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3D thematic maps of the chemical parameters of orange fruits

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ABSTRACT. Since orange is the most produced and consumed fruit in Brazil and since its position on the tree may influence its physical and chemical attributes, current assay modeled a three-dimension spatial variability of total soluble solids (TSS) and ascorbic acid (AA) contents of the fruit in an orange orchard according to fruit position (coordinates x, y and z) on the plant and analyzed solar radiation on them. The experiment was conducted in Nova Laranjeiras, Paraná State, Brazil, and analyzed 715 fruit (Monte Parnaso variety) from nine trees in 2011, 2012 and 2013. Results showed that high TSS contents were reported in the tree´s peripheral area in the two analyzed thirds due to a high solar radiation. Highest AA rates were reported in the apical third. In the case of quadrants, higher AA levels were found in SE and NE (morning sun) with regard to the apical third and in SW and SE (afternoon sun) with regard to the basal third. The three-dimension interpolation method displays the spatial variability of the fruit's physical attributes by three-dimensional maps.

Keywords: ascorbic acid, fruit position, geostatistics, total soluble solids.

Mapas temáticos 3D dos parâmetros químicos de frutos de laranjeira

RESUMO. Considerando que a laranja é a fruta de maior produção e consumo no Brasil e que, a posição do fruto na planta pode influenciar suas características químicas, o objetivo deste trabalho foi modelar a variabilidade espacial tridimensional do teor de Sólidos Solúveis Totais (SST) e teor de Ácido Ascórbico (AA) de frutos em pomar de laranjas em função da posição (coordenadas x, y e z) dos frutos na planta e dos níveis de radiação solar incidente nos mesmos. O experimento foi conduzido no município de Nova Laranjeiras - PR, por meio da análise de 715 frutos (variedade Monte Parnaso) provenientes de nove árvores, nos anos de 2011, 2012 e 2013. Os resultados evidenciaram que maiores teores de SST são encontrados na área periférica da árvore em ambos os terços analisados, devido à maior incidência de radiação solar. Para os teores de AA, maiores valores foram encontrados no terço apical em relação ao terço basal. Em relação aos quadrantes, maiores teores de AA são encontrados nos quadrantes SE e NE (sol da manhã) para o terço apical e nos quadrantes SO e SE (sol da tarde) para o terço basal. O uso de metodologia de interpolação tridimensional permite a visualização, por meio de mapas tridimensionais, da variabilidade espacial de atributos químicos de frutos.

Palavras-chave: ácido ascórbico, posição do fruto, geoestatística, sólidos solúveis totais.

Introduction

Knowledge on the spatial and temporal variability of fruits´ chemical attributes makes one decide on adopting a specific management of land, orchards or individual plants. Several studies have been carried out on this subject, including the distribution of the root system of a citrus crop under water stress (Alves Junior, Bandaranayake, Parsons, & Evangelista, 2012), relief and spatial variability of soil properties in an area cultivated with citrus (Leão, Marques Junior, Souza, Siqueira, & Pereira, 2011), citrus yield maps (Molin, Colaço, Carlos, & Mattos Junior, 2012) and the study on determinants of acceptability of orange tastes (Obenland et al., 2009). The states of São Paulo in Brazil and Florida in the United States are the largest producers of orange (*Citrus sinensis* (L.) Osbeck) in the world (*Organização das Nações Unidas para a Alimentação e a Agricultura* [FAO], 2014).

The chemical properties of fruits depend on weather conditions and on the exposure of plant and fruits to solar radiation during their formation and maturation (Lemos, Siqueira, Salomão, Cecon, & Lemos, 2012). As a rule, total solar radiation on a vertical surface depends on its azimuth angle (Mohammadi & Khorasanizadeh, 2015). According to Detoni, Herzog, Ohland, Kotz, and Clemente (2009), the size of trees, spacing, row orientation, canopy shape and type of planting system adopted influence the distribution of solar radiation on the plant.

Selecting the right time to harvest citrus fruits is highly important, although different stages of fruit maturation may occur on the same tree. The position of the fruit on the tree canopy is an important factor, with qualitative differences (Cronje, Barry, & Huysamer, 2011, Khalid et al., 2012).

According to Verreynne, Rabe, and Theron (2013), studies on the position of the fruit on the tree may define a fruit sampling plan for quality analysis and may serve as a guide for harvest and post-harvest. They may even be a help in the development of pruning strategies. Fruits facing west (morning sun) have higher levels of total soluble solids and maturity index. On the other hand, higher rates of total titratable acidity and ascorbic acid content may be found in fruits harvested inside the canopy, regardless of their height (Lemos et al., 2012).

Orange fruit is Brazil's most produced and consumed fruit and besides being an important source of vitamin C, it assists in one's resistance to infections, wound healing and burns. It strengthens bone structure, promotes the absorption of glucose and the functioning of the intestine, reduces cholesterol and neutralizes uric acid (*Companhia de Entrepostos e Armazéns Gerais de São Paulo* [Ceagesp], 2011).

Given the scarcity of studies involving 3D maps on the chemical characteristics of citrus fruits, methods already employed in the analysis of three-dimensional variability of soil properties (Choi & Park, 2006, He et al., 2010), three-dimensional display of forest landscapes (Lim & Honjo, 2003) and ground magnitude and impedance (Karaoulis et al., 2011), albeit not in fruit culture, were used in current study to identify the spatial variability structure of the variables by means of geostatistics and ordinary kriging interpolation.

Thus, considering that the orange is the most produced and consumed fruit in Brazil and that the position of the fruit on the tree may influence its physical and chemical attributes, current analysis modeled a three-dimensional spatial variability of total soluble solids (TSS) and ascorbic acid (AA) contents of the fruit in an orange orchard according to fruit position on the plant and evaluated solar radiation on them.

Material and methods

The study area measured approximately 1 ha, in Nova Laranjeiras, midwestern Paraná, Brazil, with an average altitude of 760 m and approximate central UTM coordinates 7,191.655 m S and 341.660 m E, 22J (25° 23' 00,57" S and 52° 34' 26,11" W). The average annual rainfall is 1900 mm and the average relative air humidity is 75%. Local soil is classified as Dystroferric Red Latosol, according to *Empresa Brasileira de Pesquisa Agropecuária* (Embrapa, 2013).

Local climate is characterized as humid and very humid sub-montane (warm temperate), with an average annual temperature 19.5°C. The orange orchard was established in August 2005, with 4 x 6 m spacing. The rootstock used was *Poncirus trifoliata* L. Raf. grafted with Monte Parnaso variety (*Citrus sinensis* L. Osbeck). The orchard has 394 orange producing trees.

The UTM coordinates of the area were collected by GPS receiver with post-processing, at ± 30 cm precision, set to run Datum WGS84, by using the same reference ellipsoid in data processing. Considering each tree as a set of sampling units (oranges), nine trees were defined (Figure 1A) for spatial representation of the total area of the orchard, with minimum distance of 28 m and maximum distance of 44 m between the sampled trees. The 3D coordinates of the fruits (E - longitude, N - latitude and Altitude, further represented as local coordinates x, y and z) were collected with the aid of a total station with reading without the use of prism. Fruit were chosen randomly and identified (Figure 1B and C). Besides the coordinates of the fruit, the coordinate at the base of each tree was also collected. The collection of these coordinates occurred at an average of 30 days prior to fruit harvest. Further, 715 fruit were harvested (2011, 2012 and 2013) from the nine trees, ranging between 25 and 30 fruit per tree/year.

Harvest occurred simultaneously for all fruit each year at the end of May to visualize the heterogeneity of their chemical properties according to the position of each fruit on the tree. The instantaneous solar radiation was measured by a digital pyranometer, with a cloudless sky, just after noon. The trees were delimited into quadrants (NE, SE, SW and NW) to characterize the prevalence of solar radiation rates in relation to fruit arranged on the orange trees.

After harvest the fruit were stored in a refrigerator until laboratory tests, which took place within five days. Further, 203, 249 and 263 oranges were analyzed respectively for 2011, 2012 and 2013.

Fruit analysis comprised contents of TSS in ºBrix with a portable refractometer and ascorbic acid (AA), according to Tillmann´s methodology (method No. 365/IV) (*Instituto Adolfo Lutz* [IAL], 2008), applied to the analysis of samples with low vitamin C, such as fruit juices. Sample trees were divided into basal, intermediate and apical thirds for data analysis (Figure 2A). Figure 2B shows the daily sun path according to the latitude of the orchard.

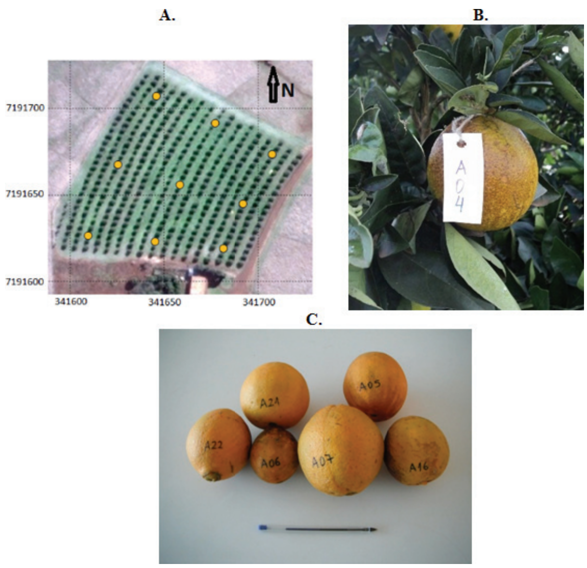

Figure 1. Location of orange trees in the orchard (A) in Nova Laranjeiras, Paraná State, Brazil, and fruit identification (B) and (C).

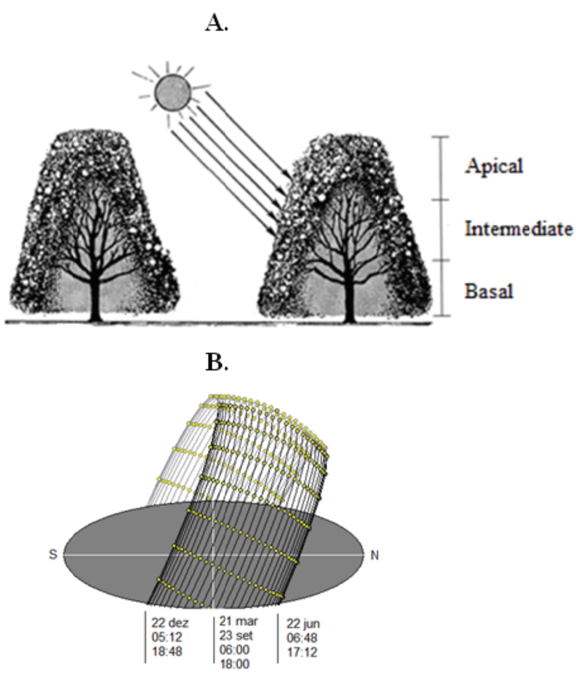

Figure 2. Position of fruit on the plant (A), adapted from Tucker, Wheaton, and Muraro (1991), and illustration of the daily sun path (B) during the seasons according to the latitude of the orchard (25.5°S). Adapted from http://www.labeee.ufsc.br/downloads/softwares/sunpath.

Data were statistically analyzed with exploratory analysis, in which position, dispersion and shape were measured. The Shapiro-Wilk and Kolmogorov-Smirnov tests at 5% significance were employed to verify data normality. Data showing normality in at least one of the tests were considered normal.

To verify the spatial variability of the variables of interest, spatially geo-referenced data were analyzed by means of geostatistical methods using the semivariance function and the classical variogram estimator proposed by Matheron (1963).

Experimental semivariograms were built in the usual directions (0, 45, 90 and 135°) to verify the existence of anisotropy. Since different directions showed similar patterns of spatial dependence (isotropy), omnidirectional semivariograms were also built. A theoretical model (spherical, exponential or Gaussian) was built to the semivariance function and parameters were estimated by the ordinary least squares (OLS) method (Cressie & Hawkins, 1980) with a 50% cutoff in the maximum distance between the sampled points.

After the parameters for nugget effect (C_0), range (*a*), contribution (C_1) and sill (C_0 + C_1), which define the spatial variability of structure analysis (SST and AA), were estimated, the most suitable model of the semivariance function was obtained by employing the cross validation method (Faraco, Uribe-Opazo, Silva, Johann, and Borssoi, 2008), by the computation of the comparison-wise error rate (CER) (Santos, Souza, Nóbrega, Bazzi, & Gonçalves Júnior, 2012). When selecting the models j, it provides a value closer to zero (0) for average error, and closer to one (1) for reduced average error. Therefore, the best is that with lowest CER when choosing among several models. Data were interpolated by average ordinary kriging, using the structure of spatial variability identified in semivariance function with the best fit (lowest CER).

The degree of spatial correlation was sorted according to the spatial correlation index (SCI) (Equation 1). Cambardella et al. (1994) proposed the following intervals for verifying the correlation: SCI ≤ 25% - strong spatial correlation; 25 < SCI < 75% - moderate spatial correlation and SCI ≥ 75% - weak spatial correlation.

$$IDE = \frac{C_0}{C_0 + C_1} \text{ x } 100 \qquad (1)$$

where:
C_0 = nugget effect;
C_1 = contribution;

$C_0 + C_1$ = sill.

Data normalization method was employed (Equation 2) to remove the influence of the seasonal data (2011, 2012 and 2013) from the fruit´s chemical attributes (Xiang, Yu-Chun, Zhong-Qiang, & Chun-Jiang, 2007, Suszek, Souza, Uribe-Opazo, & Nóbrega, 2011).

$$ND_{ij} = \frac{D_{ij}}{\overline{D}_j}, \quad (2)$$

where:

ND_{ij} – normalized data at point i in year j;

D_{ij} – original data at point i in year j;

$\overline{D}_j$ – average data of year j.

Scrolling (transport) of the coordinates of the fruit of eight trees was employed to analyze the orchard´s overall model, or rather, a new arrangement was conducted so that the 715 samples (fruit) were analyzed as if they were all located in only one tree (E), which is the central tree in the orchard.

ArcGIS® 10 and SGeMS® (Remy, Boucher, & Wu, 2009) were used for the interpolation process and generation of the 3D thematic maps. Interpolation applied to three-dimensional map generation was done by the process commonly used for two-dimensional interpolation. However, computational processes completed the information in three dimensions and provided a 3D image using a group of 2D images. Tests of means aiming at assessing the statistical differences of TSS and AA attributes as to the thirds were not performed due to the spatial correlation among data.

Results and discussion

Daily average solar radiation from blossom to harvest presented minimum rates of 363.9, 351.8 and 308.3 W m^{-2}; maximum values of 542.9, 515.0 and 495.9 W m^{-2}, and mean values of 425.1, 455.9 and 417.5 W m^{-2} for harvest in 2011, 2012 and 2013 respectively.

The average instant solar radiation in the three years under analysis was 951, 209, 56 and 592 W m^{-2} for quadrants NE, SE, SW and NW, respectively (Figure 3A). Figure 3B shows the planialtimetric map of the orange orchard in UTM coordinates oriented towards the north (N), south (S), east (E) and west (W).

The coefficient of variation (CV) was classified as low when CV ≤ 10% (homogeneous data); medium when 10 < CV ≤ 20%; high when 20 < CV ≤ 30%; very high when CV > 30% (heterogeneous data) (Gomes & Garcia, 2002). As to TSS content, CV was considered low for the nine trees analyzed. The lowest, medium and highest TSS rates were 7.0, 9.3 and 12.8 °Brix, respectively, for the group of 715 fruit analyzed. According to Brasil (2000), the minimum TSS content for industrialized orange juice must be 10.5 °Brix.

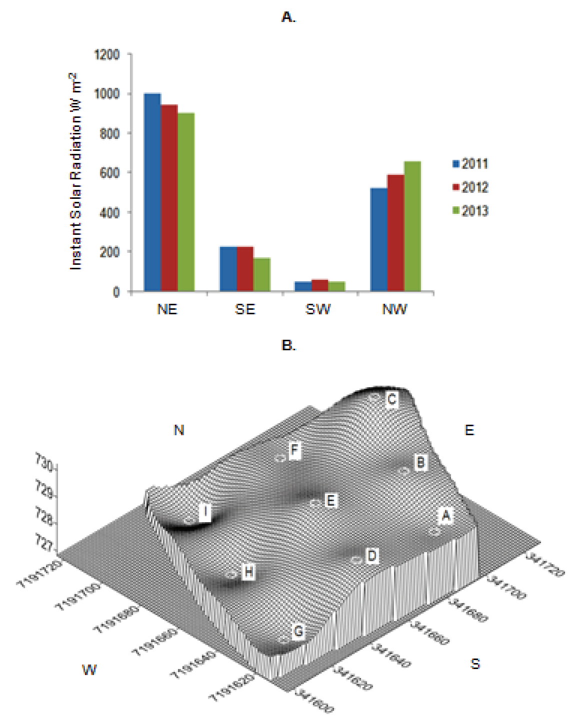

Figure 3. Average solar radiation in three years (2011, 2012 and 2013) in W m^2 (A); planialtimetric map of the orange orchard in Nova Laranjeiras, Paraná State, Brazil (B).

Since the goal of current study was not only to gather ripe fruits but also to verify the heterogeneity of their chemical attributes in relation to their three-dimensional position on the tree, the results are coherent. Rates ranging from 8.5 to 10.8 °Brix were found by Reis et al. (2008) also in an experiment with Monte Parnaso oranges in an orchard in Butiá, Rio Grande do Sul State, Brazil.

The lowest rate for AA content was 40.0 mg 100 mL^{-1}, whereas the highest was 76.7 mg 100 mL^{-1}, with mean rate at 55.5 mg 100 mL^{-1}. The above rates were considered normal, as studies on citrus by other researchers provided rates between 25.5 and 77.0 mg 100 mL^{-1} (Andrade, Diniz, & Neves, 2002, Chitarra & Chitarra, 2005). Minimum AA content for industrialized orange juice must be 25 mg 100 mL^{-1} (Brasil, 2000). The CV was considered between low and moderate for the trees analyzed. However, Couto and Canniatti-Brazaca (2010), studying other five varieties, found higher mean rates: 62.5 (Pêra orange); 64.6 (Lime orange); 84.0 (Natal orange); 78.5 (Valência orange) and 80.0 mg 100 mL^{-1} (Bahia orange).

As to the thirds, AA rates ranged between 47.0 and 59.3 mg 100 mL^{-1}; 48.0 and 60.2 mg 100 mL^{-1} and between 48.28 and 61.38 mg 100 mL on the basal, intermediate and apical thirds, respectively. Lemos et al. (2012) reported lower rates of AA content for Pêra oranges (32.0; 29.1 and 31.7 mg 100 mL^{-1}) on the basal, intermediate and apical thirds respectively.

Results refer to the study of individual trees. Data of the localization (x, y and z) of the fruits on each tree were recalculated and transported to match only one point (tree) to have a general view of the behavior of chemical attributes of the fruit in the orchard (715 samples). The above preserves the vertical quotas and the normalized rates of the attributes, since the higher the number of points, the higher the number of pairs for the calculation of semivariances and, theoretically, the higher the precision in the estimation of the semivariances.

The TSS content averaged 9.3 °Brix within the general model of the orchard (Table 1), with rates ranging between 7.0 and 12.8 °Brix and CV equal to 9.4% (low), whereas the average AA content was 55.5 mg 100 mL^{-1}, with values ranging between 40.0 and 76.7 mg 100 mL^{-1} and CV of 13.1% (medium).

Table 1. Mean rates of chemical attributes with regard to position of fruit on the thirds of nine trees in the orange orchard in 2011, 2012 and 2013 in Nova Laranjeiras, Paraná State, Brazil.

Third	TSS (°Brix)	AA (mg 100 mL^{-1})
Basal	9.3	54.7
Intermediate	9.4	55.5
Apical	9.3	56.5
Mean rate	9.3	55.5

TSS: total soluble solids; AA: ascorbic acid.

Mean rates between the thirds were similar in TSS content, with a CV of 0.37%. These rates were lower to those found by Lemos et al. (2012) in a study on Pêra oranges: 10.6, 10.6 and 10.8 °Brix for the basal, intermediate and apical thirds, respectively.

Lemos et al. (2012) reported AA content of 32.0, 29.1 and 31.6 mg 100 mL^{-1} respectively for the basal, intermediate and apical thirds. Rates were lower than those given in current study. Thus, the relationship between TSS increase and AA content as a function of the increase in fruit quota cannot be proved. The CV between thirds was 1.55%

Table 2 shows the result of the geostatistical analysis and the best-adjusted model to each chemical attribute, estimated parameters and respective classification of spatial dependence. The best adjusted models were the exponential for SST and Gaussian for AA, as they presented the lowest CER rates. Spatial dependencies were classified as moderate by the SCI for both variables because the range (*a*) marks the distance from which a point of the variable under study has no more influence on the neighboring point. In current study, the ranges obtained were 0.09 and 0.08 meters for SST and AA, respectively, showing the distances within which the samples presented spatial autocorrelation. The experimental semivariances did not present anisotropy (Guedes, Uribe-Opazo, Johann, & Souza, 2008, Guedes, Uribe-Opazo, & Ribeiro Junior, 2013), since the semivariances behaved similarly in different directions, that is, they exhibit similar patterns of spatial dependence.

Table 2. Models and estimated parameters of the experimental semivariograms of the chemical attributes of fruit in the orange orchard in Nova Laranjeiras, Paraná State, Brazil.

Variables	Models	C_0	C_1	$C_0 + C_1$	*a* (m)	SCI (%)	Correlation
TSS	Exponential	0.3468	0.4339	0.7806	0.09	44.42	Moderate
AA	Gaussian	42.9941	20.2439	63.2381	0.08	67.99	Moderate

TSS: total soluble solids; AA: ascorbic acid; C_0: nugget effect; C_1: contribution; $C_0 + C_1$: sill; *a*: range; SCI: spatial correlation index.

As previously mentioned, the coordinates of the fruit of eight trees were recalculated and transported to coincide in only one point (base of tree E) to increase the number of samples and to ensure consistency of results. The analysis of the three-dimensional spatial variability in the data group, with the nine trees superimposed, required the construction of a three-dimensional grid (Figure 4A). Thus, starting from the minimum local coordinates 0.000, 0.000 and 0.000 m, the new maximum local coordinates were 4.002, 3.966 and 2.269 m, accounting for 81, 80 and 46 voxels (volume x element) for x, y and z respectively. The two-dimensional representation of the fruit is illustrated in Figure 4B.

Figure 5 depicts the three-dimensional maps visualized from the y-axis (north-south), x-axis (east-west), z-axis (quota) and in cuts on the basal, intermediate and apical thirds. The analysis of the thematic map revealed that lower rates of TSS content are reported in the basal and intermediate thirds, as well as in the central and SW regions of the tree, whereas rates above the average are concentrated in the peripheral area of the tree in all thirds, with higher concentrations in the extreme north region, in the apical third and in the NW region of the basal third, or rather, the highest rates of solar radiation (quadrants NE and NW).

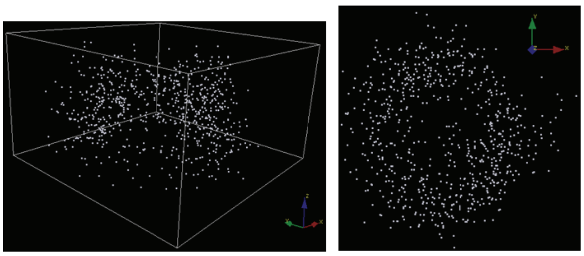

Figure 4. Three-dimension grid with the position of 715 oranges (A) and respective two-dimension grid (B).

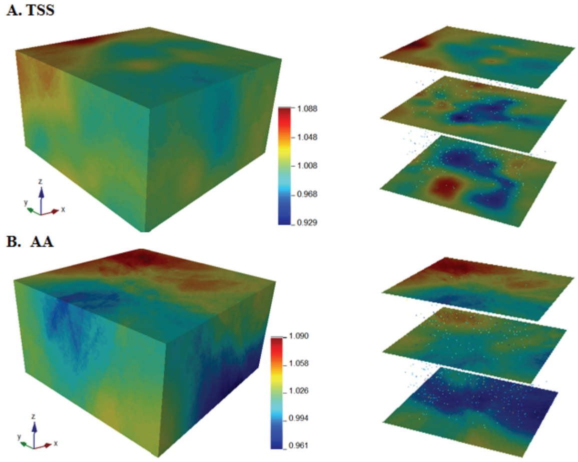

Figure 5. 3D maps referring to the normalized rates of the chemical attributes (TSS and AA) and in cuts in the z-axis, considering the nine superimposed trees, in 2011, 2012 and 2013 in Nova Laranjeiras, Paraná State, Brazil.

The 3D map shows higher rates of AA content on the apical third in the eastern region of the tree (morning sunshine), whereas lower rates occurred in the western region (afternoon sunshine). The same behavior has been observed in the intermediate third; however, there was an opposite behavior in the basal third, or rather, rates above the average have been reported in the western region and rates below the average have been reported in the eastern region of the tree.

Conclusion

Higher TSS content was registered in the peripheral area of the tree in all thirds assessed due to higher solar radiation.

Higher AA content was reported in the apical third rather than in the basal third. As to quadrants, higher AA contents were registered in SE and NE (morning sunshine) for the apical third and in the quadrants SW and SE (afternoon sunshine) for the basal third.

The use of the three-dimensional interpolation methodology displays spatial variability of the chemical attributes of fruits through a 3D map.

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