect between 25% and 75%) according to Cambardella et al.'s (1994) classification.

In a similar study, Molin et al. (2012) also found a high range of values (688.20) and randomness (69.00%) for yield, similar to those found in this study in the NW and SE quadrants in 2012. The other variables showed spatial dependence.

Working with Pêra-Rio cultivar in 2002 and 2003, Siqueira et al. (2010) evaluated the spatial dependence for the attributes TA, TSS/TA and JY, and the attributes presented strong and moderate spatial dependence, evidencing similar results compared to this work. Zucoloto et al. (2011) found spatial dependence for total weight and DSD was classified as moderate for this physical property for the Folha Murcha orange cultivar.

### Spatial Distribution

The spatial variability surface map of the physical characteristics and orange yield in relation to geographic quadrants, in 2011, are shown in Figure 1. The lowest ED and TM values were observed in the NE quadrant. On the other hand, in the NW quadrant of the ED variable, smoothing points were observed, which occurred from the interpolation process, as well as the variable TM in the NE quadrant. For ED and JY variables in the SW quadrant, we observed a continuity of estimated values of the variables.

The highest values found for JY were observed primarily in the NW quadrant. The yield maps represent the spatial variability of the orchard, growth and yield of plants showing complete information about the orchard (Oliveira et al., 2009). Therefore, the predominance of values in yield maps was observed, as ranging from 14 to 17 kg.quadrant<sup>-1</sup> in all quadrants studied.

Surface maps of the physical characteristics and orange yield in relation to geographical quadrants in 2012 are shown in Figure 2. For ED and JY attributes, it was observed that in the NE/SE and SE quadrants, respectively, small dots occurred related to smoothing in the interpolation process. It was observed in the TM attribute that the highest values were primarily in the SW quadrant. The highest values for yield were found in the NW and SE quadrants.

Cruz et al. (2010) found that the tangerine fruit Ponkan, located in the western quadrant of the canopy, presented higher weight values and juice yield than those located in the east quadrant. Detoni et al. (2009) observed that the fruits developed in the orientation in which there is a higher incidence of sun, presented higher weight values and a longitudinal diameter. In a similar study, Molin et al. (2012) characterised the orange tree yield in a commercial orchard and found the non-occurrence of spatial dependence and large spatial variability in the orchard, as was observed in this study.

## Materials and Methods

### Characterisation of the area

The experiment was carried out in a 1 ha commercial orchard of orange trees cv. Monte Parnaso (*Citros sinensis* [L.] Osbeck), implanted in August 2005, using the *Poncirus trifoliata* (L.) Raf. as rootstock, spaced 4x6 m between plants. The experimental area is located in Nova Laranjeiras, the midwest region of the state of Parana, with a total area of about 1 ha, and centre coordinates are 25°23'03''S latitude and 52°34'27''W longitude (Figure 3a). The region's soil is classified as red dystroferic latosol consisting of approximately 76% clay. The climate is classified as a humid subtropical climate (Cfa), according to Köppen classification, with infrequent frosts events. The average temperature is 22 °C with hot summers. For the sampling of oranges, 12 fruits were collected from each of the 13 sampled trees, resulting 39 fruits per quadrant, totalling 156 fruits each crop-year (2011 and 2012).

**Table 1.** Statistical analysis of the yield and physical properties of orange fruits in 2011 and 2012 located in Nova Laranjeiras, Paraná.

Quadrants	Properties	2011			2012		
		Mean	Extent	CV(%)	Mean	Extent	CV(%)
SW	ED (mm)	78.65	31.00	8.77	84.70	27.46	6.39
	TM (g)	258.20	272.50	24.15	310.40	244.00	17.42
	JY (%)	43.38	27.70	14.73	43.38	27.70	14.73
	Yield(kg.quadrant <sup>-1</sup> )	15.52	11.80	24.72	19.95	22.03	32.84
NW	ED (mm)	79.95	32.89	9.70	84.42	18.02	5.30
	TM (g)	264.20	302.30	27.14	312.60	232.40	18.63
	JY (%)	44.88	16.70	9.45	47.62	15.40	7.68
	Yield(kg.quadrant <sup>-1</sup> )	14.02	19.15	36.32	16.15	14.17	26.86
SE	ED (mm)	79.27	23.43	7.11	82.12	21.99	5.86
	TM (g)	260.00	226.60	20.60	322.90	232.80	21.13
	JY (%)	41.97	14.70	7.99	48.69	13.51	6.36
	Yield(kg.quadrant <sup>-1</sup> )	17.64	12.36	21.12	13.09	11.94	28.94
NE	ED (mm)	79.19	22.93	6.24	84.10	25.10	7.25
	TM (g)	260.50	210.40	16.91	311.60	304.80	20.98
	JY (%)	42.15	20.80	11.95	47.01	16.97	6.57
	Yield(kg.quadrant <sup>-1</sup> )	17.15	20.85	34.35	18.72	21.99	40.07

SW (southwest), NW (northwest), SE (southeast), NE (northeast), ED (equatorial diameter), TFM (total fruit mass), JY (juice yield), CV (coefficient of variation), ED (equatorial diameter), TM (total mass) and JY (juice yield).

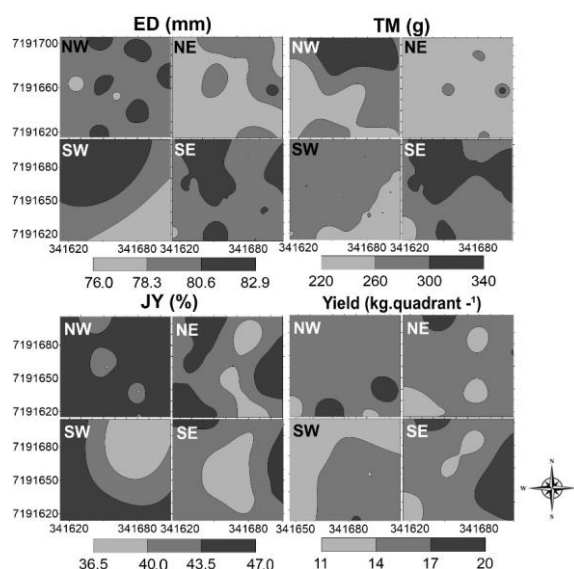


**Fig 1.** Location of the experimental area (a); identification of the tree fruits (b) and laboratory (c), respectively.

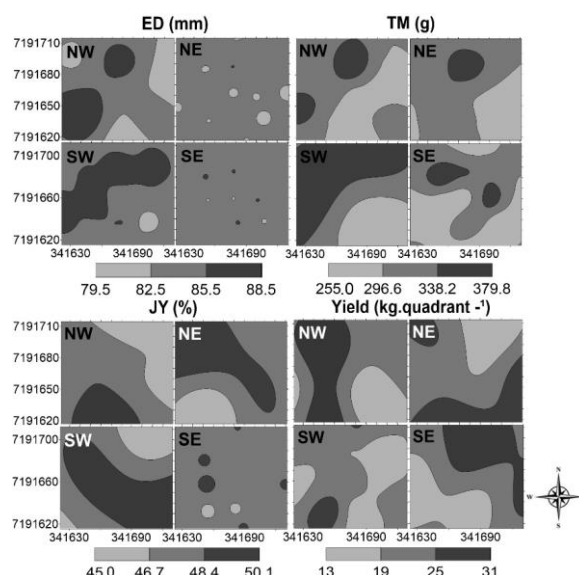
**Table 2.** Models and parameters of the semivariograms for the yield and physical properties of orange fruits in 2011 and 2012 located in Nova Laranjeiras, Paraná.

Quadrants	Properties	2011			2012		
		Model	al (m)	ISD (%)	Model	al (m)	ISD (%)
SW	ED (mm)	Gau	57.99	95.48	Sph	26.91	77.94
	TM (g)	*	-	-	Gau	36.30	86.96
	JY (%)	Gau	57.81	62.93	Gau	57.81	62.93
	Yield (kg.quadrant <sup>-1</sup> )	*	-	-	Sph	49.60	15.63
NW	ED (mm)	Sph	18.16	57.14	Gau	31.95	56.86
	TM (g)	Gau	25.08	40.00	Sph	47.34	60.00
	JY (%)	*	-	-	Gau	42.17	46.73
	Yield (kg.quadrant <sup>-1</sup> )	Sph	26.48	27.42	Gau	39.34	56.36
SE	ED (mm)	*	-	-	Sph	47.32	61.82
	TM (g)	Sph	39.02	25.00	Sph	35.39	65.38
	JY (%)	Exp	63.84	20.51	Gau	7.04	54.89
	Yield (kg.quadrant <sup>-1</sup> )	Exp	26.40	67.57	Gau	32.49	58.82
NE	ED (mm)	Sph	13.77	63.16	Gau	30.93	48.00
	TM (g)	Sph	28.41	50.00	Exp	40.70	68.68
	JY (%)	Sph	37.79	50.00	Gau	46.12	61.65
	Yield (kg.quadrant <sup>-1</sup> )	Sph	17.88	47.06	Gau	44.47	17.24

SW (southwest), NW (northwest), SE (southeast), NE (northeast), ED (equatorial diameter), TFM (total fruit mass), JY (juice yield), \* maps interpolated by inverse distance did not present spatial dependence, Gau (Gaussian), Exp (exponential), Sph (spherical), al (reach), ISD (index of spatial dependence), ED (equatorial diameter), TM (total mass) and JY (juice yield).



**Fig 2.** Maps of the spatial variability of the properties of oranges relative to their respective quadrants for 2011. (NW = northwest, NE = northeast, SW = southwest, SE = southeast; ED = equatorial diameter, TM = total mass, JY = juice yield).



**Fig 3.** Maps of the spatial variability of the properties of oranges relative to their respective quadrants for 2012. (NW = northwest, NE = northeast, SW = southwest, SE = southeast; ED = equatorial diameter, TM = total mass, JY = juice yield).

The orange trees (sample units), 30 metres from each other, were divided into the following quadrants: northwest (NW), northeast (NE), southwest (SW), southeast (SE). The collection of fruit coordinates occurred 30 days before harvest. The fruits were located by local coordinates within each quadrant of the trees (Figure 3b and Figure 3c), using a total station TOPCON GTP-7505, and after this procedure, the fruits were collected. For georeferencing the area and each sample of orange trees, we used the GPS receiver Trimble GeoExplorer 2005 XT, with submetre accuracy for post-corrected data.

#### **Yield estimation and physical analysis**

The yield was estimated by adapting the methodologies by Farias et al. (2003) and Triboni and Barbosa (2004), for which we counted orange fruits belonging to each quadrant of the sample trees. After harvesting, fruits were weighed, and thus the average yield value was obtained ( $\text{kg.quadrant}^{-1}$ ) for each quadrant.

Physical analyses were performed at the Product Quality Control Laboratory, LACON, UNIOESTE campus of Cascavel, Parana. For each fruit, the following physical properties were quantified: equatorial diameter (ED), total mass (TM) and juice yield (JY) using analytical standards of the Institute Adolfo Lutz (IAL, 2008).

#### **Statistical and geostatistical analysis**

Initially, an exploratory analysis of data was performed to verify the position measurements, dispersion and shape. The normality of the data was verified using the Shapiro-Wilk test and Anderson-Darling at 5% significance level, assuming normality of data when it was verified in at least one of the tests. The spatial analysis was performed to model the spatial variability of the variables studied in order to determine the degree of spatial dependence between samples through adjustments to semivariograms using theoretical models. The semivariograms were adjusted by theoretical models (spherical, exponential and Gaussian) using the following

parameter estimation methods: ordinary least squares (OLS), weighted least squares and maximum likelihood.

In the analysis of the degree of spatial dependence, we used Cambardella et al.'s (1994) classification, considering the degree of spatial dependence (DSD) strong to semivariograms that have a nugget effect  $\leq 25\%$ , moderate when it is between 25 and 75% and weak when  $DSD \geq 75\%$ . The DSD is described in Equation 1.

$$DSD = \frac{C_0}{C_0 + C_1} \times 100 \quad (1)$$

where:  $C_0$  is the nugget effect and  $C_1$  is the contribution. Cross-validation was used to evaluate the best model for the theoretical semivariogram. Surface maps were generated using data interpolation by kriging for the variables that presented spatial dependence and the inverse of the distance to the variables that did not present spatial dependence.

## Conclusion

The PA techniques used were important tools to model the spatial variability of the physical properties and orange yield. The physical property values and orange yield vary according to the position of the fruit on the tree canopy, primarily evidenced in this study by the characteristics of juice yield (JY) and yield per quadrant. The spatial dependence was observed in all the physical characteristics studied as well as the yield, indicating the influence of spatial location of the fruit on the tree canopy, regardless of the quadrants.

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