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Spatial and temporal variability of productivity of coffee plants grown in an experimental field located in Três Pontas, Brazil

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Abstract. The coffee grower seeks to increase productivity, as well as reduce the operating costs of his crop. Precision Agriculture (PA) is composed of a cycle of tools and technologies that can bring a good return to coffee growers, seeking to optimize production processes, bringing better yields and minimizing costs. Therefore, the objective of this research is to evaluate the space-time behavior of productivity in a coffee plantation, aiming to apply AP techniques. The study was carried out in a coffee plantation of the species *(Coffea arabica)*, cultivar Topázio MG1190, located in the municipality of Três Pontas, Brazil, with an area of 1.2 ha. With the aid of a GNSS RTK, 30 plants were georeferenced, from which their yields were later sampled in the years 2020, 2021 and 2022. The collected data were evaluated in two statistical processes in the RStudio software. The first stage consisted of a one-way analysis of variance with repeated measures, from the results it is concluded that there are differences between the production averages when buying the productivity of the years 2020, 2021 and 2022 and, in addition, the coefficient of variation for the three sets of samples was quite high (CV > 30%) indicating a heterogeneity between the data. The second stage consisted of a geostatistical analysis the data were fitted in a model and interpolated by ordinary kriging; the result was maps of spatial variability. Through these maps it was possible to evaluate the behavior of productivity spatially and temporally, as well as to quantify areas that had higher and lower levels of this attribute. It is concluded that productivity, even in the case of such a small productive area, can vary substantially in space and time, and the use of PA can help producers in decision making regarding management.

Key words: biennial, geoestatistics, precision agriculture in coffee trees.

INTRODUCTION

The coffee agro-industrial system is the focus of several studies due to its importance in the economic and social history of Brazil since the colonial period. This commodity played an important role in the accumulation of foreign exchange that started the country's industrialization process (Cardozo et al., 2019).

Coffee cultivation in Brazil occurs in environments with great diversity (Alves et al., 2011) and this cultivation is very sensitive to climatic conditions (Aparecido et al., 2015). Climate variability has a strong impact on agricultural activities (Sá Junior et al., 2012), being the main factor responsible for fluctuations and oscillations in coffee bean productivity (Camargo, 2010).

According to Santana et al. (2022) the Precision Agriculture applied to coffee production still needs to be developed and implemented. But the same authors indicate that there is still a propensity to research, defunded, and adopted due to the benefits and adopted due to the benefits it can bring as efficiency, environmental and economic sustainability.

Productivity maps are one of the precision agriculture tools and are an excellent indicator of problems that may occur during the productive cycle of a crop. Failure to use tools like these leads the producer to consider mean values for decision-making in relation to management, which can lead to decisive errors. Even if the crop is treated (fertilizing, spraying, controlling pests and diseases, etc) throughout this cycle, productivity is a factor that will not be uniform, as this is an attribute that is influenced by factors such as: biennial (Camargo & Camargo, 2001), soil fertility and leaf nutrition (Wadt & Dias, 2012; Scalco et al., 2014) occurrence of pests, diseases and weeds (Fialho et al., 2010; Carvalho et al., 2012, Lopes et al., 2012), physical attributes of the plant (Carvalho et al., 2013; Burak et al., 2016; Santos et al., 2023) among other factors.

Taking into account that coffee production is strongly influenced by several factors which may lead to a high rate of spatial variability of this attribute, in this context, Precision Agriculture (PA) arises with the objective of evaluating and quantifying this spatial variability. PA when applied to coffee growing is called Precision Coffee Growing (Ferraz et al., 2012a). Precision Agriculture (PA) approaches seek to understand the spatial and temporal variability present in agricultural variables within a production field (Martello et al., 2022).

The need to modernize agricultural production has encouraged more and more producers to adopt agricultural practices within the PA context (Dong et al., 2013). A more up-to-date definition of precision coffee farming was described by Santana et al. (2022) who define it as updated techniques and technologies use that aim to maximize crop profitability, increase operations efficiency, search for business sustainability, environmentally sustainable production, and unceasing search for maximizing productivity and improving final product quality.

Ferraz et al. (2017) state that geostatistics is an important methodology for data analysis, being used as a tool within PA to analyze the factors involved in production systems (Carvalho et al., 2013). Through geostatistical analysis, it is possible to identify whether there is spatial dependence for the analyzed factors, enabling the creation of thematic maps that help in decision making (Carvalho et al., 2013). The use of the GIS environment has great potential for accurate and rapid research, bringing clear results (Piri et al., 2019) especially when it comes to assessing climate variability and its consequences on productivity.

It is important to mention that the application of PA techniques and technologies in coffee growing is recent, mainly when it comes to the evaluation of heterogeneity of factors related to soil and plants, and bearing in mind that few studies evaluate small-scale productive crops. In this context, this work aims to evaluate the spatial variability of the productivity obtained for three consecutive years, 2020, 2021 and 2022 and, in this way, if the spatial dependence is proven, generate maps through interpolation by kriging, which will establish values of this attribute at unsampled locations within the study area.

MATERIALS AND METHODS

Workflow

The workflow of this research (Fig. 1) was defined in the following stages: construction of the sampling grid, georeferencing of points, productivity sampling and geostatistical analysis.

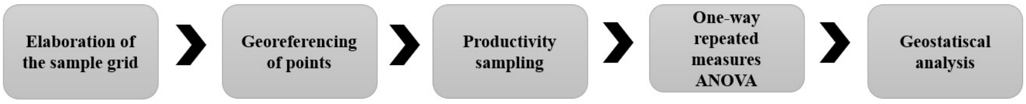
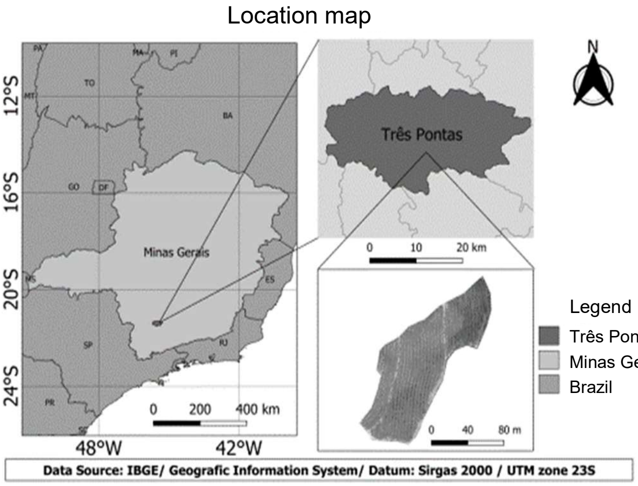


Figure 1. Work flowchart.

Description of the Study Area

The study was conducted in a coffee plantation of the Experimental Field of the Minas Gerais Agricultural Research Company (EPAMIG, as abbreviated in Portuguese), located in the municipality of Três Pontas in the southern region of the state of Minas Gerais, Brazil, at an altitude of 905 m and a Universal Transverse Mercator (UTM) coordinate system position of 7640030.4 S and 449531.5E, Zone 23K. This municipality has an mean annual temperature of 20.3 °C and an mean annual rainfall of 1,429 mm (Climate Data, 2023).

The soil in this area is classified as oxisol. The area of the experiment comprised 1.2 ha of a coffee plantation of the species *Coffea arabica* L. of the Topázio MG1190 cultivar (Fig. 2). This crop was established in 1998 with spacings between rows of 3.70 m and between plants of 0.70 m (EPAMIG, 2023).


Location map

Data Source: IBGE/ Geografic Information System/ Datum: Sirgas 2000 / UTM zone 23S

Figure 2. Location map.

Sampling grid

The sampling grid was prepared with QGIS software, version 3.4.8, and 30 sampling points representing a sampling density of 25 points per hectare were laid out (Fig. 3).

For the construction of the sampling mesh, the methodology of the equidistant sampling mesh proposed by Faria (2019) was used, this method consists of reducing the walking within the plot using walking routes. Within the sampling of 30 points, the smallest distance between them was 6m and the greatest distance was 175 m.

For this study, the productivity data of the 30 georeferenced plants were sampled on the following dates: 1st collection (30 June 2020), 2nd collection (08 June 2021) and 3rd collection (13 June 2022).

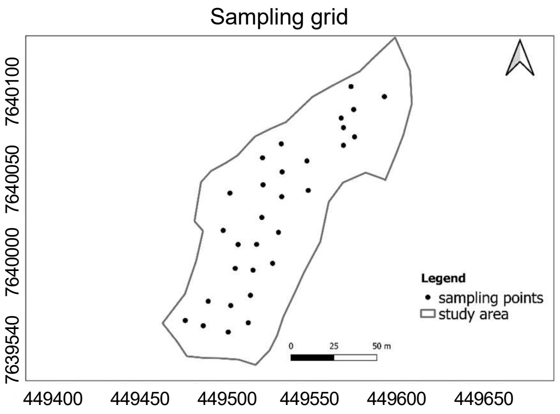


Figure 3. Equidistant sampling grid used for sampling the 30 georeferenced points in this study.

Productivity sampling

Productivity data were sampled at 30 georeferenced points within the study area. For each sampling point represented by 1 coffee plant, productivity was obtained through semi-mechanized harvesting using a derriçadora (Fig. 4, a). After harvesting each sampling point, the fruits that fell under the cloths were selected to separate them from leaves and branches (Fig. 4, b), and then they were deposited in a graduated container, which will indicate the productivity in liters per plant (L /plant) (Fig. 4, c).

Figure 4. Productivity sampling (a) semi-mechanized harvesting, (b) separation of leaves and branches and (c) productivity measurement in L/plant in graduated bucket.

Statistical analysis

Taking into account that during the three years of sampling, the same 30 plants were sampled, in this way, as the dataset represents a group of samples where repeated measurements of productivity were obtained during a time interval (2020, 2021 and 2022), The one-way analysis of variance (ANOVA) statistical test with repeated measures was used in order to evaluate the mean productivity of each group as a whole. For this analysis, tests were first performed to verify outliers in the samples and then a Shapiro Wilk test to verify data normality.

Then, the analysis of variance model was built using the variables year (independent variable) and productivity (dependent variable), the result of this model is a table containing: degree of freedom of the evaluated variable, degree of freedom of error, sum of squares, F-value and p-value. For this F test to be valid, it is necessary to verify the sphericity of the data, and this will be done using the Mauchly test, this test considers the following hypotheses:

$H_{0Mauchly}$: data are spherical when $p > 0.05$;

$H_{1Mauchly}$: data are not spherical when $p \leq 0.05$.

If sphericity is verified and the null hypothesis is accepted, the following hypotheses for the F test performed in the analysis of variance of a repeated measures way must be considered:

H_{0ANOVA}: mean productivity 2020 = mean productivity 2021 = mean productivity in 2022; $p > 0.05$

H_{1ANOVA}: there is at least one difference between the means of productivity $p \leq 0.05$

If the null hypothesis of the Mauchly test ($H_{0Mauchly}$) is rejected and the alternative hypothesis ($H_{1Mauchly}$) is accepted, it is necessary to correct the degrees of freedom of the variance analysis using the Greenhouse-Geisser method for the lack of sphericity, and from there, obtain a new p value, and only then apply the hypothesis analysis of the one-way ANOVA method with repeated measures. After performing the F test by one-way ANOVA with repeated measures and if the null hypothesis (H_{0ANOVA}) of the test is rejected and the alternative hypothesis is accepted (H_{1ANOVA}), that is, that there is at least one difference between the measurements of productivity it is necessary to verify what this difference is, through a pair comparison test using the Bonferroni adjustment, which will result in a comparison matrix between the mean productivity, where the following hypotheses must be considered:

$H_{0\ Bonferroni}$: if $p > 0.05$ there is no difference between the productivity means;

$H_{1\ Bonferroni}$: if $p \leq 0.05$ there is a difference between the productivity means.

And finally, to close the statistical analysis of the data, a descriptive statistics table was generated containing: productivity mean for the three years, standard deviation and coefficient of variation. Gomes & Garcia (2002) state that the variability of an attribute can be classified according to the magnitude of its coefficient of variation (CV), according to the authors, the CV is low when it is less than 10%, moderate when it is in the range from 10 to 20%, high when it is between 20 and 30% and very high when it is above 30%. All statistical analysis of the data was performed using the RStudio software using the dplyr, ez, reshape and rstatix libraries.

Geostatistical analysis

Semivariograms were used to analyze the spatial dependence of the productivity. The semivariance is classically estimated by Eq. (1) according to Vieira (2000):

$$\hat{\gamma}(\mathrm{h}) = \frac{1}{2\,N(\mathrm{h})} \sum_{i=1}^{Ni=(\mathrm{h})} [Z\,(x_i) - Z\,(x_i + \mathrm{h}\,)]^2 \qquad (1)$$

where N (h) is the number of experimental pairs of observations $Z\,(x_i)$and $Z\,(x_i + \mathrm{h}\,)$, separated by a distance h. The semivariogram is represented by the graph $\hat{\gamma}(\mathrm{h})$ versus h. From the fitting of a mathematical model to the calculated values of $\hat{\gamma}(\mathrm{h})$, the coefficients of the theoretical model are estimated for the semivariogram, called the nugget effect (C_0), sill ($C_0 + C_1$), and range (a), as described by Bachmaier & Backes (2008).

The semivariograms were adjusted using the Ordinary Least Squares (OLS) method. The adjusted semivariogram model was the spherical one, since this is the most used in geostatistics studies related to soil and coffee culture (Grego & Vieira, 2005; Silva et al., 2007) mainly evaluating coffee productivity (Ferraz et al., 2012a; Ferraz et al., 2012b; Carvalho et al., 2013, Carvalho et al., 2017; Ferraz et al., 2017).

To verify that this model fits the cross-validation requirements, the mean error (ME) was calculated as described by Isaaks & Srivastava (1989). ME should be as close to zero as possible.

With the adjustment of the semivariograms, after the identification of the spatial variability, the data were interpolated by ordinary kriging. Thus, the variable was estimated in places where it was not sampled, which allowed us to visualize its distribution in space in the form of thematic maps.

The calculation of the degree of spatial dependence (DSD) of the variables followed the classification proposed by Cambardella et al. (1994). In this classification, the authors point out that there is strong spatial dependence when the semivariogram shows a nugget effect equal to or less than 25% of the sill, moderate spatial dependence when this ratio is between 25% and 75%, and weak spatial dependence when it is greater than 75%.

The geoR package of the R software was used for geostatistical analysis and for the creation of the thematic maps (Ribeiro Junior & Diggle, 2001).

RESULTS AND DISCUSSION

Statistical analysis

Fig. 5 represents a column chart containing the productivity data sampled in the 30 georeferenced plants in the years 2020, 2021 and 2022. It is observed that the highest values of productivity in coffee trees were found in the year 2022 for plants 25 (39 L/plant) and 2 (34 L/plant) respectively. The lowest productivity values were found for plants 2 and 8 in the year 2021 and for plant 21 in the year 2022, both with zero productivity.

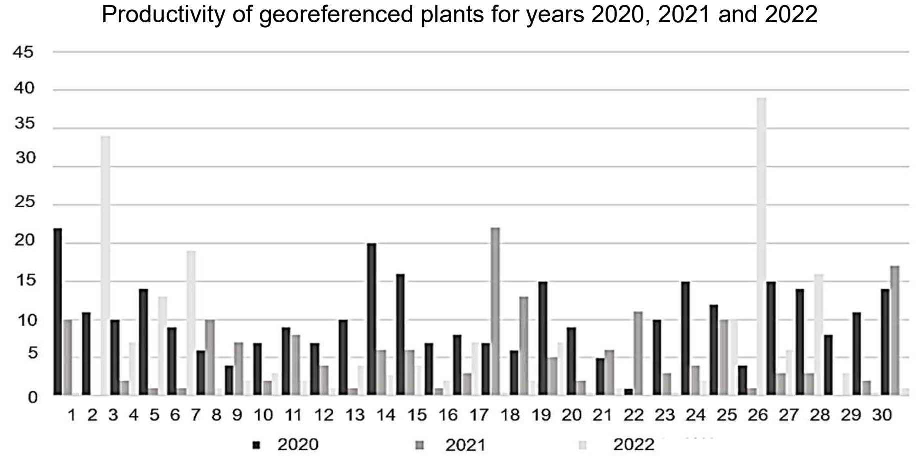


Figure 5. Productivity in liters per plant (L/plant) obtained for the 30 plants georeferenced and sampled in the years 2020, 2021 and 2022.

Table 1 represents the results generated by the one-way analysis of variance with repeated measures, including the F test of hypotheses, as well as the Mauchly test to verify the sphericity of the data.

Table 1. One-way analysis of variance with repeated measures and Mauchly test to verify sphericity

Analysis of variance							Mauchly's Test	
Variable	DFn	DFd	SSn	SSD	F	P_{ANOVA}	W	$P_{Mauchly}$
Year	2	58	650.2889	2459.0440	7.6690	0.0011*	0.9271	0.3466

DFn: sample degrees of freedom; DFd: error degrees of freedom; SSn: sample sum of squares; SSd: error sum of squares; F: value of F; pANOVA : probability of observation of the test F; W : statistics of the test; $p_{Mauchly}$: observation probability of the Mauchly test; *: significant at the 5% level of probability.

Through the analysis of variance modeling, it was observed that the $_{Mauchly}p$ value was greater than 0.05 (pMauchly > 0.05), that is, the Mauchly null hypothesis is accepted ($H_{0Mauchly}$) that the data are spherical, so the hypotheses of the F test can be evaluated without a sphericity correction using the Greenhouse-Geisser method. The F test performed by analysis of variance indicated an $_{ANOVA}$ p value = 0.0011 that is ($p_{ANOVA} \leq 0.05$), thus rejecting the null hypothesis of the analysis of variance (H_{0ANOVA}) and accepting the alternative hypothesis (H_{1ANOVA}) stating that there is at least one difference between the average productivity in the coffee tree between the years of 2020, 2021 and 2022. To quantify this difference, a comparison between pairs was performed using the Bonferroni test, which resulted in a matrix (Table 2) for comparing means by pairs.

Table 2. Bonferroni test for comparing means between pairs

Year	2020	2021
2021	0.2477	-
2022	0.0005*	0.1808

*: significant at the 5% probability level.

The results show that between the years 2021/2020 and 2022/2021 there were no differences between the productivity means ($p > 0.05$), while between the years 2022/2020 there was a difference between the productivity means, that is, the average productivity for the year 2022 differs significantly from the average productivity for the year 2020 ($p \leq 0.05$). After carrying out the analysis of variance of the set of data obtained in the field, the analysis of descriptive statistics was performed (Table 3).

Table 3. Data descriptive statistics

Year	mean	SD	CV (%)
2020	8.47	4.64	54.78
2021	11.30	7.29	64.51
2022	15.00	7.65	51.00

SD: standard deviation, CV: coefficient of variation.

After the variance analysis of the coffee productivity data, sampled in the years 2020, 2021 and 2022, the following hypotheses are concluded:

a) As much as the average productivity for the year 2022 is higher (15 L/plant), no it was necessarily the year that produced the most, and this was justified by the Bonferroni test, where the average productivity of the year 2022 differed significantly from the year 2020, the year in which most of the plants produced more compared to the years 2021 and 2022;

b) The difference in productivity between the productive cycles of the coffee tree can be justified by the bienniality, a phenomenon found in coffee plantations, where one year there is a lot of production and the next one less production.

c) The high productivity heterogeneity between plants during the same year can be explained by two factors: the first is the age of the coffee tree (25 years) and the second is the management adopted over all these years (conventional fertilization based on average fertility sampled in the field) which can generate a lack or excess of nutrients in the plants, which directly affects the individual production of each plant in this coffee tree.

Silva et al. (2007) evaluating the 2004 harvest of a 4.2 ha Mundo Novo coffee tree with 4m spacing between rows and 1m between plants, found in their study an average productivity of 4.81 (L/plant). Ferraz et al. (2012a) evaluating soil chemical attributes and productivity for the 2007–2008 season in a coffee plantation of 22 ha under the cultivation of coffee trees of the Topázio cultivar planted at spacing of 3.8 m between rows and 0.7 m between plants, found a productivity average of 1.45 (L/plant). With the aim of evaluating the spatial and temporal variability of productivity Ferraz et al. (2012b) the authors sampled this attribute in three harvests (2008, 2009 and 2010) in diferente sampling grids within the same coffee tree of 22ha. As a result, the authors obtained average productivity values of 1.45 (L/plant) for the 2008 season, 2.72 (L/plant) for the 2009 season and 4.93 (L/plant) for the 2009 season. 2010.

All the authors mentioned above found average productivity values much lower than those found in this study, and this is justified by several factors such as: coffee variety, spacing, climatic conditions, sampling mesh used in each study, management adopted in the field, etc.

Geostatistical Analysis

Table 4 represents the adjustment parameters of the semivariograms by the spherical model and by the ordinary least squares method. Figs 6 and 7 represent the semivariograms adjusted for the productivity variable and the thematic maps generated by kriging interpolation for the three years of collection, respectively.

Table 4. Parameters for fitting the spherical and exponential semivariogram models of the variables evaluated by the OLS method

	Year	C_0	C_1	$C_0 + C_1$	A	SDD		ME
Productivity	2020	0.10	24.00	24.01	25	0.41	strong	-0.01
	2021	0.50	20.00	20.5	30	2.43	strong	-0.02
	2022	0.01	80.00	80.01	12	0.01	strong	0.00

C_0 – Nugget effect; C_1 – Contribution; $C_0 + C_1$ – Sill; A – Range (m); SDD – Spatial dependence degree; ME – Mean error.

Through the geostatistical analysis of the productivity data obtained for the 2020, 2021 and 2022 harvests, it was possible to identify and quantify the spatial dependence of this variable. Camargo et al. (2004) states when an increase is observed between the absolute value of the difference between two samples and the increment of the separation distance between them until reaching a value in which there is no more spatial influence, thus causing the stabilization of the semivariogram the spatial dependence of the attribute is confirmed.

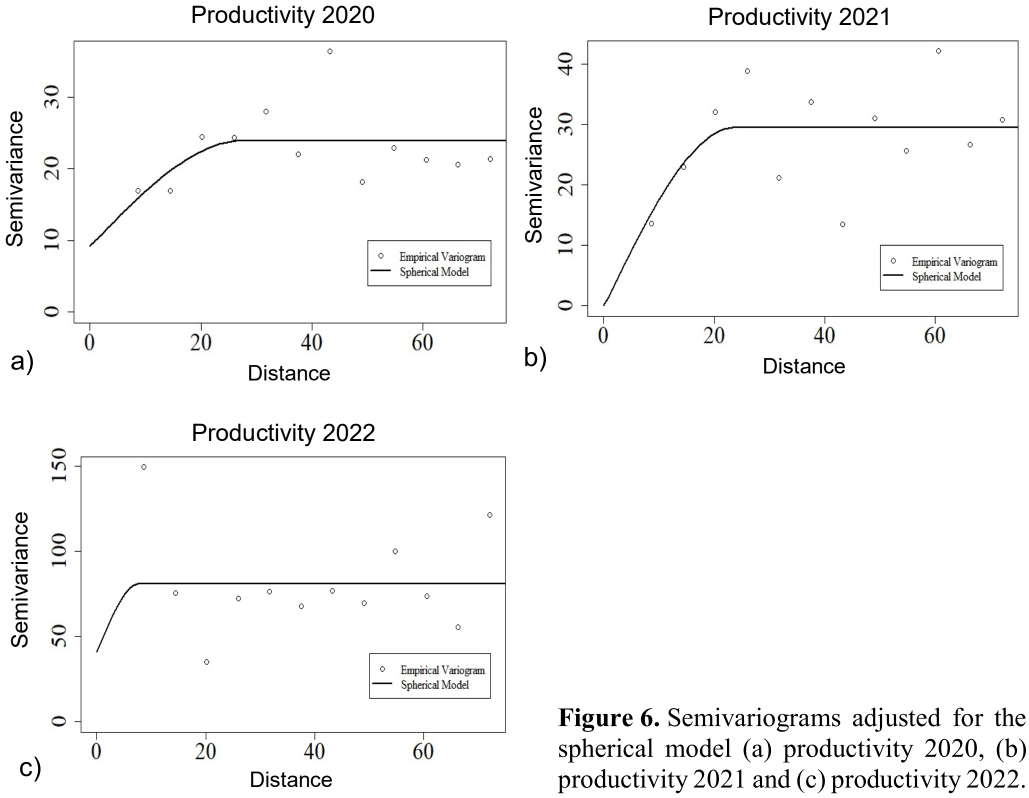


Figure 6. Semivariograms adjusted for the spherical model (a) productivity 2020, (b) productivity 2021 and (c) productivity 2022.

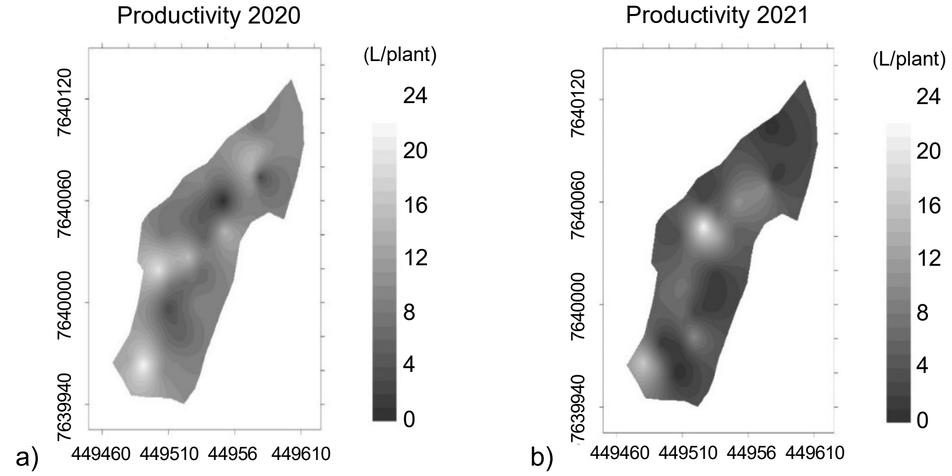
Regarding the adjustment parameters of the semivariograms, it is observed that the nugget effect was different from zero for all years of collection of the productivity attribute, it is an important parameter of the semivariograms as it indicates unexplained variability or even measurement errors, considering the sampling distance used (Carrasco, 2010). The nugget effect can be expressed as a percentage of the plateau, making it easier to compare the degree of spatial dependence.

All seasons (2020, 2021 and 2022) showed a strong degree of spatial dependence according to the criteria of Cambardella et al. (1994). Carvalho et al. (2017) state that the amplitude values relative to the semivariograms are of considerable importance in determining the limit of spatial dependence and can also be an indicator of the interval between the mapping units, important for optimizing future samplings. The highest range was for the 2021 productivity (25 m) and the lowest was for the 2022 productivity samples (12 m). The spherical model used in this study was efficient, as the mean error value calculated for all seasons was very close to zero, thus meeting the cross-validation criteria.

Geostatistics has been widely used in productivity mapping, as observed in the works Silva et al. (2007, 2008, 2010), Molin et al. (2010), by Ferraz et al. (2012a, 2012b), Carvalho et al. (2013), Carvalho et al. (2017), Ferraz et al. (2017) and Ferraz et al. (2019), all these authors confirmed the spatial dependence of productivity, but no research evaluates the spatial dependence in such a small crop. In relation to the semivariogram adjustment parameters, all these authors found different nugget and range effect values.

These differences can be justified, among other factors, by: crop management, crop age, chosen cultivar, soil management and type, climate.

As represented by figures 7, a, 7, b and 7, c, it can be seen that there was a wide variation in productivity for all the years evaluated. The highest values of this attribute are represented by the lighter color (light gray/white), while the lower concentrations of productivity are represented by dark colors (dark gray/black). Visually, the largest contractions in productivity were represented by the year 2020 and the lowest recorded in the year 2022.



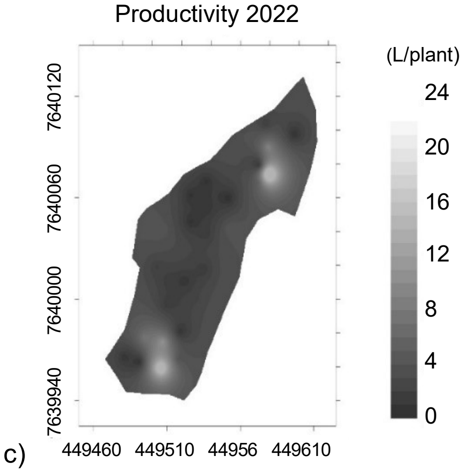


Figure 7. Kriging maps (a) productivity 2020, (b) productivity 2021 and (c) productivity 2022.

Ferraz et al. (2012a) state that productivity maps can be used in harvest management, be it manual, semi-mechanized or mechanized, that is, these maps are important for harvest logistics. In manual harvesting, in addition to estimating productivity, maps may be necessary to establish the number of workers to be hired. As for mechanized harvesting, in addition to the benefits mentioned above, the productivity maps helped in decision-making regarding the rent and/or purchase of machinery and equipment. And finally, in mechanized harvesting, they will be important for the construction of routes, especially when it comes to emptying the tractor support cart, avoiding unnecessary stops and maneuvers.

Fig. 7, a represents the spatial variability of the productivity evaluated in the year 2020, it is observed that a good part of the productivity was in the range of 7 to 13 L/plant and two points of high productivity were observed in the southwest of the area and two points of low productivity in the center of the area.

Fig. 7, b represents the map of spatial dependence of the productivity obtained in the year 2021, it was observed that in this year a good part of the productivity was concentrated in the low productivity interval (1 to 7 L/plant) and only a small point of high productivity was found in the center of the area.

The spatial variability of productivity for the year 2022 (Fig. 7, c) was also concentrated in the range of low productivity (1 to 7 L/plant) and unlike what happened in 2021, where there was a high concentration of productivity (center of the area for the 2021 harvest) in the year 2022, this point had low productivity.

The coffee tree, as a perennial plant with a biennial production cycle, also has different needs from one year to the next. In years of high load, the nutrient demand for fruit production, added to the demand for continuous plant growth, results in a greater need for fertilization (Mesquita et al., 2016). The biennial is a phenomenon considered to be a constant in the production of coffee trees. According to Mendonça et al. (2011) there is a high correlation between management and the biennial, that is, the inefficiency of the cultural management and the climatic adversities accentuate the biennial in the coffee tree, however the nature and magnitude of this influence still lack scientific clarification.

A visual comparison demonstrates the occurrence of biennial productivity, as the regions that in 2020 had the highest productivity had the lowest productivity for the years 2021 and 2022 in the following and consecutively. Plants that produced a lot in 2020 (regions with lighter coloring Fig. 7, a) used their reserves for fruiting, negatively influencing branch growth and, consequently, reducing productivity in 2021 and 2022 (regions with dark coloring). This can be confirmed by the difference between the evaluated harvests (Fig. 7, a, 7, b and 7, c), as these maps show that the areas with the greatest difference, positive or negative, coincide with areas with greater or lesser productivity respectively. Similar results are found in the work by Carvalho et al. (2017) where the authors evaluated two harvests (2012 and 2013) in a 22 ha field under the cultivation of *Coffea arabica* L, cultivar Topázio.

We can call this phenomenon internal variability, by definition the biennial is described as one year producing more and one year producing less, but taking into account that this crop is over 20 years old and the management system adopted is conventional, the needs The specific characteristics of each plant within that crop have not been met over the years, and thus, even with the biennial within coffee crops, for this specific crop the behavior was individual for each evaluated plant, that is, the highest productivitys are observed in the 2020 crop, then the 2021 crop is smaller than the 2020 crop and finally the 2022 crop is smaller than the previous two.

The results obtained by a map of spatial variability of productivity and together with maps of chemical and physical attributes of the soil can be useful to find the reasons for the occurrence of variability in productivity, mainly in the case of low productivity, which will enable the correction failures, allowing these problems to be minimized in the next harvest.

CONCLUSION

By using one-way analysis of variance with repeated measures, it was possible to verify and quantify the difference between productivity means. The descriptive statistics analysis proved the existence of high variability among the data, by calculating the coefficient of variation.

Through the geostatistical analysis of the productivity data collected in different seasons, it was possible to verify that this attribute has spatial dependence. By adjusting the semivariogram and kriging interpolation, it was possible to prove the magnitude of this spatial dependence. The final product generated by this study were thematic maps, where through them it was possible to identify areas that have the highest and lowest concentrations of productivity.

It is important to emphasize that due to the biennial phenomenon that occurs in coffee growing, productivity is an attribute that will always present a high rate of spatial variability within the same crop, this effect can be minimized with practices and techniques of precision agriculture, that is, the use of specific and localized management can be a great ally to minimize the impacts caused by this variation in productivity. Geostatistics has shown good results in estimating results in unsampled locations, which directly benefits the producer, avoiding intensive and expensive sampling and bringing a quick and reliable return to the producer.

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